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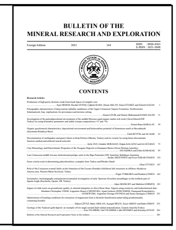

Role of the Cretaceous normal faults on the formation of the Eocene (Pontide) fold-thrust belt structures in offshore Akcakoca-Amasra area, Western Black Sea basin, Turkey

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Research Article

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ABSTRACT

The Western Black Sea basin formed during therifting of the Moesian Platform in Early Cretaceous. The closure of the Neotethys Ocean in the Middle Eocene resulted in the formation of the Pontide fold and thrust belt in northern Turkey. During this study, eight seismic reflection profiles were interpreted to determine the subsurface structural geometry and tectono-stratigraphic evolution of the offshore Akçakoca-Amasra area. The stratigraphy of the study area is determined based on a composite wireline well log of the Akçakoca-1 wildcat well, which was also used to construct a velocity model based onsonic data. We suggest that a major décollement surface was developed during the Eocene Pontide Orogeny. The decollement is located at the limestone clay-shale intraformational transition within the Late Cretaceous (Maastrichtian) - Paleocene Akveren Formation. Normal faults formed during the Cretaceous rifting in the region are located below the décollement surface. They provide tectonic ramps along the décollement surface and allow the decollement to develop ramp-flat thrust fault geometry. A well-developed duplex structure is also present along the seismic lines. The décollement surface serves as the floor thrust of the duplex structure. The roof thrust of the duplex is in the Pliocene Sarıkum formation, dominantly composed of claystone.

1. Introduction

The Black Sea basin (Figure 1) is composed of the Western and Eastern Black Sea basins. The Western Black Sea Basin formed as a result of rifting of the Moesian Platform in Aptian (Okay et al., 1994) (Figures 1 and 2). The Eastern Black Sea basin formed during the counterclockwise rotation of the Eastern Black Sea block around pole of rotation located north of Crimea (Görür and Tüysüz, 1997) in Santonian – Campanian (Figures 1 and 2). This rotation was coeval with the rifting in the Western Black Sea basin, and continued until Miocene (Okay et al., 1994) (Figures 2 and 3).

After the Aptian (Early Cretaceous) rifting, both Eastern and Western Black Sea basins experienced deep water depositions. In middle Eocene, the Istanbul and Sakarya blocks collided (e.g., Görür, 1988; Robinson et al., 1995; Yigitbaş et al., 1995; Stephenson et al., 2010) and formed the Pontide mountain range to the south of the Western and Eastern Black Sea basins . During Late Miocene, a major sea level fall occurred in the region which caused the two basins to become large shallow lakes and the interiors of the basins were filled with muds and basin floor clastics (Okay and Nikishin, 2015). The depth of water in the center of the basins was reduced to a few hundred meters.

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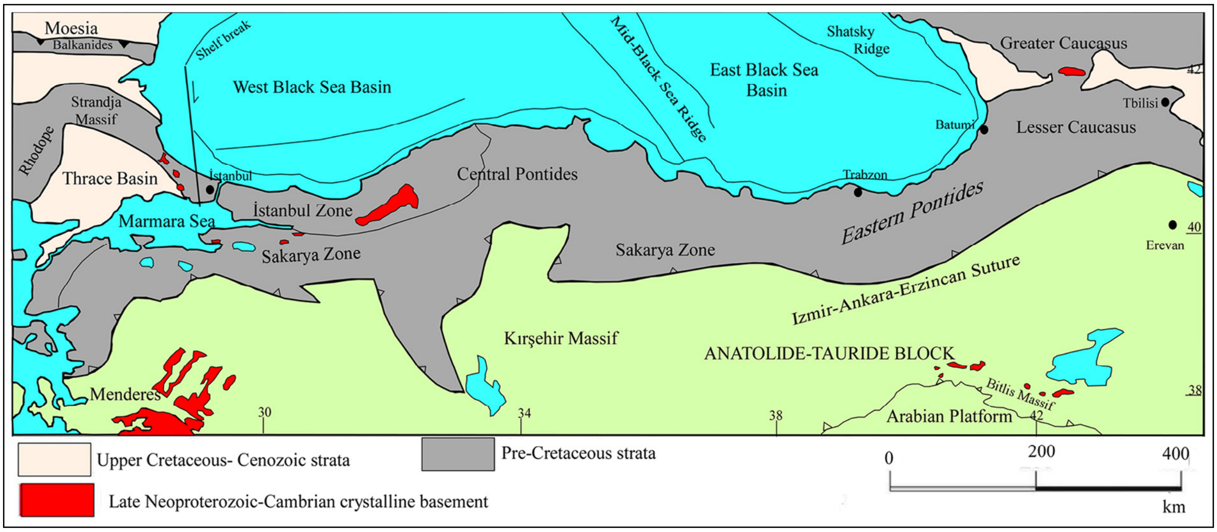

Figure 1- The main tectonic units in the Black Sea region (Modified from Okay and Nikishin, 2015).

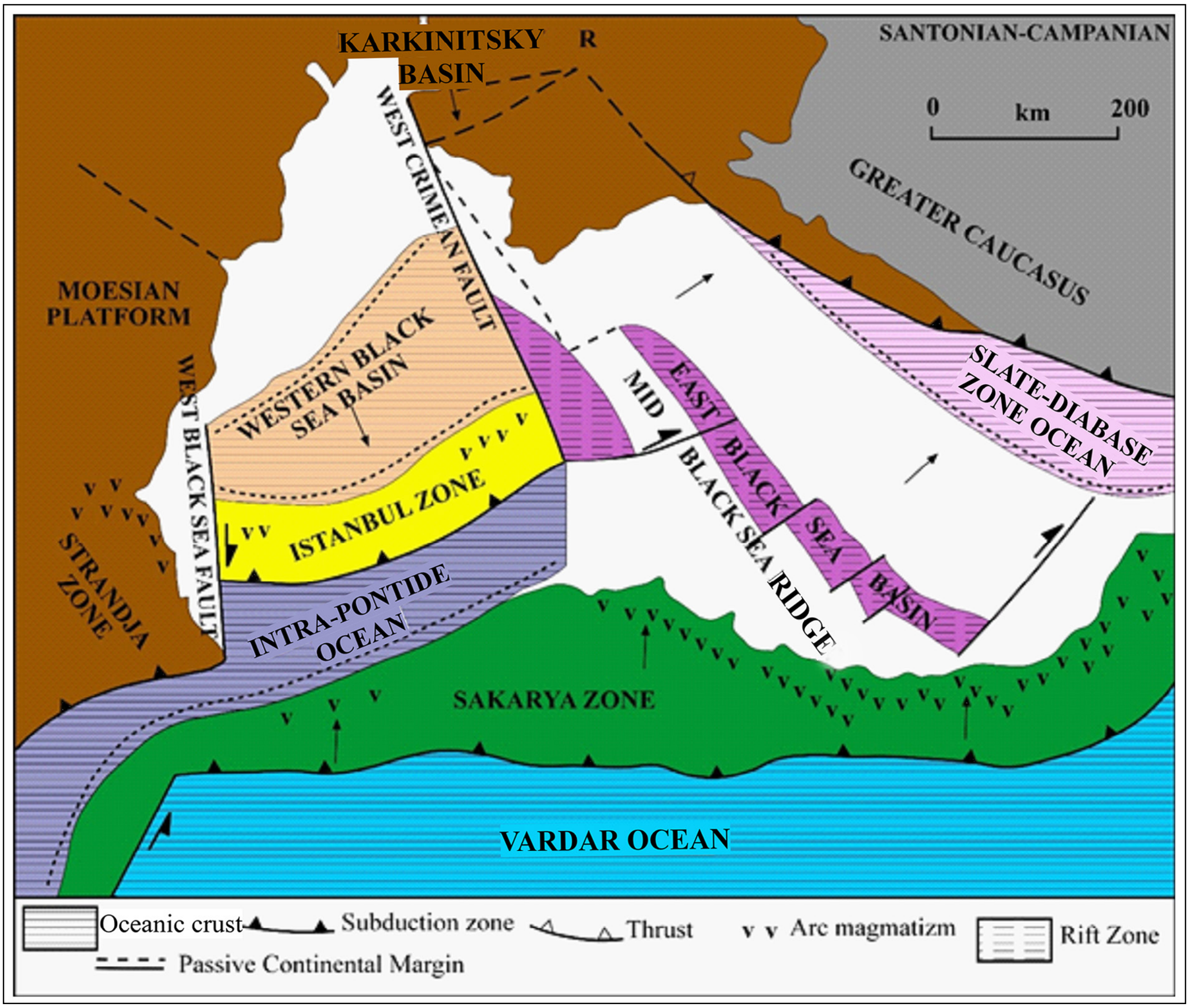

Figure 2- Diagram showing major tectonic elements of the Western and the Eastern Black Sea basins during the Santonian to Campanian (Cretaceous). R = rotation pole of the Eastern Black Sea block (Modified from Okay et al., 1994).

