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Balanced cross section of the northeast of Adiyaman, Turkey

Mustafa Tuncer

BALANCED CROSS SECTION OF THE NORTHEAST OF ADIYAMAN, TURKEY

by

MUSTAFA TUNCER

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John Patrick Hogan, Advisor
Kelly Liu
Stephen Gao

ABSTRACT

Deformation during closure of an ocean basin and continent-continent collision in southeast Anatolia Turkey during the Late Cretaceous to Middle Miocene was investigated by construction of a geologic map, structural cross-section and retrodeformed palinspastically restored cross-section. The area of study is a N-S transect across the Bitlis Suture Zone of Northeast of Adiyaman. The study area is situated in the southeast Anatolian orogenic belt which includes, from south to north, the Arabian platform, the zone of Imbrication, and the zone of Nappes. A geologic map of this region was prepared in order to construct balanced and restored cross sections from the Bitlis Suture Zone, Northeast of Adiyaman, Turkey. This balanced cross section integrates surface and subsurface data to analyze the structural geometry of the region, calculate the vertical extension and tectonic shortening. The cross section was restored using the line and area balancing methods. A balanced structural cross section suggests that structural uplift in the Bitlis Suture Zone was the result of a thin skinned, imbricated thrust and fold system. The imbricated thrust system sequence is composed of Late Cretaceous and younger strata. Shortening and vertical length estimates based on the direct comparison between the present-day balanced cross section and the reconstructed section from Late Cretaceous to Late Miocene time indicate 24.6 % shortening in the horizontal direction. Vertical thickening is greater in the north 36.56 % than in the south 11.18 % consistent with maintaining a wedge with a critical taper necessary for continued south directed thrusting during continent-continent collision. The interpreted structural evolution model from the restoration of geological structure will assist planning for petroleum exploration in this area.

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This project is dedicated to my family whom I am grateful for their understanding, continue support and assistance while studying.

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1. INTRODUCTION

1.1. PURPOSE AND SCOPE

The Adiyaman oil field occurs within one of the geologically significant provinces of southeast Anatolia, the southeast Anatolian Fold and Thrust Belt (Rigo de Righi and Cortesini, 1964) (Fig.1.1). This region is one of the most productive areas in Turkey. There are several oil fields which occur in and around the study area (Fig.1.1) and the study area itself is a potential target region for future petroleum exploration in Turkey. The main purpose of this study is to use field observations, structural data, and well data to construct a restorable balanced geologic cross-section of this region. This cross-section can then be used in the future to guide further investigations, such as seismic experiments, and eventually assist with identifying potential subsurface traps for petroleum exploration.

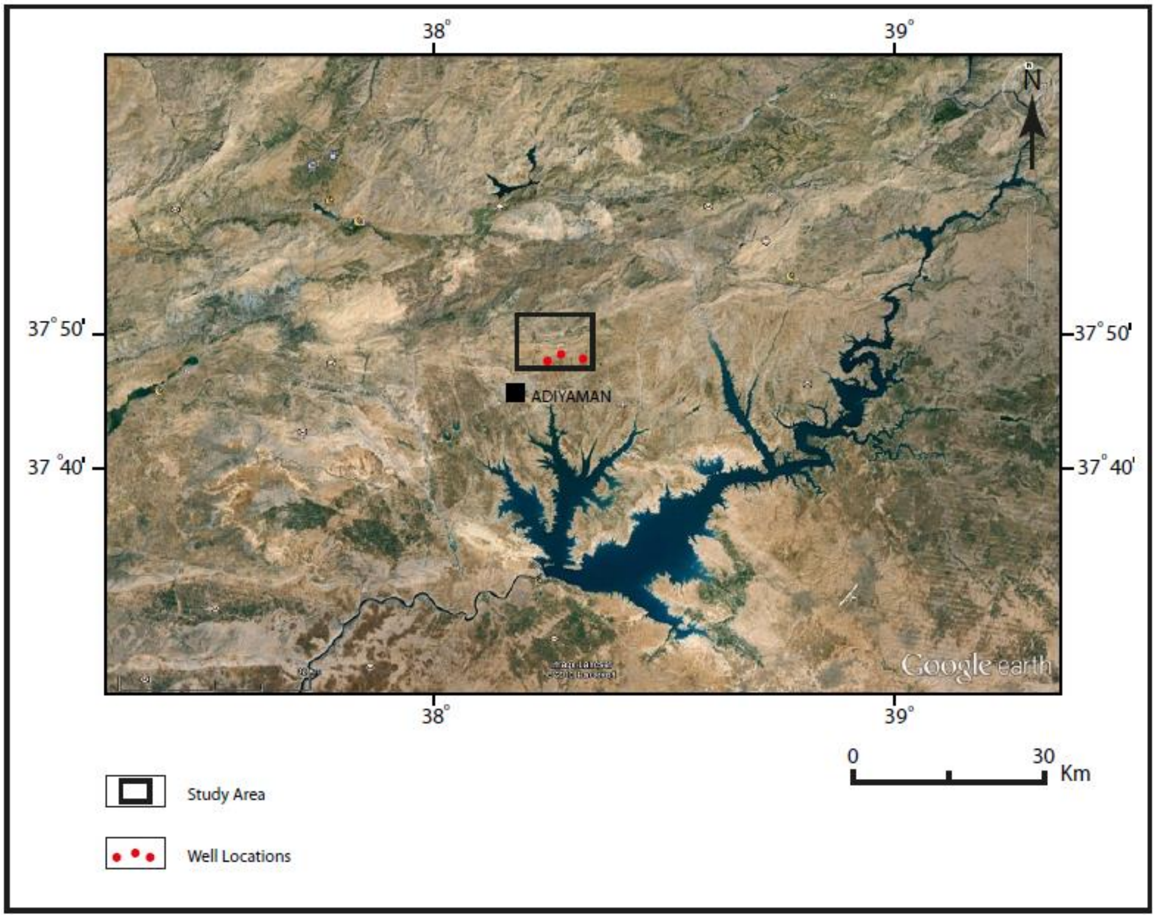


Figure 1.1 Map showing location of the study area (Northeast of Adiyaman) Turkey, Google Earth, 2013).

1.2. GEOGRAPHIC LOCATION

The study area is located near the city of Adiyaman, SE Turkey (Fig.1.1). The study area covers an area of 120 km^2 approximately 6 km northeast of Adiyaman.

1.3. METHODS OF STUDY

The main purpose of my study is to construct a restorable line-balanced geologic cross-section through a portion of the southeast Anatolian Fold and Thrust Belt that can be used in the future to identify potential subsurface traps for petroleum exploration. To do this I used the following approach (see Fig.1.2): Firstly, I conducted a literature review about geology of the study area. I then identified potential field areas and contacted the Turkish Petroleum Corporation regarding the availability of subsurface well data and seismic data within these areas. I also used Google Earth Pro to identify regions that had both sufficient bedrock exposures and good accessibility for field mapping. After selecting my field area I collected structural data on the orientation (strike and dip), location, and nature of contacts (e.g., depositional, fault, etc.) between major formations, as well as bedrock exposures, and constructed a geologic map. Using my geologic map, data from subsurface wells, and published information about the nature of the formations in this area I constructed a balanced cross section. Using line-balancing methods I palinspastically restored my cross-section.

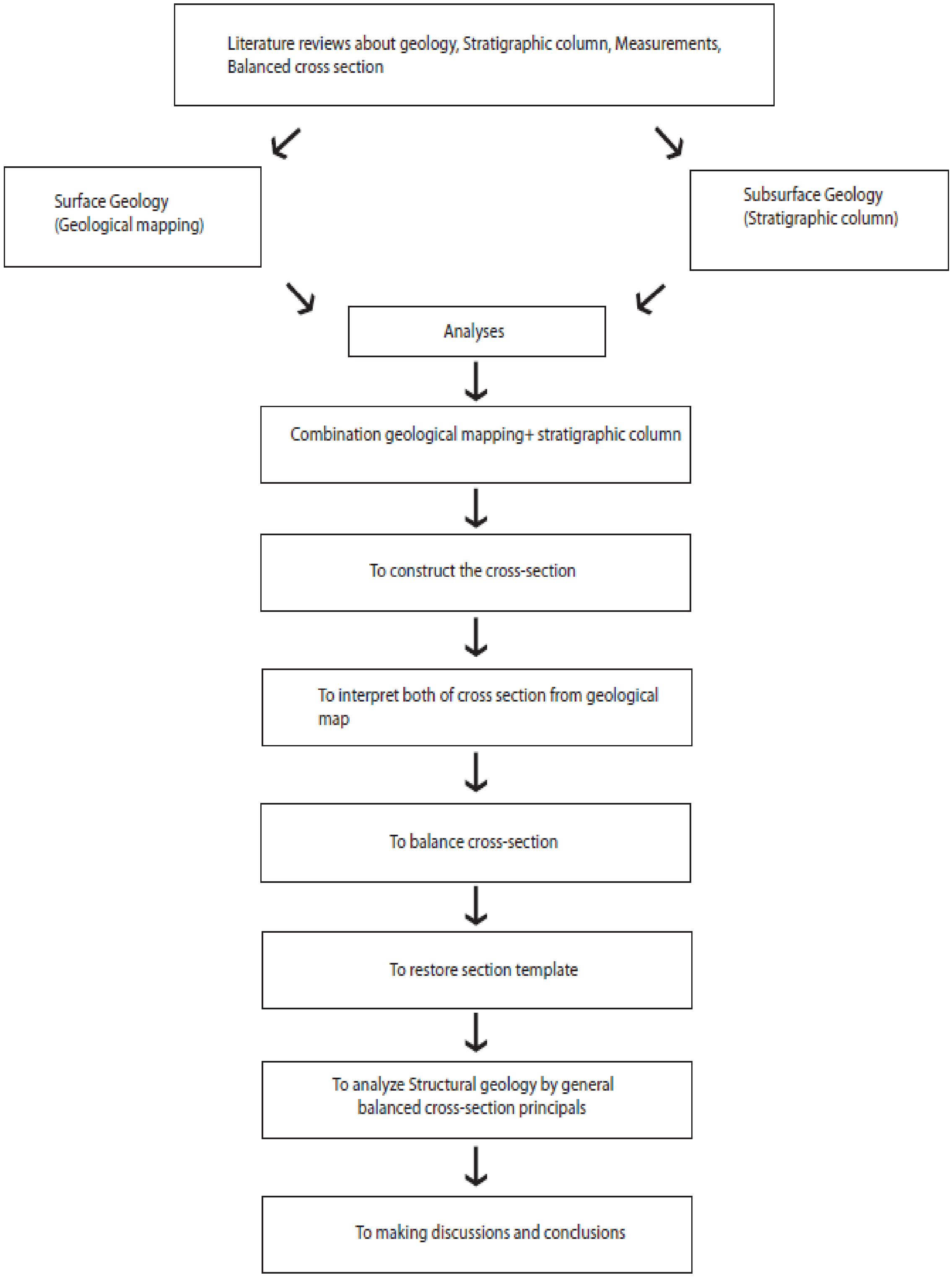


Figure 1.2 A flowchart detailing the steps needed to complete the study.

1.4. PREVIOUS STUDIES

The Adiyaman region of southeast Anatolia has been a region of considerable interest to geologists because of the potential for abundant petroleum traps. Therefore, there are many geoscientists who have studied the sedimentology, structure, and tectonic evolution of this region. A compilation of the papers I reviewed with a brief summary of each paper is presented in Appendix A.

1.5. GEOLOGICAL SETTING

The Adiyaman region for petroleum exploration covers an area of about 1800 km^2 situated in the northwestern part of southeast Anatolia (Sengor and Yilmaz, 1981). Adiyaman is surrounded by the East Anatolian Fault zone (EAFZ) and Bitlis-Zagros Suture zone (Fig.1.3).

In the region of southeast Anatolia three geologically different zones could be distinguished from south to north the Arabian Platform, the Imbrication Zone, and the Nappe Zone (Yilmaz and Clift, 1990 and Yilmaz, 1993). The Arabian Platform includes the Arabian autochthonous and parauthochtonous sedimentary succession which have accumulated since the early Paleozoic. The platform sequence is relatively undeformed in its exterior parts. However, towards the north, in the region which was affected by the southeast Anatolian orogeny, the platform sequence gradually becomes more deformed into a foreland fold and thrust belt (Yilmaz and Clift, 1990). The Imbrication Zone is a narrow structural E-W trending belt located between the Arabian platform and the Nappe Zone. It is separated from the other two regions by thrust faults.

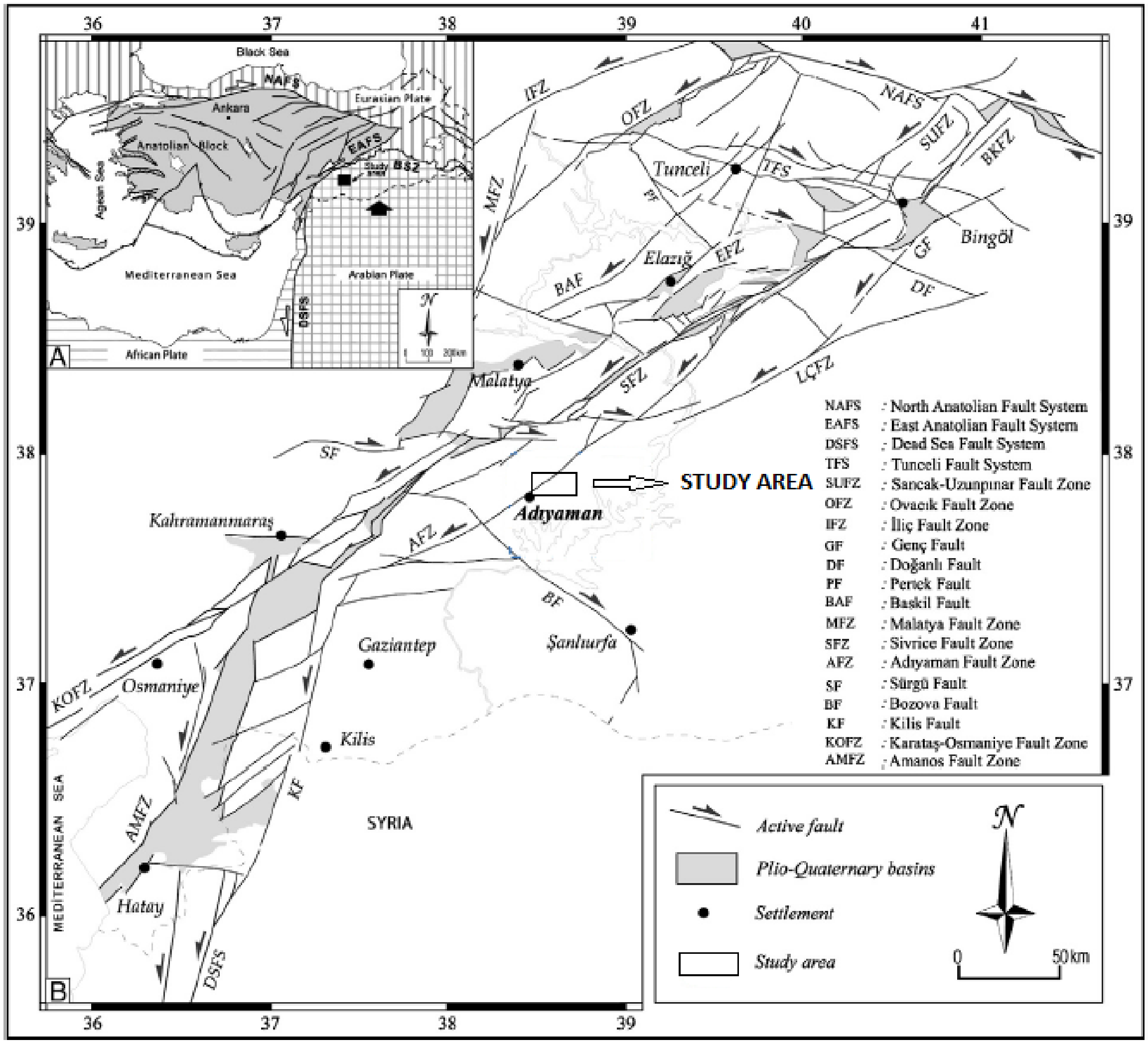


Figure 1.3 (A) A simplified geologic map showing major plates and their boundary faults in the Eastern Mediterranean region and (B) a simplified neotectonic map showing major fault zones in the area surrounding and location of the study area, Adiyaman (modified from Tasgin et al., 2011).