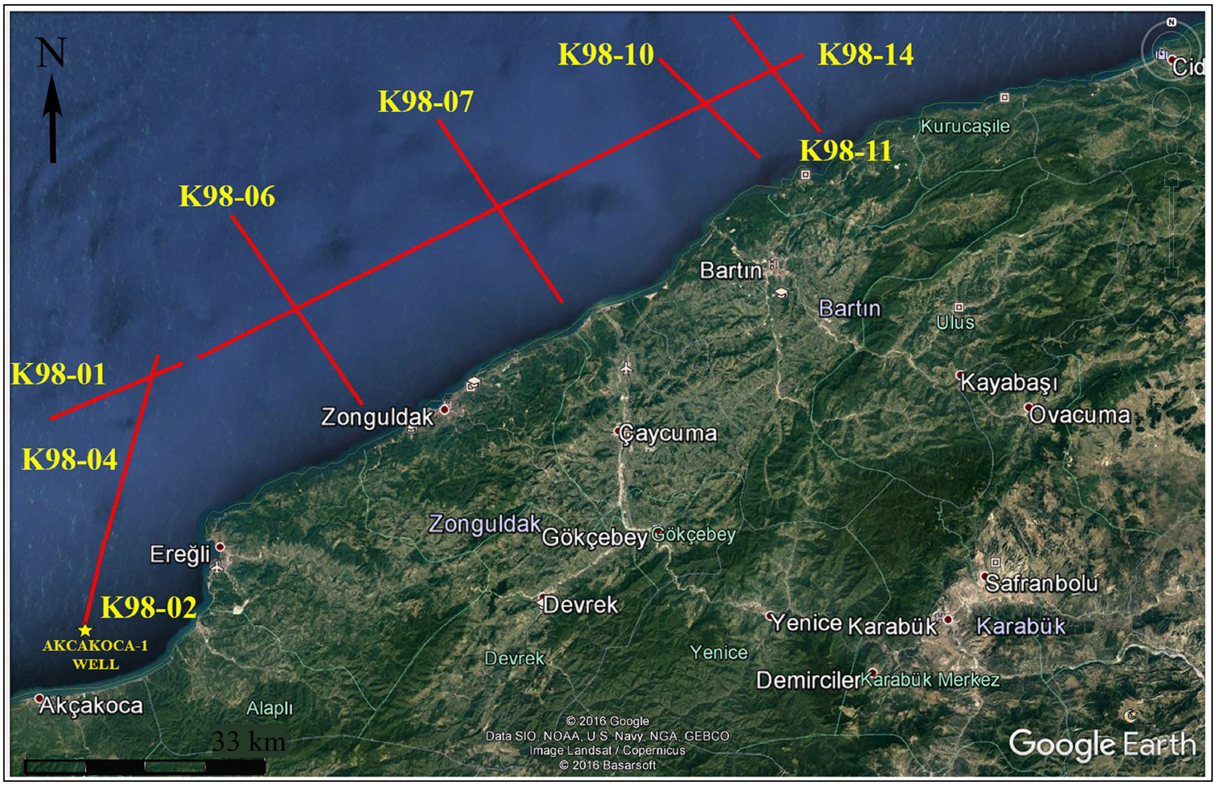

Figure 3- Location map of the offshore seismic lines of the study area.

This caused major incision of the basin margins and widespread deposition of fluvial strata over earlier shelf and even basinal areas (e.g., Robinson et al., 1995). The water level rose rapidly from the late Miocene to Pliocene due to a world-wide sea level rise and the two basins were coalesced again giving way to formation of the present day Black Sea basin (Figures. 1 and 2). The general tectonic evolution of the Western Black Sea basin is relatively well understood (e.g., Şengör and Yılmaz, 1981; Okay et al., 1994; Nikishin et al., 2002). However, tectonostratigraphic evolution of the southern margin of the basin remains poorly understood because there is no published geological research based on interpretation of available seismic reflection profiles and well data.

The main purpose of this study is to determine the tectonostratigraphic evolution of the offshore Akçakoca-Amasra (NW Turkey-Black Sea) area (Figure 3) along the southern margin of the Western Black Sea basin based on interpretation of the four Southeast-Northwest (K98-06, K98-07, K98-10, K98-11), two Northeast-Southwest (K98-01, K98-14) and two approximately North-South (K98-02, K98-04) seismic reflection profiles (Figure 3), provided by the Turkish General Directorate of Mineral Research and Exploration (MTA).

2. Geologic Overview

There are three main tectonostratigraphic units in the offshore Akçakoca-Amasra (NW Turkey-Black Sea) area (Figures 1 and 4) and its surrounding:

(i) Early Devonian to Early Cretaceous pre-rift Paleozoic sedimentary units.

(ii) Aptian to Eocene syn-rift Mesozoic sedimentary units.

(iii) Eocene to present post-rift sedimentary units, deposited during the Pontide Orogeny.

The pre-rift Paleozoic sedimentary units include Istanbul Zone Paleozoic succession and Ordovician to Carboniferous non-metamorphosed sedimentary units (Figure 4) (Görür, 1997). They are not penetrated by the Akçakoca-1 well within the study area and cannot be identified in the available seismic reflection profiles. Therefore, the reader is referred to Tokay (1954 and 1955); Görür (1988); Görür and Tüysüz (1997); and Tüysüz (1999) for a thorough discussion

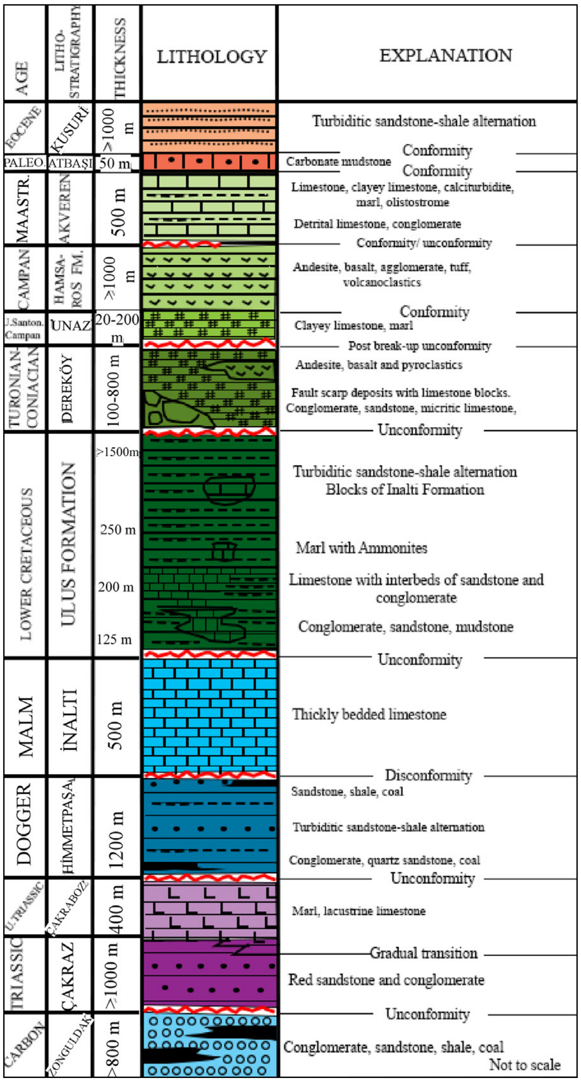

Figure 4- Generalized stratigraphic column of the southern margin of the Black Sea basin (Modified from Nabiev, A., 2007).

of pre-rift sedimentary units. The syn-rift and post-rift sedimentary units are penetrated by Akçakoca -1 well (Figures 3 and 7) and are discussed below.

The Aptian (Early Cretaceous) to Eocene syn-rift sedimentary succession unconformably overlies the pre-rift sedimentary units. The base of the syn-rift succession is the Ulus Formation composed of conglomerate, sandstone, mudstone, limestone and turbiditic rock units (Figure 4). The nannoplankton age determination indicates that the formation is Hauterivian to Late Aptian (Early Cretaceous) in age (Hippolyte et al., 2010). Therefore, the initiation age of rifting in the Black Sea basin is considered to be Early Cretaceous. The Ulus Formation is unconformably overlain by the Turonian-age Derekoy formation (Figure 4), containing island arc magmatic rocks derived from the Western Pontides (Sunal and Tüysüz, 2002). The Derekoy formation contains voluminous volcanic rocks (Görür, 1997) and displays abrupt thickness and sedimentary environment changes attributed to normal faulting (Tüysüz and Yiğitbaş, 1994; Tüysüz et al., 1995) in a back-arc rift setting. Syn-rift succession continued with the deposition of the Santonian Unaz Formation (Figure 4), composed of thin pelagic limestone. The Unaz Formation has a different contact relationship with the underlying units due to the horst-graben topography developed during the time of the Dereköy deposition. This suggests that erosional and deep marine depositional areas were closely juxtaposed before the deposition of the Unaz Formation. The dissected topography, developed during the deposition of the Dereköy formation, was covered by the pelagic carbonates of the Unaz Formation indicating regional subsidence in the Late Santonian-Campanian period (Tüysüz, 1999). The overlying Campanian Canbu formation (Figure 4) was deposited in an arc magmatism setting (Tüysüz, 1999). The Maastrichtian Akveren Formation records the end of arc-magmatism in the area and is composed of calciturbidites, olistostromes and pelagic mudstone and grades into Paleocene to the Eocene Kusuri Formation (Figure 4), which is primarily composed of pelagic mudstone and marl representing the beginning of the post-rift stage The Pontide fold-thrust belt extends as a morphological entity from the Rhodope Mountains of Bulgaria in the west to the Caucasus Mountains in the east (Figure 1). It marks the post-rifting stage in the region and comprises three parts: Western, Central and Eastern Pontides (Figure 1). The northern boundary of the Pontides is covered by the Black Sea, in Northern Anatolia, Turkey. From Ankara westward, it splays into two branches; the northern branch is called as the Intra-Pontide suture, and the southern branch is called the İzmir-Ankara suture zone (Figures 1 and 4).

The Pontide fold-thrust belt (Figure 1) formed during the closure of the Neotethys Ocean in the region (Figure 5). The closure caused the tectonic style in the Western Black Sea area to change from extension to contraction in middle Eocene (Figure 5). The contraction dominated structural and sedimentological evolution of Western Black Sea basin from Eocene to recent (Robertson et al., 2012) (Figure 5).