It consists of imbricated thrust slices which cover a succession comprising the late Cretaceous to early Miocene sequence. The Nappe Zone is the structurally highest tectonic units of the southeast Anatolian orogenic belt. It is composed of two stacks of thrust nappes termed the lower nappe and the upper nappe. The lower nappe is comprised of the Maden Group and tectonic slices of a polyphase metamorphic ophiolitic assemblage. The upper nappe contains the Poturge and Bitlis metamorphic massifs. The upper nappe package rests on top of the lower nappe along a gently folded thrust surface (Yilmaz and Clift, 1990 and Yilmaz, 1993).

Southeast Anatolia was subjected to two major episodes of Alpide deformation (Yilmaz, 1993). The first episode of deformation took place during Late Cretaceous period when the ophiolite (i.e., the Kocali and the Karadut complex) was obducted onto the Arabian Platform. However, this event was not the consequence of a continental collision (Yilmaz, 1993). The ophiolite obduction onto the Arabian platform was followed by a region wide extension and a subsequent marine transgression over the platform immediately after the ophiolite obduction during late Cretaceous time. The second episode of deformation took place during middle Eocene-Miocene time. This deformation took place in two obvious stages as a consequence of the continuing destruction and complete closure of the ocean basin(s) during the collision between the Arabian plate (located to the South) and the Nappe Zone (located to the North). The second stage of deformation occurred during the Miocene when the combined lower and upper nappes were thrust onto the Arabian plate representing the latest stage of the orogenic evolution (Yilmaz, 1993).

Two contrasting morphologic features dominate southeast Anatolia, in the North east-west trending mountain ranges and in the south a low lying flat plain. These conform to the Southeast Anatolian Alpine orogenic segment and the Arabian Platform (Fig.1.4). Three structural units crop out along the orogenic belt and the thick sedimentary successions of the Arabian Platform. These are the old metamorphic basement rocks (Bitlis and Poturge massifs) of the region and the tectonic fragments of a dismembered ophiolite. The Poturge and Bitlis massifs of late Paleozoic-Mesozoic age (Fig.1.4) are considered to represent older basement rocks (mica schist, marble, basal quartzite) that have been thrust over the younger sedimentary units of the Arabian Platform. The fragments of ophiolite crop out in the Suture Mountains and in lower and upper nappes which were thrust on to the Arabian Platform. The ophiolites units cover much larger areas than the metamorphic massifs (Fig.1.4). The ophiolite fragments were obducted onto the Arabian Platform during the late Cretaceous, Eocene, and early Miocene time (Yilmaz, 1993). Some of the ophiolitic bodies are chaotic whereas others are internally ordered. In the nappe region, the ophiolites record polyphase metamorphism (Yilmaz, 1993) whereas ophiolites obducted onto the Arabian Platform are mostly non-metamorphosed.

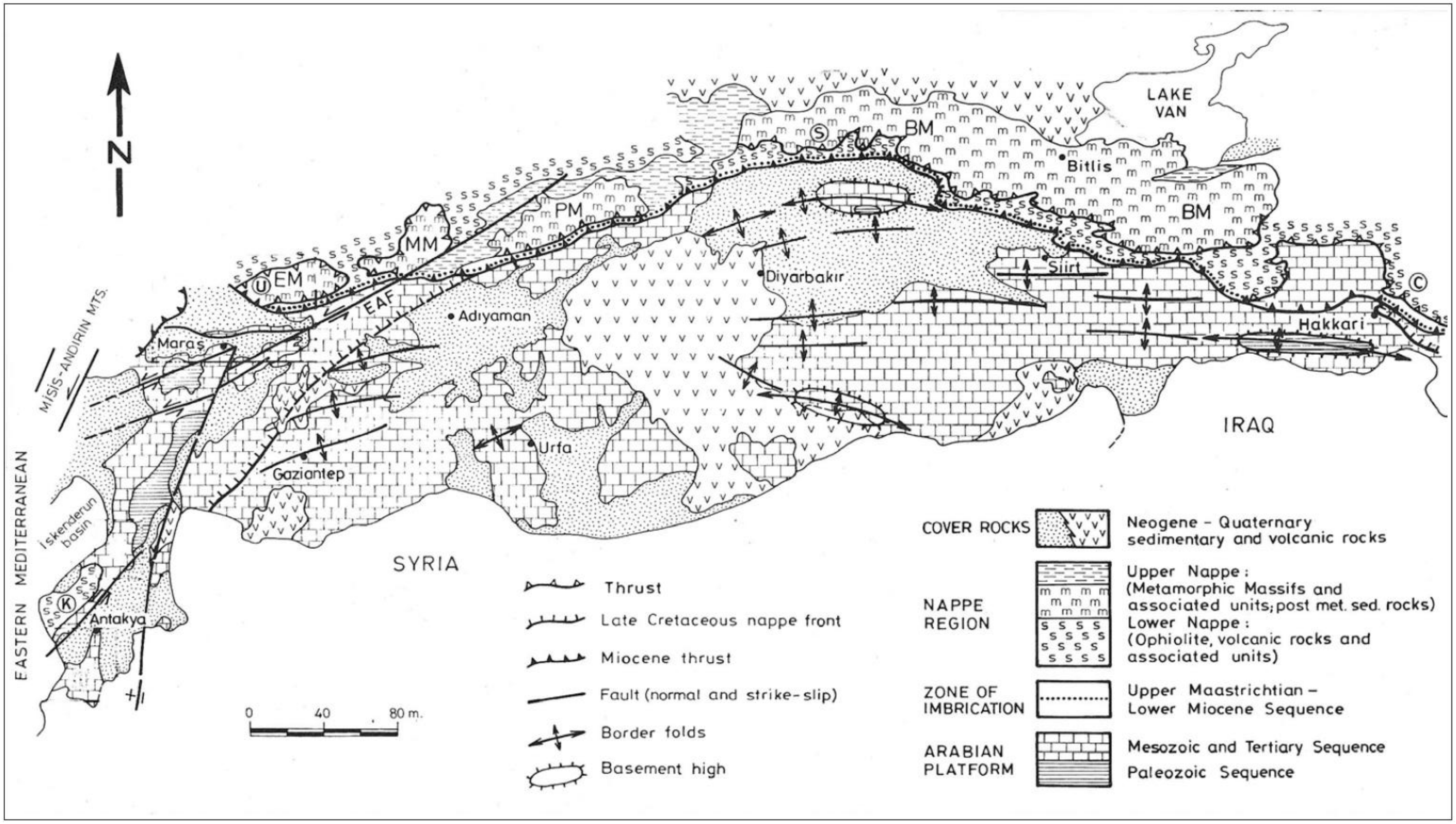


Figure 1.4 Geologic map of the Southeast Anatolia (Yilmaz, 1993).

2. REGIONAL GEOLOGY

2.1. STRUCTURAL UNITS AND STRATIGRAPHY OF SOUTHEAST ANATOLIA

The stratigraphy of the study area is known from both the surface stratigraphy and subsurface stratigraphy from wells drilled in the area. The surface stratigraphy was investigated by field observations aided by previously published maps. Knowledge of the subsurface stratigraphy data was acquired from wells in the study area that were drilled in different years by the Turkish Petroleum Corporation. The stratigraphy of southeast Anatolia is summarized in (Fig. 2.1). Additionally, the study area is a highly deformed terrane known as the SE Anatolian Orogenic belt. There are several faults and folds that define the main structural trend as ENE-WSW in the study area. The attitude of bedding is acquired from the field measurements to discover the folding orientation in the region. In the study area, there are three major approximately east-west-trending tectonic zones which are the Arabian platform, a zone of imbrication, and a zone of nappes (Yilmaz, 1990, 1993) (Figs.1.4). The first matches the Jura-type border folds (Ketin, 1966) whereas the second and third matches the orogenic zones of previous workers (Rigo de Righi and Cortesini, 1964; Ketin, 1966). Major thrusts separate these zones.

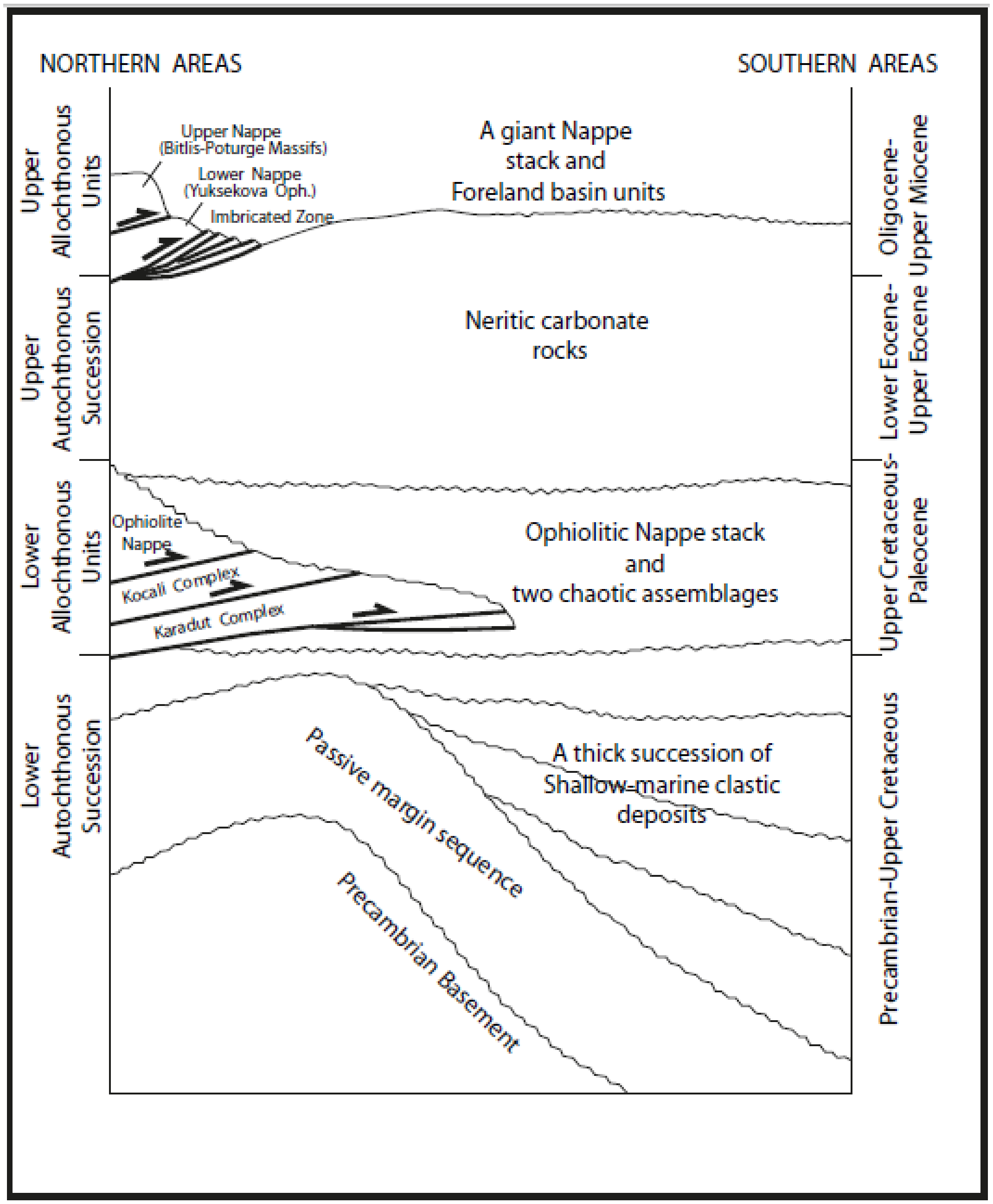


Figure 2.1 Generalized (composite) stratigraphic section of the Arabian Platform in southeastern Anatolia (Modified after Yilmaz, 1993).

2.1.1 The Arabian Platform. The Arabian platform is composed of mostly a marine sedimentary succession deposited from the early Cambrian to middle Miocene time as well as the upper Cretaceous ophiolite nappes that were thrust onto platform. Yilmaz (1990, 1993) subdivided the Arabian Platform into four units. From the bottom to the top they are;

-the lower autochthonous succession,

-the lower allochthonous units,

-the upper autochthonous succession

-the upper allochtonous units (Fig. 2.1)

2.1.1.1 Lower autochthonous succession. The Lower Autochthonous Succession unconformably overlies the Precambrian Basement and comprises platform carbonate succession, limestone, siltstone, marl, sandstone, and shale ranging from Precambrian to upper Cretaceous time. A thick succession of shallow-marine clastic deposits is represented in the lower Paleozoic sequence and the clastic deposits are replaced by neritic carbonate rocks (Fig.2.1) from Devonian to Cretaceous time. Permian rocks consist of limestone, dolomite, and rare red beds (Fig.2.1) that grade upward into lower Triassic marly limestone. In addition, the Triassic units include clastic and carbonate rocks that rest conformably on as much as 500 m of alternating beds of shallow-water limestone and dolomite. Albian-Cenomanian age dolomite-rich limestone such as Korudag and Derdere Formations (Tuna, 1973) are more abundant toward the higher levels of the section (Yilmaz, 1984).

2.1.1.2 Lower allochthonous units. The Lower Allochthonous Zone consists of a series of stacked thrust nappes. The uppermost thrust nappe is an ophiolite complex which rests in fault contact on two noticeably different and internally chaotic assemblages (Yilmaz, 1993). Below the ophiolite, from top to bottom, is the Kocali Complex (Rigo de Righi and Cortesini, 1964) which is a mélange and then the Karadut Complex (Sungurlu, 1974; Perincek, 1979) which is flysch and wild flysch. The compound stratigraphic thickness of nappes is substantially more than 6 km; the thickness of the sub-ophiolitic nappes varieties between 1 to 3.5 km. The Karadut Complex is composed of clasts of igneous rocks derived from erosion of the ophiolite nappes. Within this formation, there is a distinct lithologic division from Upper Triassic to Upper Cretaceous (Fourcade et al., 1991). The lower part of the complex is a passive margin sequence including outer shelf and continental-slope deposits and consisting of hemipelagic limestone and calcareous turbidite succession.

In thrust contact with the Kardut Complex is the overlying Kocali Complex which consists of ophiolitic rocks and epiophiolitic sedimentary rocks (Sungurlu, 1974), sheared serpentinite, chert, shale, and interlayered basaltic lavas formed the matrix rocks evolved from the continental platform. Overlying this sequence and also in thrust contact is the Ophiolite Nappe. The base of the ophiolites sequence include serpentinized and tectonized peridotite. These rocks grade upwards into subordinate bodies of dunite, harburgite, lherzolite, and small patches of websterite.

2.1.1.3 Upper autochthonous succession. During the Maastrichtian marine sedimentation, commonly with neritic carbonate, was deposited without interruption in this succession. Resting unconformably on the top of the nappe units is a basal sandstone and conglomerate unit known as the Terbuzek Formation (Fig.2.1). The Terbuzek Formation is overlain by a conformable thin, reefal limestone unit the Besni Formation (Fig.2.1) which in turn is overlain by a thick shale-siltstone unit the Germav Formation which is late Maastrichtian to Paleocene in age.