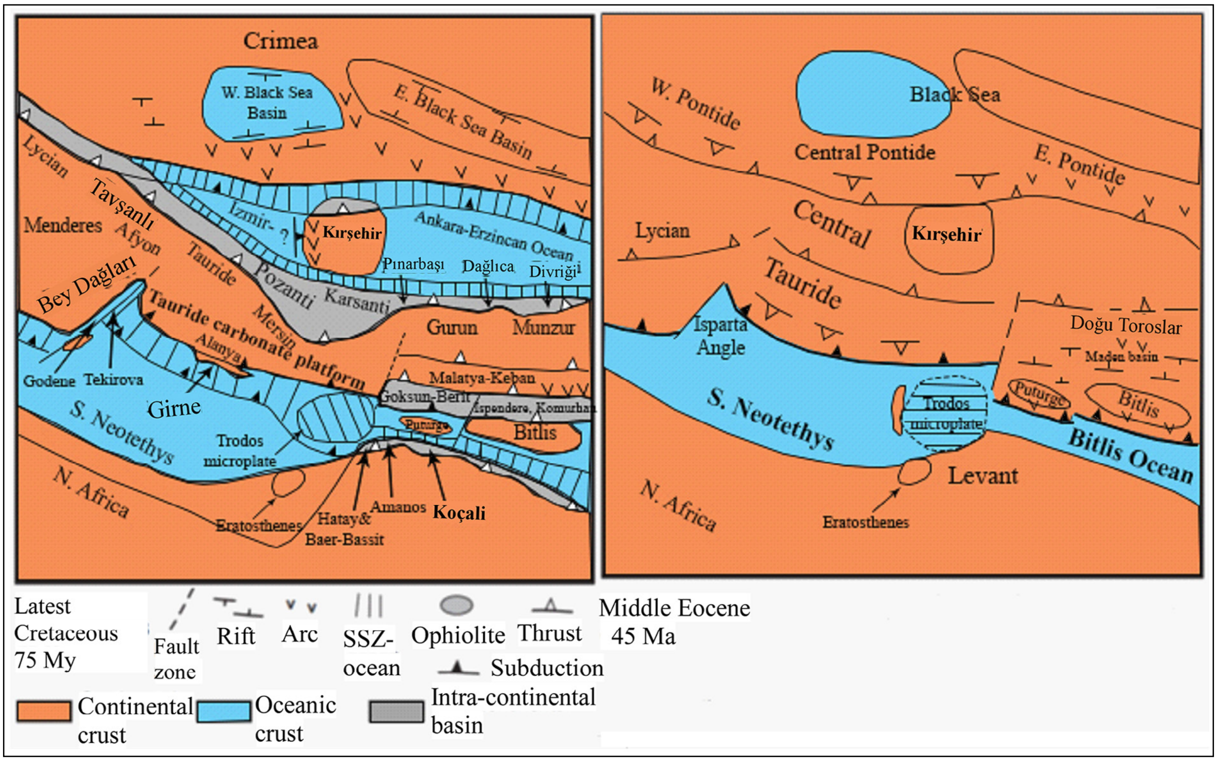

Figure 5- Closure of Neotethys Ocean and formation of Pontide Mountain belt from Late Cretaceous to Mid Eocene (Robertson et al., 2012)

3. Data and Methodology

The seismic reflection profiles used in this study were made available by the Turkish General Directorate of Mineral Research and Exploration (MTA). The data were acquired by R/V Sismik-1 vessel in 1998 by MTA. Although the first seismic process was applied in 1998, the whole data set was reprocessed by geophysicists in MTA Department of Marine Research using Promax software in 2015. The data set include eight 2D seismic reflection profiles with an 8-second TWT record length and a 50-m shot point interval between offshore Akçakoca and Amasra (Figure 3). The seismic data consist of five NW-SE trending seismic profiles: K98-06, K98-07, K98-10, K98-11, two NE-SW trending seismic profiles, K98-01, K98-14, and one almost N-S trending K98-02 and K98- 04 seismic profile which connects to the longest seismic profile of the study area, K98- 14 (Figure 3). The location of the seismic lines is arbitrary and the header data and location of geophones are not included in the seismic lines in order to protect the confidentiality of data.

Eight available seismic lines (Figure 3) were uploaded to Petrel software and their elevation differences from the sea bottom were corrected by matching the top seismic reflections of each cross cutting seismic line (Figure 6). Structural interpretation of the seismic lines was carried out by Özgür Türkmen as part of his MS degree program at the University of Alabama under the supervision of İbrahim Çemen. The Akçakoca -1 wildcat well is located along the seismic profile, K98-02 (Figure 3). It was drilled in the study area by TPAO for exploration in 1976 and completed as a gas well. Its coordinates are: 41°12’36N and 31°07’36”E on the N-S trending seismic profile, K98-02. The well spotted at the Quaternary sea bottom sediments at –94.8 m and penetrated the Pliocene Sarıkum formation (587 m), the Eocene Kusuri Formation (1192 m), the Paleocene Atbaşı Formation (72 m) and the Upper Cretaceous Akveren Formation (318 m) before reaching the volcanic tuff units of Upper Cretaceous Hamsaros formation (14 m) at 2,270-m below the surface (Figure 7). The Akçakoca-1 database well data provided for this study consist of SP, gamma-ray, caliper, resistivity, density, neutron porosity and sonic logs. For the seismic to well tie, Akçakoca-1 Well was uploaded and correlated with K98-02 seismic line. The formation tops in the Akçakoca-1 Well were

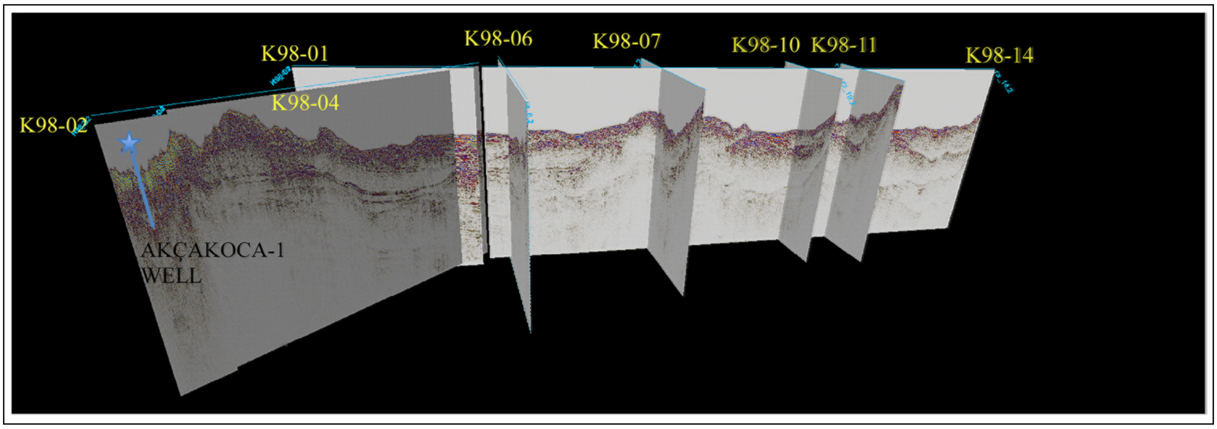

Figure 6- 3D view of the eight seismic lines from the Petrel project in the time domain.

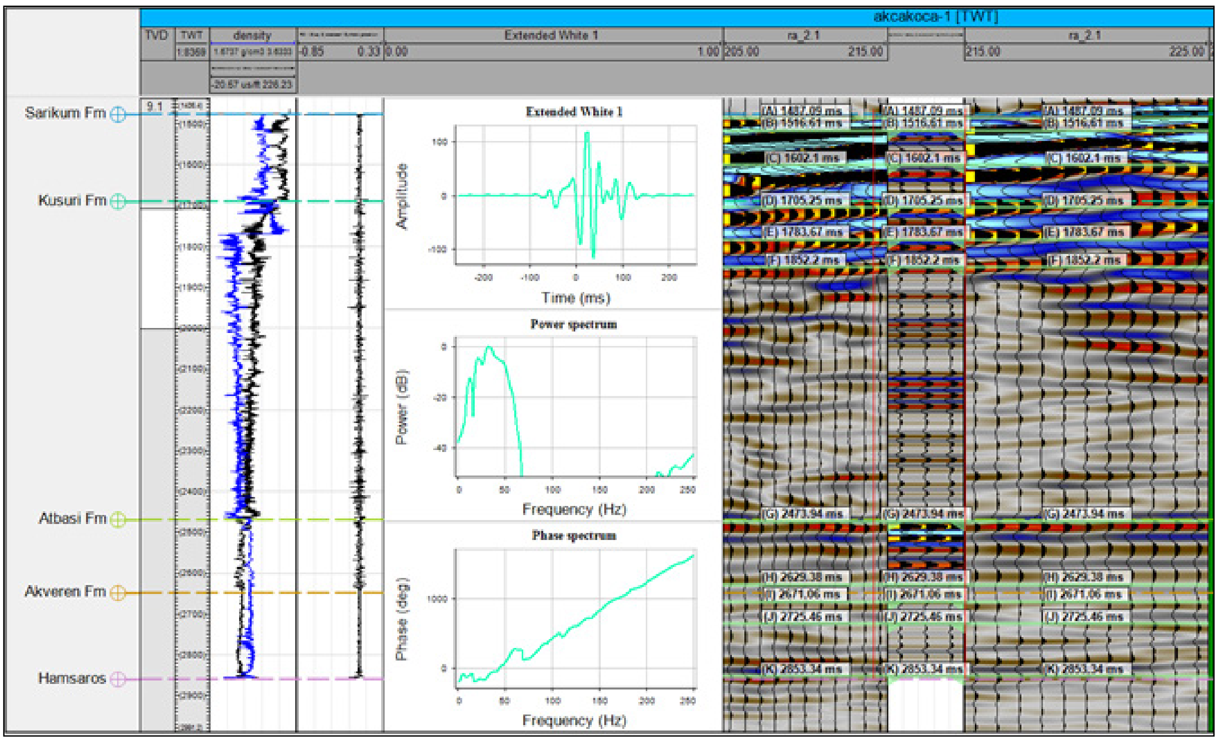

Figure 7- Synthetic seismogram generation using well log data from the Akçakoca-1 Well.

correlated to the seismic line, K98-02, by creating a synthetic seismogram (Figure7). The synthetic provided a seismic tie to determine formation tops and helped to determine structural geometry in the time domain. Although the original work, Türkmen, 2017, that this paper is based on is composed of eight seismic profiles, five of them will be discussed in order to explain the subsurface structural geology of the study area.

During this study, relative acoustic impedance is used as a seismic attribute to amplify the seismic reflections in order to trace seismic horizons, where the resolution is very low. The process helped during the interpretation of 2-D seismic reflection profiles, and well to seismic tie. Based on the model by Bag et al., (2008), relative acoustic impedance of volume attributes tool in the fracture modeling section of Petrel software was applied to eight seismic profiles in the study area. As a result of the application of this seismic attribute, better seismic images are created for the study area.

4. Structural Interpretation of Seismic Reflection Profiles

4.1. Approximately N-S Trending Reflection Profile

4.1.1. K98-04 Seismic Line

Along the seismic profile K98-04 (Figures 3 and 6), the Cretaceous syn-rift normal faults on the southern side of the profile provide ramp geometry for the décollement surface that formed during the Eocene Pontide Orogeny. These normal faults cut the sedimentary succession up to the Upper Cretaceous Hamsaros formation (Figure 4) and do not disturb the formations younger than Hamsaros formation. This indicates that the normal faults were formed during the rifting in the Western Black Sea basin.

A well-developed decollment surface and a duplex structure are present along the seismic profile, K98-04. These contractional structures were formed during the Eocene Pontide Orogeny. The Decollement surface is located in the Upper Cretaceous Akveren Formation at the transition between clay and limestone, where limestone beds are displaying unified, horizontal reflections along the seismic reflection profiles while clay units are displaying more chaotic and mixed reflections due to their ductile nature of the clay units (Figure 8). The décollement surface serves as the floor thrust of the duplex structure. It penetrates towards the north by following the same clay unit in Akveren Formation, almost horizontally. The roof thrust of the duplex was developed in the Pliocene Sarıkum formation, which is composed of claystone and splays up to the sea bottom (Figure 8).

The duplex structure between the roof thrust and the floor thrust along the seismic profile, K98-04, contains 13 horses with similar sizes (Figure 8). The horses penetrate through the Akveren Formation, and limestone units of the Paleocene Atbaşı Formation, sandstone, claystone, marl and shale intercalations of Eocene Kusuri Formation, and claystone units of Pliocene Sarıkum formation.

4.2. Approximately NW-SE Trending Seismic Reflection Profiles

4.2.1. K98-06 Seismic Line

This seismic line is the westernmost of the NW-SE trending lines (Figure 3). Along this seismic line, the décollement surface is in the Akveren Formation, same as K98-04 line. However, the roof thrust is not well developed (Figure 9). The lack of the roof thrust is probably due to the loss of the intensity in thrusting. Moreover, there are only 5 horses along the seismic section and the size of the horses is smaller than the ones in the western part of the study area. In some parts of the section, the décollement is elevated probably by the normal faults of the rifting stage; however, these faults cannot be observed clearly in the seismic section due to strong multiple effect and low resolution (Figure 9). The hanging wall strata in this section exhibit well developed folding, most likely due to the steep ramp geometry of the décollement surface southward towards the Black Sea shoreline (Figure 9).

4.2.2. K98-07 Seismic Line

While the base of this seismic line is dominated by the effects of multiples and bowties (Figure 10), the Hamsaros formation at the base and some parts of the décollement surface is questionably traced along the seismic line towards the offshore, after Common Depth Point (CDP) number 3456. This line has 5 horses (Figure 10). The roof thrust is not developed in this section similar to the seismic line K98-06 (Figure 9). However, the horse structures are bigger in size and less dense with respect to K98-06. The reason for the size and density differences of the two parallel sections is probably due to the steepness of the ramp geometry and the loss of intensity of thrusting towards the NW.

Along the section K98-06, the ramp geometry created by the normal faults of the rifting stage appear to be steeper than the ramp geometry along the line K98-07; therefore, the strata in the hanging wall of the thrust faults are folded less intensely than along the line K98-06 (Figure 10). The number of horses in this section is less than in the K98-04 seismic line, which is probably a result of decreases in the intensity of thrusting from the SW to NE.

Similar to other seismic lines, the décollement surface in the section is placed in the Akveren Formation (Figure 10), and the thrust faults are affecting all of the formations from the Akveren Formation up through to the Pliocene Sarıkum formation. The Hamsaros formation top in this section

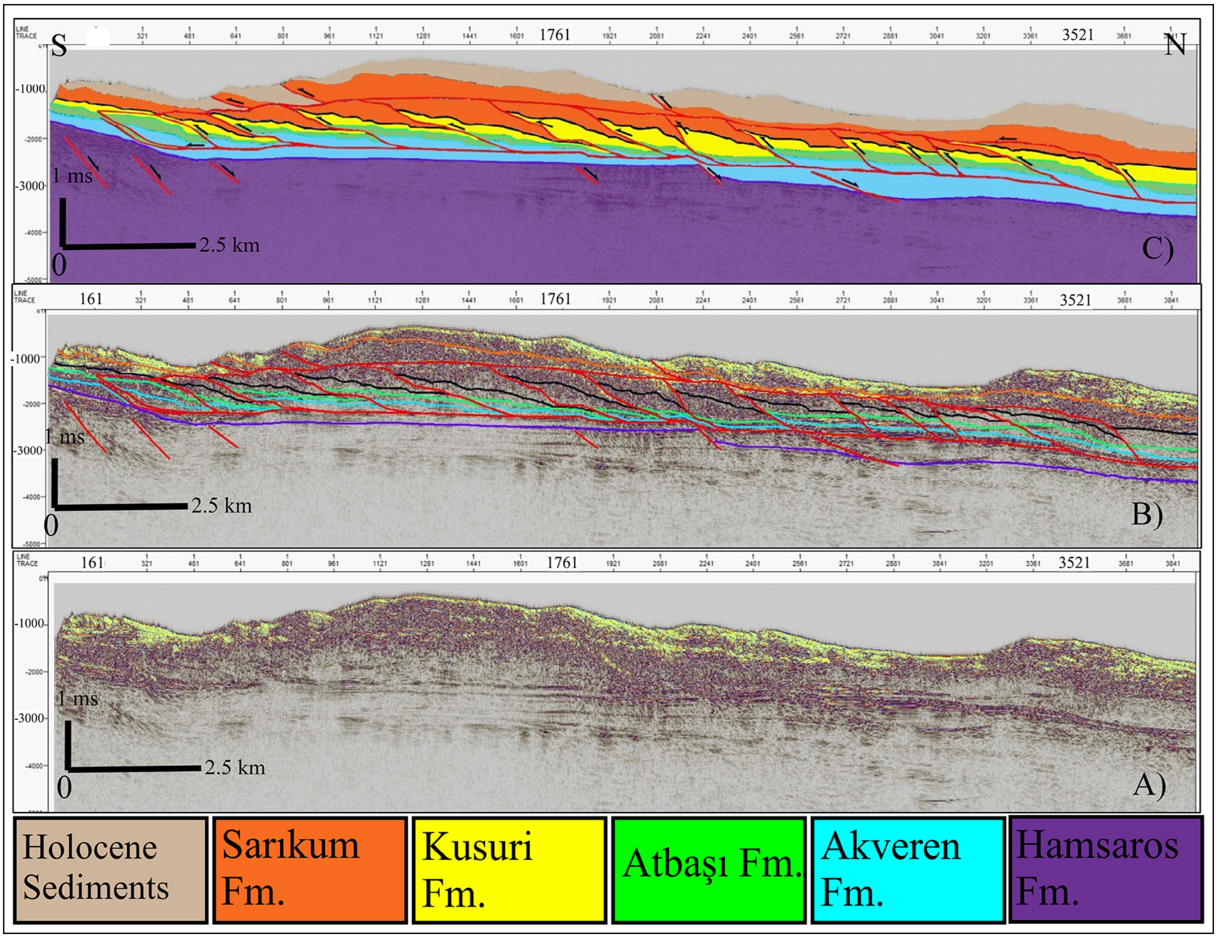

Figure 8- K98-04 seismic profile (between CDP numbers 0-3841): A) Uninterpreted; B) Interpreted and C) Line drawing. The profile shows well developed duplex structure developed between the floor within the Akveren Formation and the roof thrust within the Sarıkum formation.

is determined based on the intersection with the K98-14 seismic line and is questionable due to the strong multiple effect (Figure 10).

4.3. Approximately NE-SW Trending Seismic Reflection Profiles

4.3.1. K98-01 Seismic Line

This seismic line is the southern continuation of the 100-km long K98-14 seismic line, which trends about N60^{o}E is approximately parallel to the strike of the thrusting in the study area. Duplex structures and horses are observed in this section, similar to other sections that are approximately perpendicular to the strike (Figure 11). This is due to the change in the orientation of the strike of the thrust structure from NE–SW to almost N–S in the southeasternmost part of the study area.