2.1.1.4 Upper allochthonous units. The second major episode of nappe emplacement started during early Miocene time after the Late Mesozoic ophiolite obduction. A giant nappe stack, comprising the ophiolitic nappes, resting in tectonic contanct on top of the flat-lying metamorphic massifs (Figs.1.4), was thrust southward over the Eocene to early Miocene foreland basin units. The present mountain ranges were formed as a consequence of this episode of deformation. The two distinctive zones in the Suture Mountains are the Zone of Imbrication and the Nappe Zone.

2.1.2 The Zone of Imbrication. The Zone of Imbrication is a narrow, east-west trending belt (Figs.1.4) that is sandwiched between the Arabian plate to the south and the nappe region to the north (Figs.1.4 and 2.1). It is separated from the other two regions by a thrust zone and is comprised of a series of imbricated thrust slices which were tectonically transported towards the south (Yilmaz and others, 1987a; Yilmaz, 1990: Karig and Kozlu, 1990) that cover related succession. The stratigraphic sequences are reversed, with older units resting on the younger units (Yildirim and Yilmaz, 1992). An ophiolitic thrust slice occurs at the top of the section within the Zone of Imbrication. This overlies a sedimentary unit of Maastrichtian to early Eocene age that is comprised of shale, chert, marl, and alternating pelagic limestone deposited unconformably on an ophiolitic substratum. A thick sequence of middle to late Eocene andesite and associated pyroclastic rocks, the Helete volcanic rocks crops out beneath these thrust sheets. These volcanic rocks overlie the chaotic sedimentary deposits of late Eocene-Oligocene age. The middle Eocene calc-alkaline volcanic and volcaniclastic rocks of the Helete Formation crop out within the imbricated zone. The Maden Group presents a mostly a transgressive sedimentary succession alternating with rare basaltic lavas.

2.1.3 The Nappe Zone. The Nappe Zone is the highest tectonic units of the Southeast Anatolian Orogenic belt and is situated north of the Zone of Imbrication (Fig. 1.4). The Nappe Zone consists of two stacks of thrust sheets known as the lower nappes and the upper nappes. The lower nappes are comprised of two different metamorphosed ophiolitic associations and the Maden Group (Yilmaz, 1993). The base of the Maden Group is basal sandstone followed by alkaline basalt. These units are overlain by reefal limestone that passes upward into pelagic red limestone, radiolarian chert, shale, and intercalating tholeiitic basaltic lavas (Ozcelik, 1982). The age of Maden Group is middle Eocene (Yilmaz et al., 1987a; Perincek and Kozlu, 1984) and represents the contents of a short-lived ocean basin.

The upper nappe is comprised of the metamorphic massifs of southeast Anatolia (Ketin, 1983). The upper metamorphosed sedimentary sequence nappe is composed of early Paleozoic to Campanian age rocks known as the metamorphic massifs of Southeast Anatolia (Yilmaz et al., 1987a; Yigitbas, 1989; Yilmaz and Yigitbas, 1991).

During the Triassic period, the Permian carbonate platform of the Southeast Anatolian Orogenic Belt, underwent rifting accompanied by normal faulting and volcanism which coincided with the early stages of continental breakup (Fig. 2.2. A). In the Jurassic to Early Cretaceous time, the tectonic environment leading to the development of the carbonate platform, continental slope, and abyssal plain persisted to the end of the Early Cretaceous period (Fig.2.2.B). In the Turonian - Santonian (?) time, an ophiolitic nappe started to move towards the continent (possibly Turonian time). A foredeep and accompanying forebulge developed on the abysal plain and on the edge of the Arabian plate in front of the advancing ophiolitic nappe. While the foredeep subsided, olistostromes derived from the carbonate bank, the slope, and the outer-shelf regions were deposited into the foredeep in response to emplacement of the ophiolite. At the same time a regional unconformity developed on the forebulge as it was uplifted and eroded (Fig.2.2.C). In Campanian time, the advancing thrust nappe pile was emplaced onto the previously elevated and eroded edge of the continental platform depressing the margin beneath sea level and as a consequence a deep basin was formed (Fig.2.2. D).

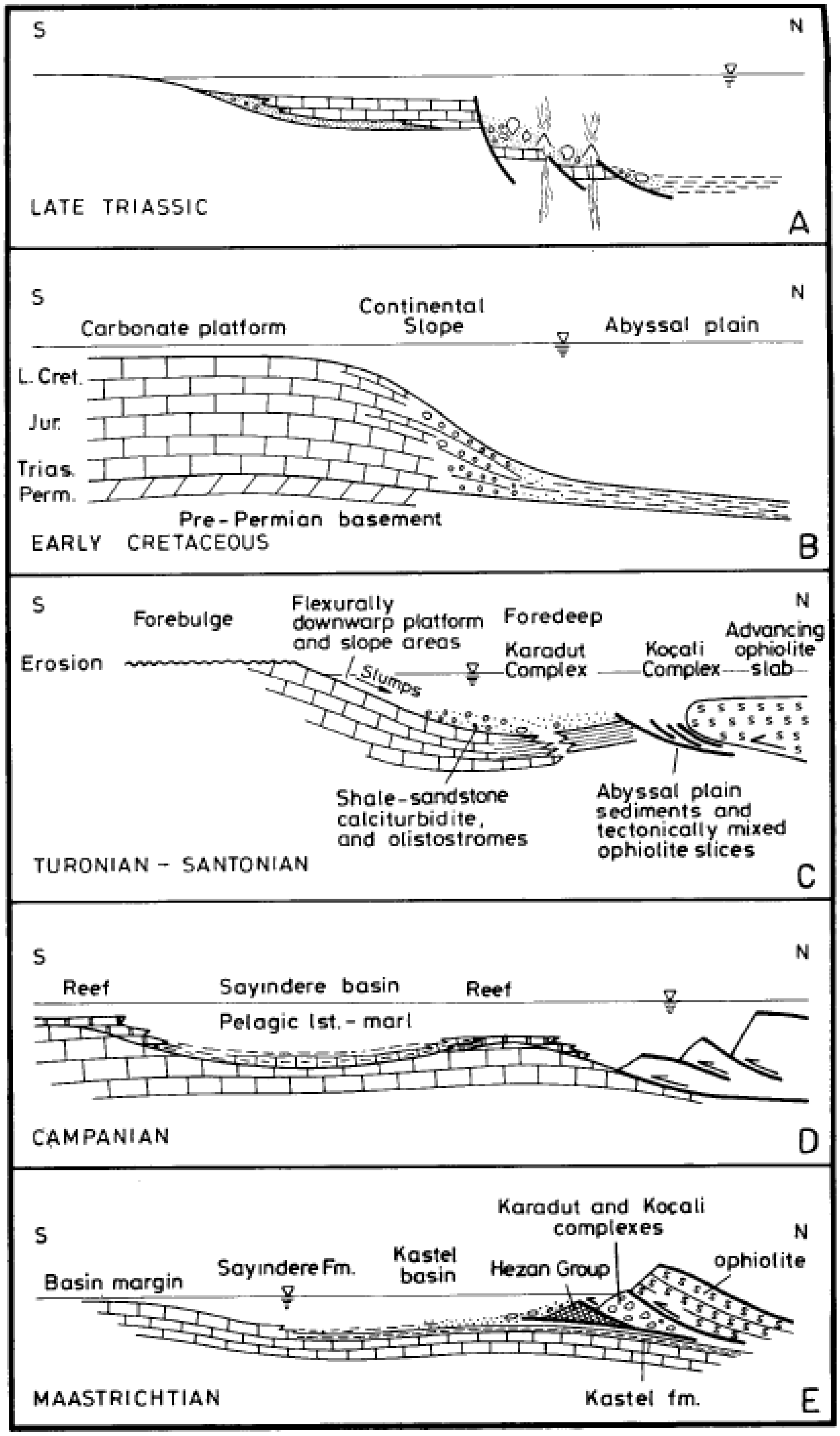


Figure 2.2 Plate-tectonic models for the Mesozoic evolution of southeast Anatolia (Yilmaz, 1993).