Although the presence of some horses are highly questionable, we have interpreted eleven horses along this seismic section, A few splays and a well-developed roof thrust can be observed in the Pliocene Sarıkum formation and décollement surface in the Upper Cretaceous Akveren Formation. The horse structures along this section are different from the other sections containing duplex structures; they are more elongated due to the oblique orientation of the section to the strike of thrusting in the study area (Figure 11). More horses are interpreted in this section than the teh sections towards the NE, probably because intensity of the thrusting was the strongest in the SW part of the study area (Figure 11).

Similar ramping of the décollement surface is observed along this section as well (Figure 11). However, due to the presence of strong multiple effect and bowties, the rifting stage normal faults,

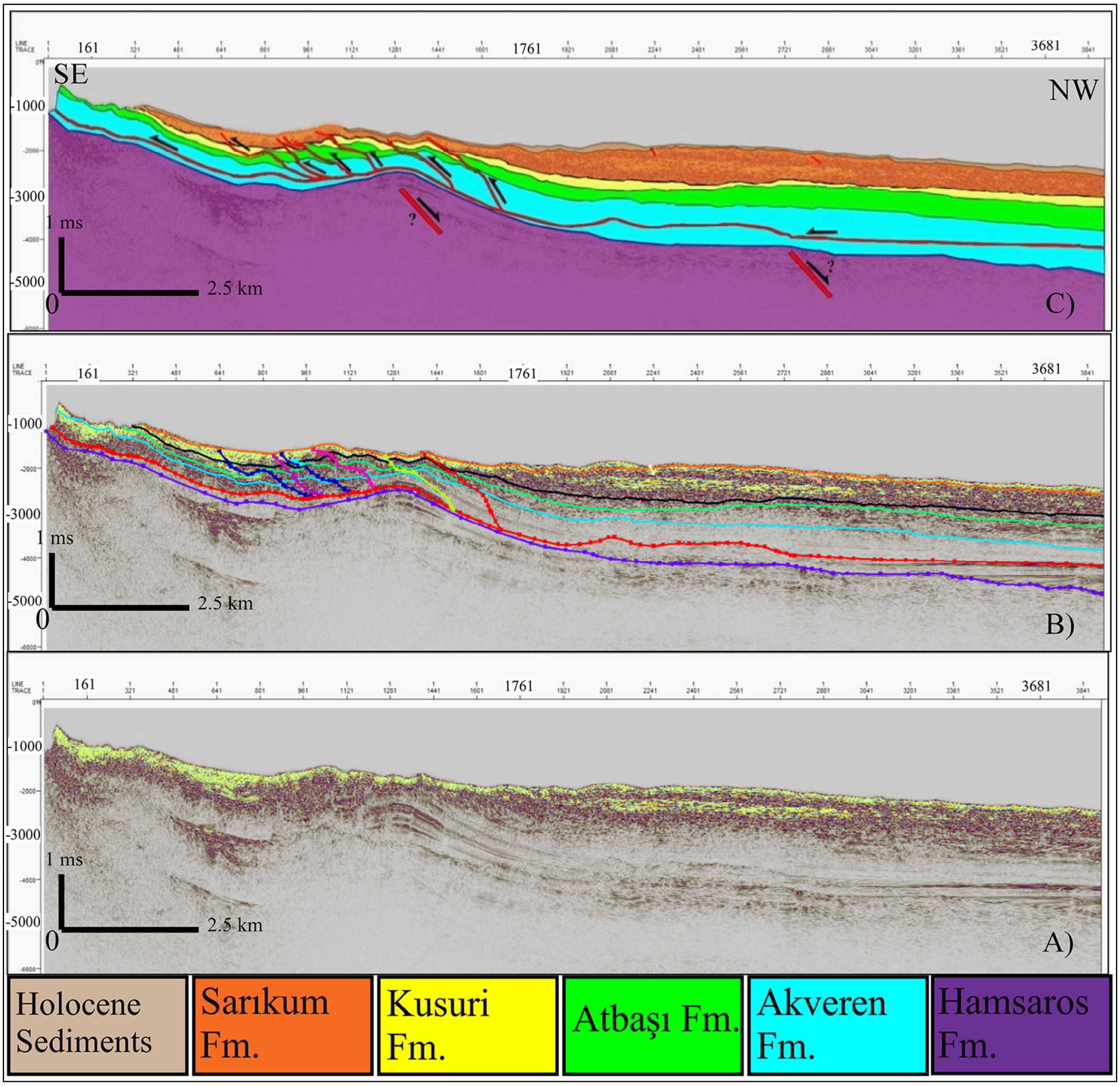

Figure 9- K98-06 (between CDP numbers 0-3841): A) Uninterpreted; B) Interpreted and C) Line drawing. Horses and décollement are well-observed. A normal fault is drawn below the décollement surface in the southeastern part of section where the décollement is elevated most likely due to a ramp along the décollement surface.

which are observed to produce ramp geometry of the décollement surface along other seismic sections (Figures 8, 9, 10), cannot be interpreted along the seismic line K98-01 (Figure 11). The normal faults strike almost parallel to the line of the section, and therefore they do not produce any diffraction along the seismic reflection profile. The K98-01 seismic section contains a Late Paleogene–Early Neogene angular unconformity towards the shoreline (Figure 11).

4.3.2. K98-14 Seismic Line

This seismic line also strike about N60^{o}E and approximately 100 km long. Therefore it is divided into three parts between CDP numbers; a) 18856 and 14856 (Figure 12), b) 14856–10856, and c) 7656 to 5576. The entire line is approximately parallel to the strike of the Pontide thrusting in the study area and is almost perpendicular to the K98-06, K98-07, K98-10 and K98-11 seismic lines (Figure 3). The décollement surface can be traced along this seismic section in the Akveren Formation (Figures. 12, 13, 14 and 15).

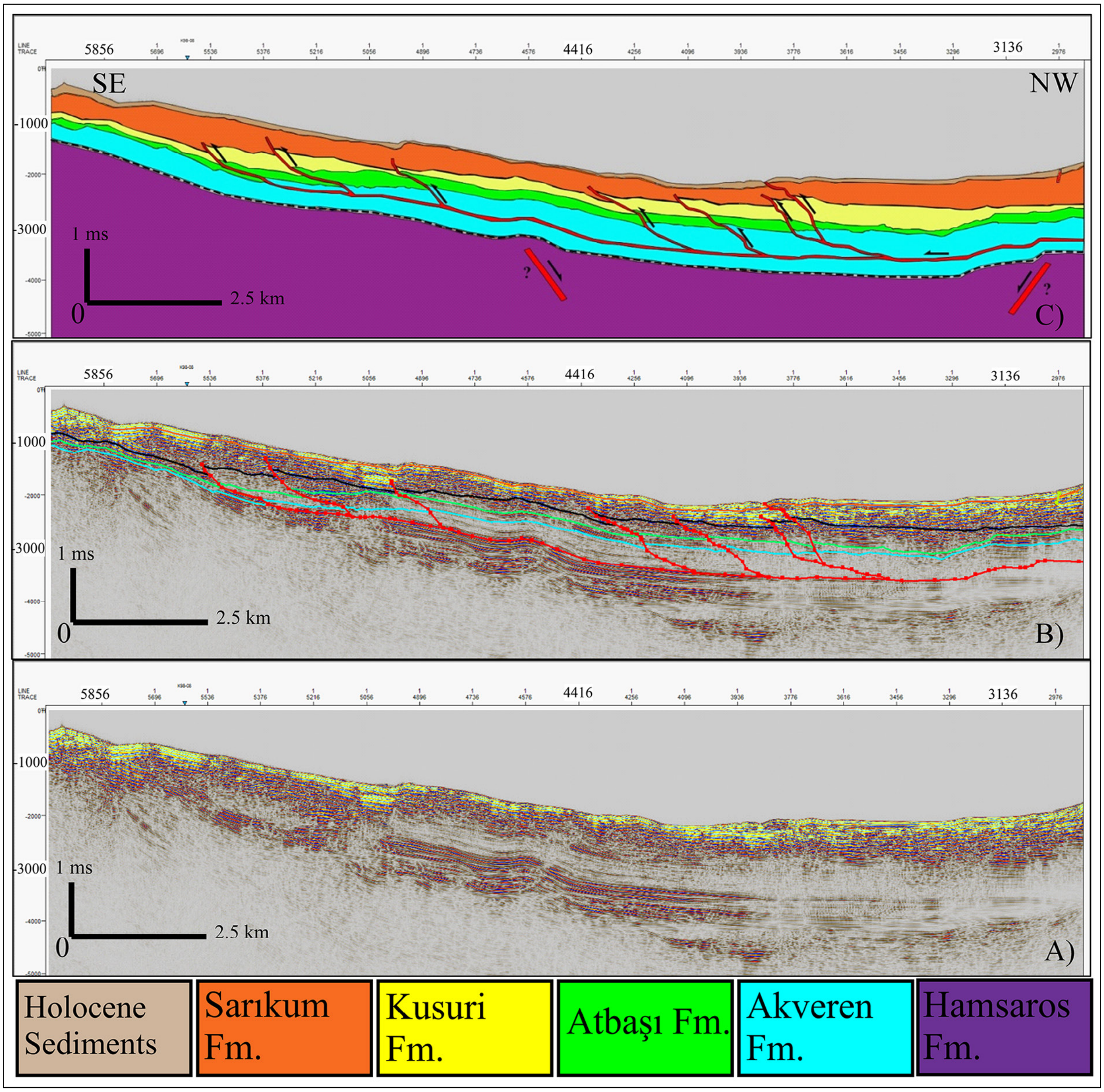

Figure 10- K98-07 (between CDP numbers 5856-2976): A) Uninterpreted, B) Interpreted and C) Line drawing. The décollement surface is present within the Akveren Formation. The section shows 5 horses within the duplex structure between the floor and roof thrusts. Normal faults, drawn below the décollement surface, are questionable becasue of teh poor uality of tehseismci line belwo the decollment surface.

Between CDP numbers 18856 and 14856 (Figure 12), there are some reverse faults, which cut through Sarıkum, Kusuri and Atbaşı Formations; however, theses faults are not connected to the main décollement surface. Towards CDP number 14856, the decollment surface all formation tops including Akveren and Hamsaros formations are elevated (Figure 12). This is interpreted as an effect of syn-rift stage extensional structures. However, these possible normal faults are not identified clearly due to the strong multiple effect in this part of the seismic section around 5,000 ms close to CDP number 18856 and rising up to almost 4,000 ms around CDP number 14856 (Figure 12).

The part of the seismic line K98-14 between the CDP numbers 14856–10856 to the NE of the intersection with the line K98-07 and K98-14 seismic lines contains a normal fault with two antitethic faults. The antithetics are considered as part of the major landslide imaged in the study area (Figure 13). This

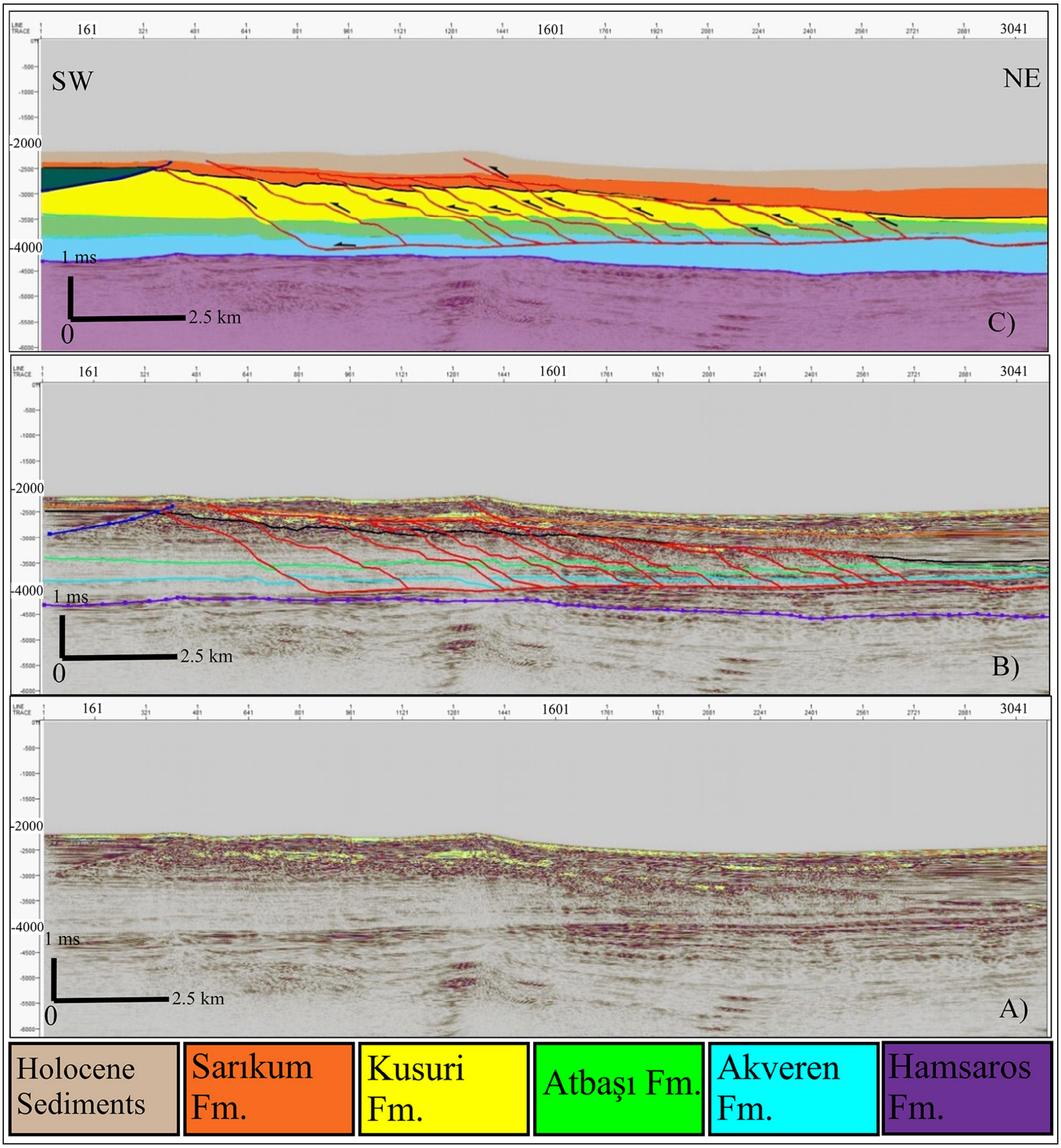

Figure 11- K98-01 (between CDP numbers 0-3041): A) Uninterpreted, B) Interpreted and C) Line drawing. Horses, roof thrust and décollement surfaces are well-observed. Rifting-stage normal faults strike almost parallel to the line of the section. Therefore, they did not produce any diffraction along the seismic reflection profile and cannot be detected below the décollement surface.

main normal fault may coincide with the décollement but was not interpreted in that way because the reflections at the base of this fault are contineous. No fault-like change in this seismic reflection line is observed in that part of the section (Figure 13). Between CDP numbers 11978 and 11498, there is a small basin possibly formed in Paleocene-Pliocene time interval. The basin is controlled by normal faults (Figure 13). Towards CDP number 10856, normal faults create ramp geometry for a décollement surface along this part of the section (Figure 13). Between CDP numbers 10856 and 7656, the formations get thinner from NE to SW due to the elevated basement (Figure 14). Some of the normal faults cutting the base of the Hamsaros formation are observed in this part of the seismic section.

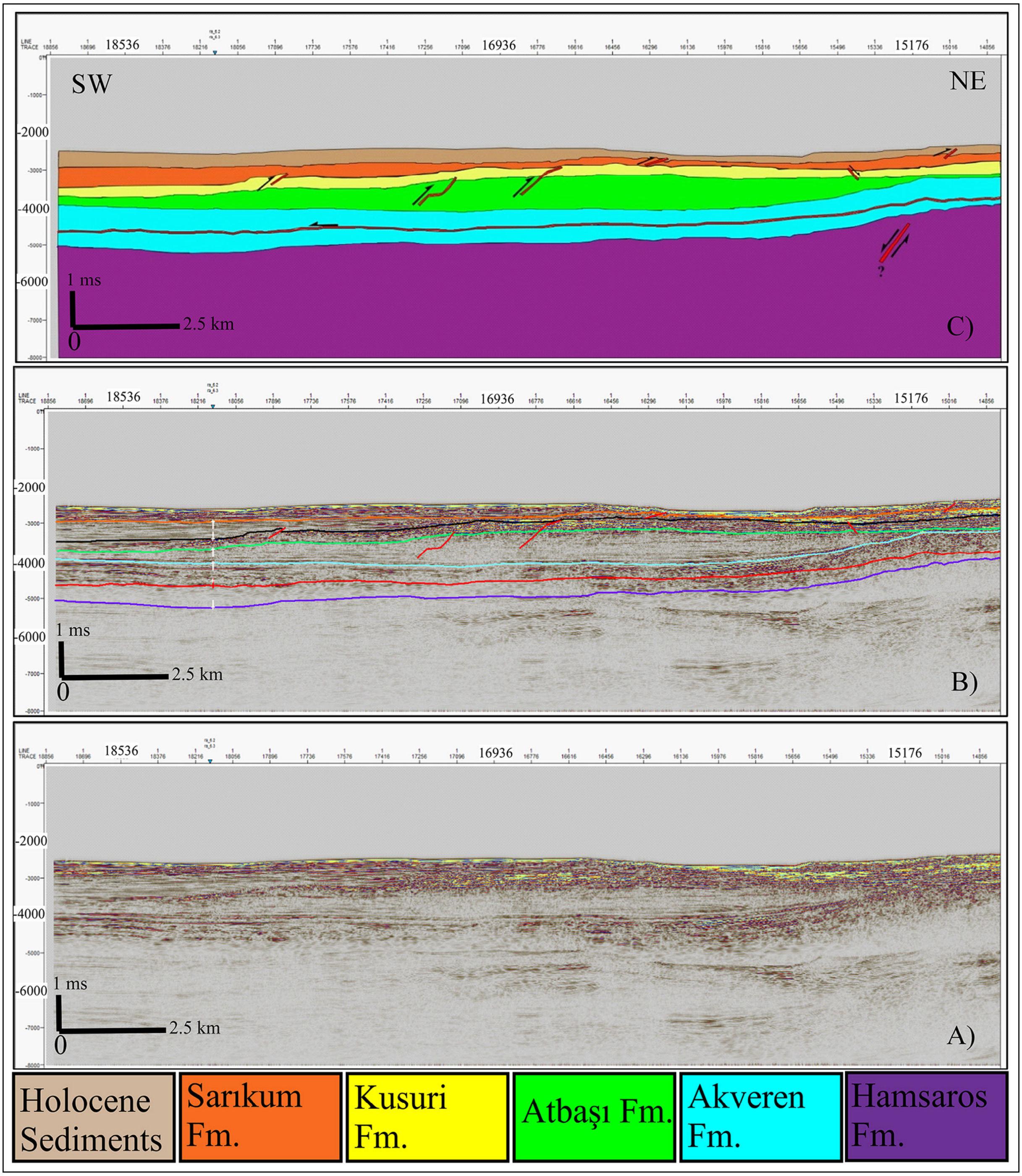

Figure 12- K98-14 (between CDP numbers 18856-14856): A) Uninterpreted, B) Interpreted and C) Line drawing. The decollement surface imaged along the seismic line perpendicular to the line K98-14 is also observed along this seismic line.