In late Campanian to early Maastrichtian interval, obduction of the ophiolitic allochthon onto the platform took place in a piggyback fashion above detached thrust sheets of platform units. During Maastrichtian time, the thick nappe pile formed a structural high along the outer margin of the continental platform that continuously reached above sea level. Debris flows and blocks acquired from this high were deposited immediately into this basin lying in front of the nappes (Fig.2.2. E).

Subsequent to the late Cretaceous ophiolite obduction onto the Arabian Platform, a north-facing passive margin developed and persisted well into the middle Eocene. The continental-slope and abyssal plain sedimentary sequence was deposited during the Maastrichtian to Early Eocene period. Also, the tectonic thrust slices of the imbricated zone and the lower and upper nappe were obducted onto the platform during the middle Eocene epoch (Fig.2.3 A). A poorly developed ensimatic island arc formed in the ocean basin. In middle Eocene, volcanism moved southward where a well-developed volcanic chain formed on the ocean floor north of the Arabian plate. Also, the metamorphic massifs (e.g., Precambrian basement) started to be consumed in the subduction zone. In addition, during this period, the Maden basin opened as a back-arc basin with respect to the volcanic chain (Fig.2.3.B).

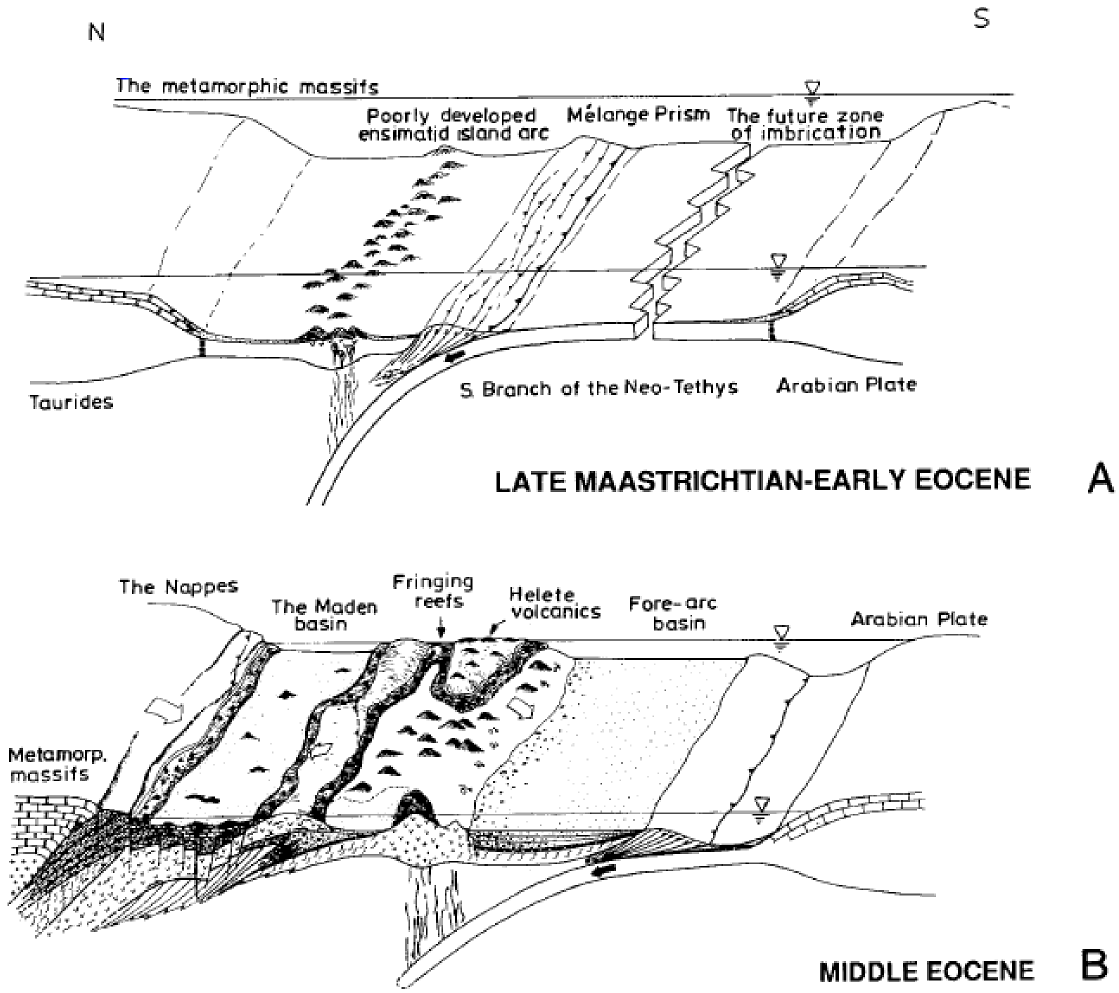


Figure 2.3 The subsequent stages of southeast Anatolian orogenic evolution during latest Cretaceous-middle Miocene time (Yilmaz, 1993).