Between CDP numbers 7656 to 5576, the floor thrust is highly elevated and Eocene Kusuri and Paleocene Atbaşı Formations are exposed at the sea floor towards CDP number 5576 (Figure 15). However, there are small normal faults in Akveren and Atbaşı Formations between CDP numbers 6376 to 6056 (Figure 15), which can also be interpretted as possible small valleys. There is a normal fault in the middle of this part of K98-14 seismic line, which cuts from Akveren Formation along the seismic line (Figure 15).

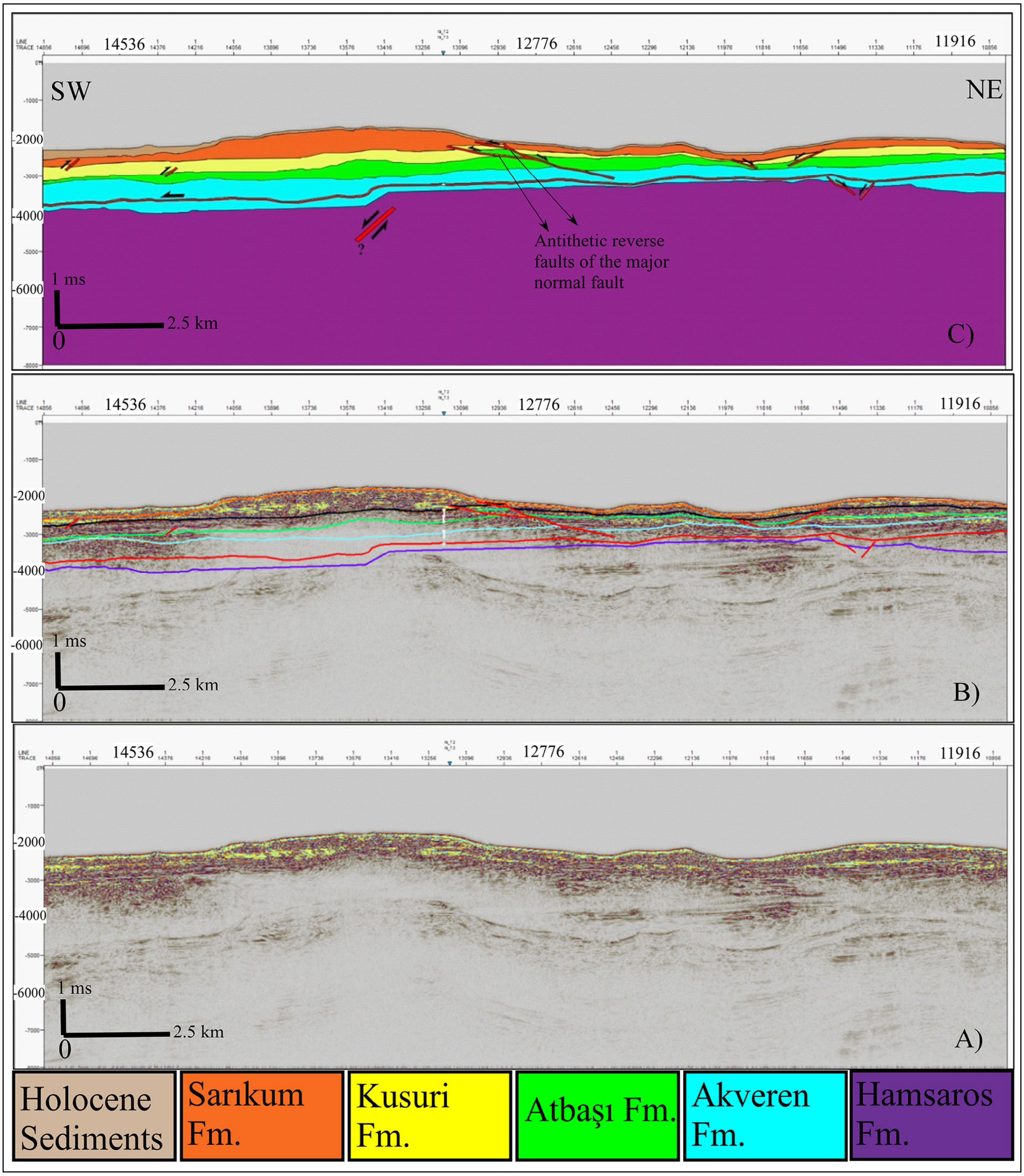

Figure 13- K98-14 (between CDP numbers 14856-10856): A) Uninterpreted, B) Interpreted and C) Line drawing. The decollement surface, southern boundary of the landslide and some of the syn-rift normal faults are well observed.

5. Summary and Conclusions

During this study area, structural interpretation of 8 available 2D reflection seismic profiles in Akçakoca-Amasra area was carried out to determine structural geometry of syn-rift extensional and post-rift contractional structural features in the area. One of the seismic lines is used to tie the Akçakoca-1 well to the other seismic lines (Figure 3). The seismic profiles were acquired by MTA Marine Researches Department in 1998 for determining the landslides in shallow depth in the area, therefore, in the profiles,

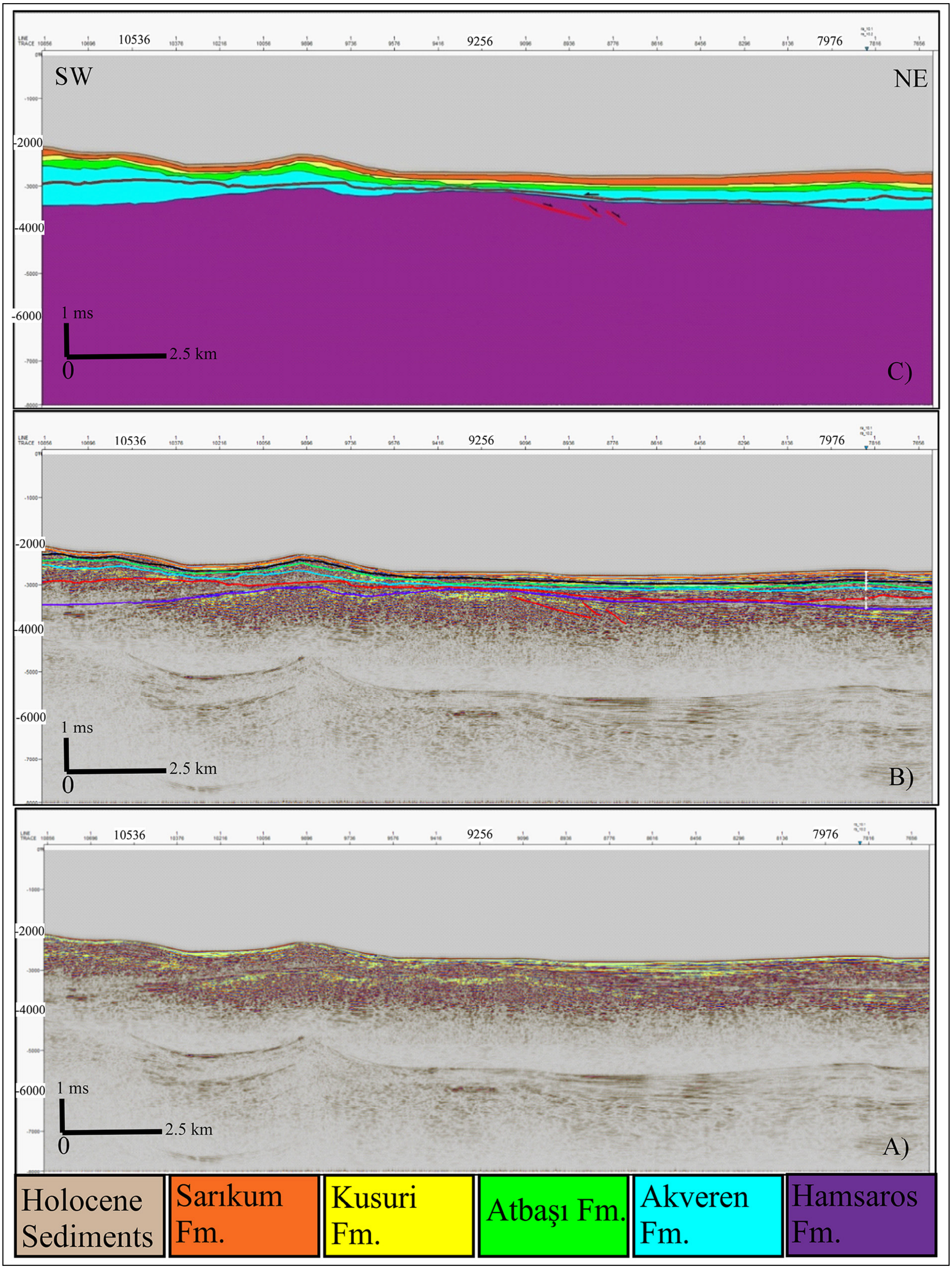

Figure 14- K98-14 (between CDP numbers 10856-7656): A) Uninterpreted, B) Interpreted and C) Line drawing. The decollement is using by the normal faults to ramp into a higher structural level.

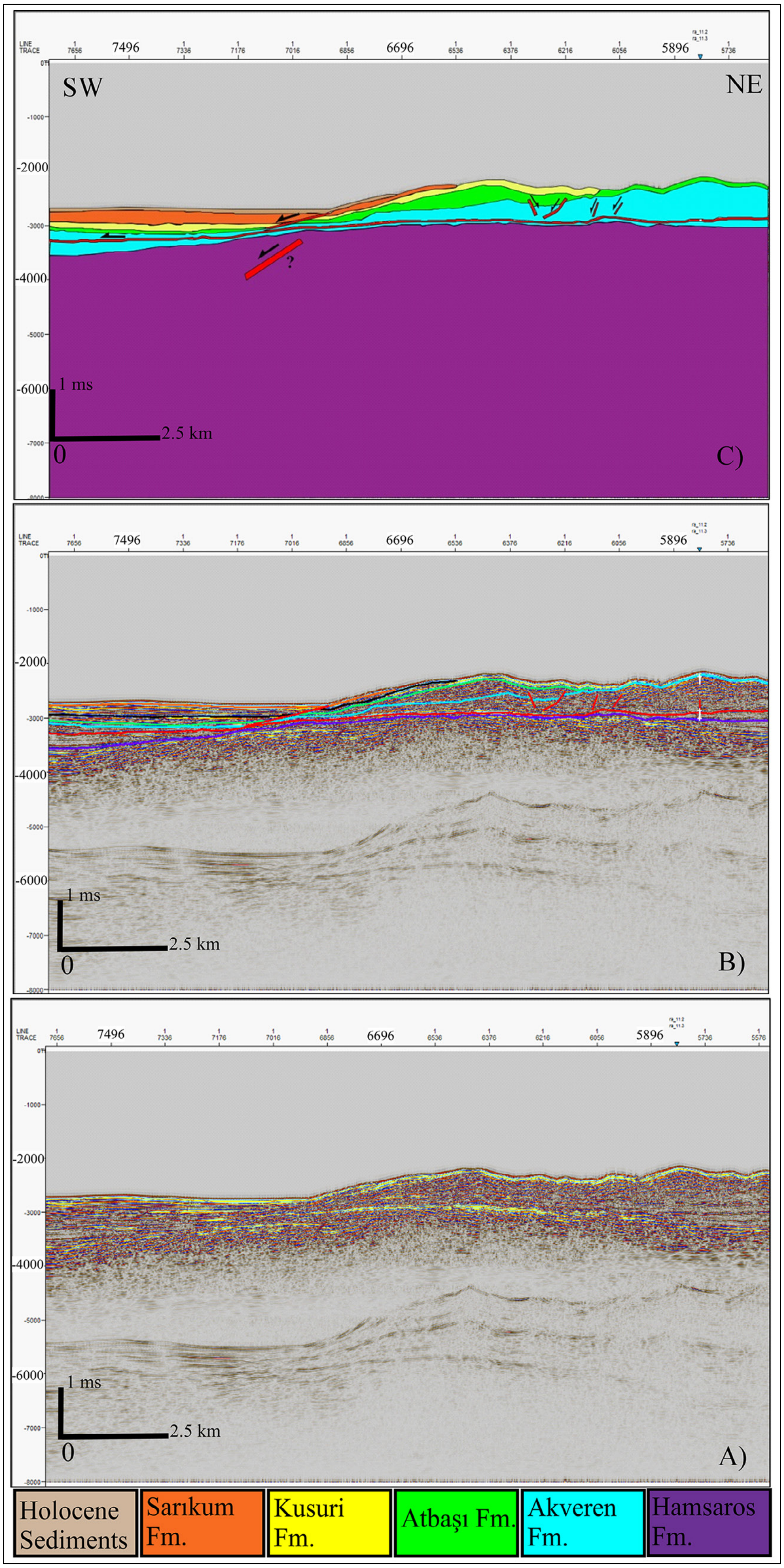

Figure 15- K98-14 (between CDP numbers 7656-5576): A) Uninterpreted, B) Interpreted and C) Line drawing. The decollement is well observed but thesyn-rift normal faultsarequestionable.

below 3500-4000 ms, the basinal structures cannot be seen very clearly due to the strong multiple effect (Figures 8, 9, 10, 12 and 13).

The study area contains the sequence of syn-rift sediments widespread along to Mesozoic Alpine Western Black Sea basin in Northern Anatolia (e.g., Tüysüz, 1999; Okay and Nikishin, 2015). The base of syn-rift rock units is the Aptian Ulus Formation (Figure 4), composed of conglomerate, sandstone and mudstone at the bottom and grades upward into limestone interbedded with sandstone, conglomerate, and marl with ammonites and turbiditic sandstone-shale alternations. There are limestone blocks of the pre-rift Inaltı Formation within the Ulus Formation. The overlaying Turonian-Coniacian Dereköy Formation is composed of fault scarp deposits with limestone blocks, conglomerate, sandstone and micritic limestone at the bottom, grading into andesite, basalt and pyroclastics (Figure 4). It is unconformably overlain by the Santonian-Campanian Unaz Formation, which is made out of clayey limestone and marl. The Unaz Formation is conformably overlain by the Campanian Hamsaros formation.

The Early Cretaceous syn-rift normal faults have been observed along most of the seismic lines (Figures 8, 9, 10, 11, 12, 13, 14, and 15). The normal faults die below the Maastrichtian-Paleocene Akveren Formation (Figure 4), which indicates that the formation was deposited after the back-arc rifting responsible for syn-rift sedimentation is ceased. The normal faults in the study area display well-developed horst-graben structures in the Western Black Sea basin during the syn-rift stage (Nikishin et al., 2012). Although there are bow-tie effects and low resolution under 3,500 ms in most seismic lines, some of these normal faults can be well delineated along the seismic line K98-04 (Figure 8). The seismic lines K98-01, K98-04, K98-06 and K98-07 (Figures 11, 8, 9, 10), which are almost perpendicular to the strike of the Early Cretaceous rifting, also show well-developed normal faults below the Pontide contractional structures.

The study area contains a well- developed contractional duplex structure. The floor thrust of the duplex is the décollement horizon in the Maastrichtian (Late Cretaceous) Akveren Formation, at the intraformational boundary between claystone and limestone (Figures 8, 9, 10, 11, 12, 13, 14, and 15). The roof thrust of the duplex is observed only in seismic lines K98-01 and K98-04 (Figures 8, 11), in the Pliocene Sarıkum formation, which is mainly composed of claystone. The roof thrust is not observed along K98-06, K98-07, K98-10 and K98-11 profiles (Figures 9 and 10) most likely due to poor quality of the seismic lines and change in lithologies of the rock units involved in thrusting. The number of the horses that we were able to interpret along the seismic lines decreases from eleven along the K98-01 profile (Figure 11) in the southwestern part of the study area to three along the K98-11 profile in the northeastern part of the study area.

The décollement surface displays a well-developed ramp geometry, which leads the floor thrust to jump into higher structural levels (Figures 8, 9, 10, 11, 12, 13, 14, 15 and 16). Many seismic lines show the décollement making a ramp above the syn-rift normal faults to “jump” into the fine grained weak (ductile) sedimentary unit, higher in the sedimentary succession (Figures 8, 9, 10, 11, 12, 13, 14, 15 and 16). Thomas (1982) and Schedl and Wiltschko (1987) stated that these kinds of ramps, which are associated with the basement normal faults, are rooted at or near the corners of the footwall blocks. Figure 16A shows development of the ramp structure along the base of Decollment surface in Appalachian Mountains. Figure 16B shows the ramp structures developed along the Pontidedecollement surface in the study area.

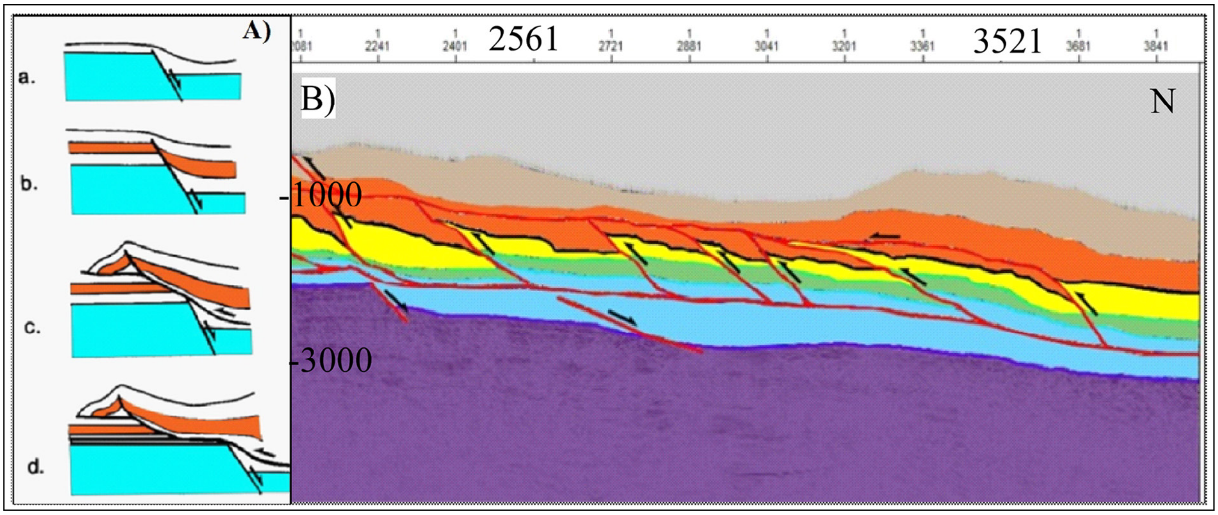

Figure 16- A) Schematic cross section showing the ramp geometry of the thrust faulting [Redrawn after Thomas (1982)]. B) One of the examples in the study area, K98-14 (between CDP numbers 14856-10856).

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