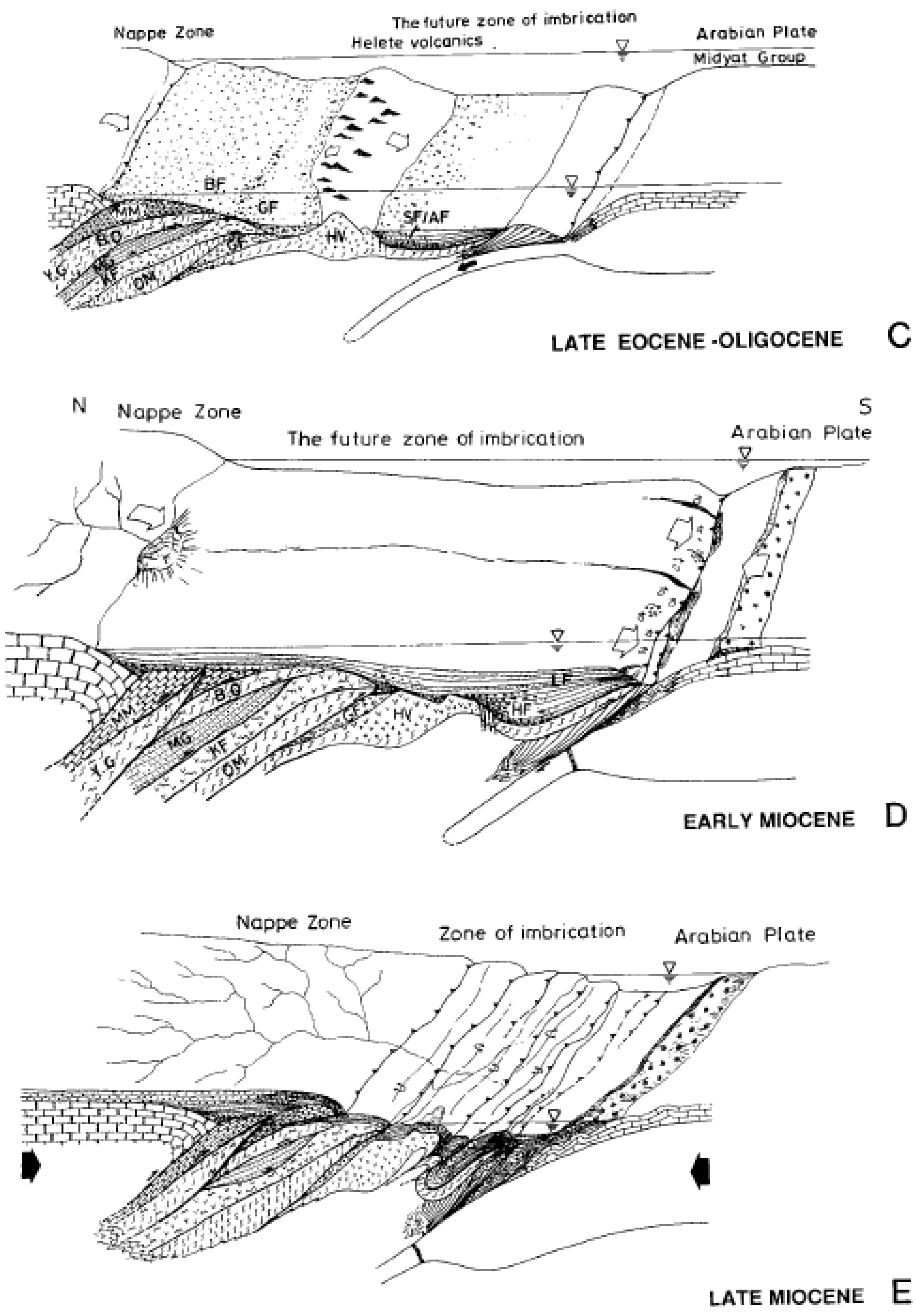


Figure 2.3 The subsequent stages of southeast Anatolian orogenic evolution during latest Cretaceous-middle Miocene time (Yilmaz, 1993) (Cont.).

In late Eocene-Oligocene time, the different tectonic zones were all buried as a group by a common sedimentary cover sequence. These sedimentary rocks are comprised primarily of material derived from erosion of the internally chaotic units of the emerging lower and upper nappes and are not oceanic in character (Fig.2.3 C). Moreover, during this period, the different tectono-stratigraphic units were spatially close to each other before their accretion. Furthermore, at the end of the middle Eocene epoch the Maden basin closed. During this time south directed thrusting emplaced the nappes of the Upper Allochthonous Units on top of the Maden Group (Fig.2.3 C). In the early Miocene, accompanying the subduction of oceanic rocks, further convergence resulted in continued tectonic transport of the nappes of the Upper Allochthonous Unit. The nappes, consisting of the passive margin rocks deposited on the edge of the continent, were thrust over the Arabian platform during the final stages of the continental collision (Fig.2.3 D). During the middle-late Miocene, continued southward advance of the nappes of the Upper Allochthonous Unit marked the end of subduction and eliminated the marine environment. During this period, geologic units in front of the advancing nappes were tectonically emplaced as thrust slices resulting in the formation of the zone of imbrication (Fig.2.3 E). Finally, the whole area was gradually elevated above sea-level and eroded.

2.2. SOUTHEAST ANATOLIA STRATIGRAPHY ALONG THE BALANCED CROSS SECTION

In this section the stratigraphy (Fig. 2.4) present within the balanced cross section is reviewed. The Mardin Group is composed of two formations which are the Derdere and the Karababa Formations. The Derdere Formation is represented by deep-marine, organic-rich limestone at the base (e.g., source rock), porous primary and secondary dolomites in the middle (e.g., reservoir rock), and micritic, argillaceous limestone at the top (e.g., sealing cap-rock) (Coskun,1990). This formation rests conformably on the Sabunsuyu Formation and has an unconformable contact with the overlying Karababa Formation. The Karababa Formation typically is comprised of limestone from bottom to top including argillaceous limestone, dolomitic limestone, and cherty limestone (Yilmaz and Duran, 1997). Highly argillaceous, radioactive limestone is represented at the base (the Karababa-A source rock), which is then overlain by argillaceous and tight micrites with sparse dolomite (Karababa B), and finally a fossiliferous, sometimes fractured, micrites at the top (the Karababa-C a partial reservoir rock). The Karababa Formation unconformably overlies the Derdere Formation and itself is unconformably overlain by the Karabogaz Formation (Tuna, 1973; Aksu, 1980; Pasin et al., 1982; Guven et al., 1988).

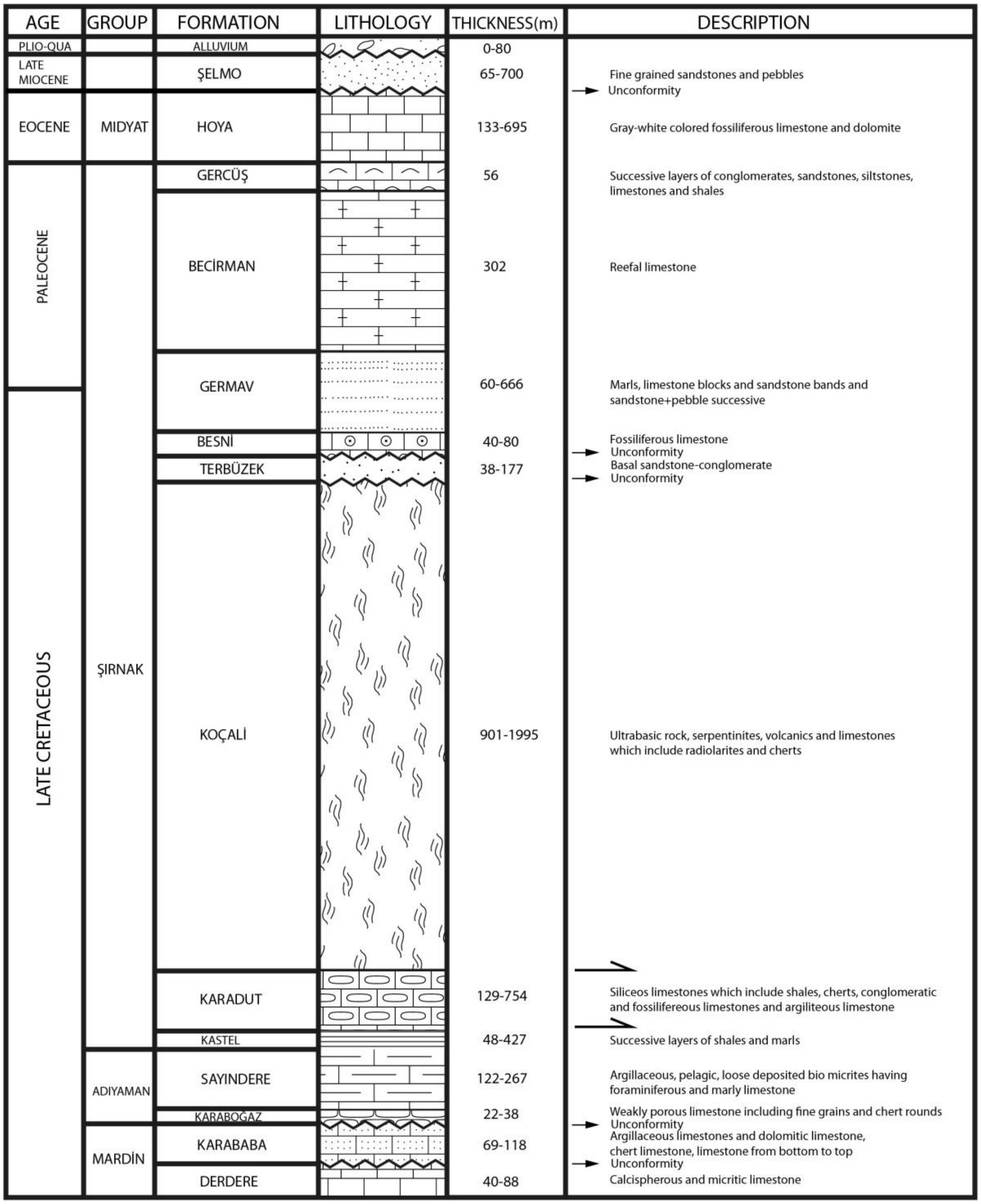


Figure 2.4 Generalized stratigraphic section of the study area (Northeast of Adiyaman) (This study).

The Adiyaman Group is divided into two formations: the Karabogaz and the Sayindere Formations. The Karabogaz Formation is a weakly porous limestone that contains fine, rounded, grains of chert (Sonel and Sarbay, 1988, Yilmaz and Duran, 1997). It unconformably overlies the Karababa Formation and has a conformable contact with the overlying Sayindere Formation (Guven et al., 1991a). The Sayindere Formation has a conformable contact with the Kastel Formation (Yilmaz and Duran, 1997). It is composed of argillaceous, pelagic, foraminiferous biomicrites, and marly limestone (Sonel and Sarbay, 1988).

The Sirnak Group has been separated into eight formations in the study area. These include the Kastel, Terbuzek, Besni, Germav, Becirman, and Gercus Formations as well as the Kocali-Karadut Complex. The Kastel Formation consists of successive layers of shale and marls (Sonel and Sarbay, 1988) and ranges in thickness between 48 m to 427 m. The chaotic assemblage of the sedimentary Karadut Complex consists of siliceous limestone which include shale, chert, conglomeratic and fossilifereous limestone, and argillaceous limestone (Sonel and Sarbay, 1988). The Kardut Complex was tectonically emplaced over the Sayindere and Kastel formation along the basal décollment in late Cretaceous time (Gunay, 1984; Perincek, 1979e and f). The late Cretaceous Kocali Complex is comprised of a thick sequence of ultrabasic rock, serpentinite, volcanics, and limestone which include radiolarites and cherts ranging between 901 m to 1995 m (Sonel and Sarbay, 1988) and was emplaced by thrusting over the Karadut Complex during late Cretaceous (Yalcin, 1978; Perincek, 1979 f; Yoldemir, 1987 b). The late Cretaceous Terbuzek Formation limestone and siltstone rest conformably on the Kastel Formation and are unconformably overlain by the Besni Formation (Bryant, 1960a). The Terbuzek

Formation ranges from 38 m to 177 m thick. While the Besni Formation is comprised of fossiliferous limestone, the Germav Formation is represented by two different lithologies one of which is marl comprised of limestone blocks and the other is sandstone bands comprised of sandstone and pebbles in successive layers. The Gercus Formation, which is a relatively thin layer, consists of successive layers of conglomerate, sandstone, siltstone, limestone, and shale (Sonel and Sarbay, 1988). The Becirman Formation is composed of reefal limestone which includes dolomite blocks.

In the field area the Midyat Group crops out as limestone and dolomite (Gorur and Akkok, 1982b; Duran et al., 1989) and conformably overlies the Gercus Formation and is unconformably overlain by the Firat Formation. The Selmo Formation is reported to consist of fine grained sandstones and pebbles and ranges in thickness from 65 m to 700 m (Sonel and Sarbay, 1988).

3. METHOD AND INVESTIGATION

3.1. DATA ACQUISITION

This study utilizes several data sets including field, satellite imagery, and subsurface well data. The surface data, acquired during field studies, and the well data, obtained from the Turkish Petroleum Corporation, were used to interpret the geologic structure. These data sets were studied separately and subsequently combined to construct a geologic map and a balanced cross-section.

3.2. FIELD WORK

The field work consisted of mapping and obtaining structural data which included the attitude of strata and lithological boundaries between geological units (dip amount and dip direction). All observations were located using a GPS receiver (Appendix B). The 1:25000 scaled topographic maps corresponding to the study area were used to construct a 1:25000 scaled geological map which was drafted by hand and with Adobe Illustrator CS5 software (Fig. 4.1). The geologic map of the study area at the scale of 1:25000 shows the locations of major formations, their contacts, and major structures such as faults and the axial traces of folds (Figure 4.1). This data was also used to construct a balanced cross section.

The strike and dip data (Appendix B) from field measurements were plotted onto the geological map using their UTM locations. The trends of the faults and folds on the geological map were determined in the field and by satellite imagery (Appendix C). This information was used in the construction of the balanced cross section.

3.3. THICKNESS OF STRATIGRAPHIC UNITS

The thickness of the exposed map units and the thickness of the stratigraphic units in the subsurface can be constrained from outcrop patterns and from well data acquired from the Turkish Petroleum Corporation. In construction of the cross-section it is assumed that the true stratigraphic thickness of the units remains constant. However, changes in the dip can result in an increase in the thickness of a unit measured in the well log, even though the section is not faulted. In order to better understand the stratigraphy and growth history of the geologic structures and to resolve some of the geometric problems caused by changes in the reported thickness of units in the well logs I calculated a structural dip for some of the units in the subsurface using the following relationship:

$$TST = TVT \times (\cos \phi)$$

Where TST equals the True Stratigraphic Thickness, TVT equals the True Vertical Thickness as measured in the well and ϕ equals the Estimated Bed Dip calculated from this equation.

3.4. CONSTRUCTING THE CROSS SECTION

A balanced geological cross section was constructed along the section studied in detail in the field data using field measurements and subsurface well data. The cross section was restored using the area and line balance method in which the original length and the original area of units in the section are preserved. The cross section was constructed and the thickness of the stratigraphic units is assumed to be the same before and after deformation. Thickness of sedimentary units is assumed to be constant within the section unless other information is provided.

Balanced cross sections have three principle sources of data which I used in the construction of my cross section; they are the spatial distribution and measured thickness of stratigraphic units, the originally unstrained nature of rock, and the orientation of bedding, cleavage, contacts (including fault contacts), and structural elements such as fold axes at spatially well constrained locations. Additionally, balanced cross sections are constructed taking into account the following characteristics;

1. The structural styles shown in the cross section are the same as those present in the region represented in the cross section.
2. The length of beds shown in the cross sections is the same as bed lengths before deformation.
3. The area of units shown in the cross sections is the same as their area in the restored, unstrained section.

The trace of the balanced geological cross section was constructed perpendicular to folding in the Bitlis Suture, which is from Esence to Cemberlitas, and parallel to the direction of tectonic transport, which is approximately N-S (Fig 4.1). Field measurements, satellite data, and well data (Figs. 4.2, 4.3, 4.4 and 4.5) were integrated to construct the balanced cross section in order to understand the geologic history and evolution of both surface and subsurface structures. The balanced cross-section also allows for constraints to be placed on the amount of tectonic shortening that occurred. In addition, cross-sections serve to elucidate the structural style that developed to accommodate this shortening and therefore provides a framework for future hydrocarbon exploration by identifying potential subsurface structural traps within this fold and thrust belt.

The following steps were used to construct this balanced cross section (Ramsey, 1987).

1. Selection of the location of the section line which should be parallel to the direction of shortening (i.e., perpendicular to the strike of contacts and trend of major structures) and avoids tear faults and lateral ramps.
2. Establishing the true stratigraphic thickness of each geologic unit.
3. Defining the depth to which the cross-section can be constructed with reasonable confidence based upon regional geologic information including information provided by deep exploratory wells.
4. Plotting along the surface profile of the cross section the location and orientation of formation contacts, fault contacts, and structural elements as determined by field observations and measurements and satellite imagery.
5. During the palinspastic restoration of the cross section I used line and area balancing methods to restore individual structural domains (e.g., bounded by faults) first and then combined these restore domains to construct the final complete restored cross section.

The assumption in structural balancing that constant volume (area) is maintained prevents the geologist from creating or destroying volume (area) to force the palinspastic restoration to work. In this way, the viability of the cross-section can be evaluated and volume changes that may accompany deformation, such as cleavage formation, can be constrained. “Retrodeformation” or “Palinspastic Reconstruction” is a technique which assumes a cross section should be restorable to an initial undeformed state because the stratigraphic units were deposited parallel to the regional dip. Preservation of line length and bed thickness can be quickly applied to the cross section to evaluate the cross section viability (Tearpock and Bischke, 2003). The two methods which are suitable for use in layered rocks to palinspastically restore balanced cross section are the “Busk” and the “Kink” methods. The Busk method (Busk, 1929) suggests that the folds are constant-thickness of stratigraphic units and they are concentric. The Kink method (Dahlstrom, 1969) is extremely beneficial for estimating the depth to geologic structures and was used in the construction of this cross-section. Also, this method assumes that the stratigraphic layers maintain constant thickness (Tearpock and Bischke, 2003). The two techniques for “balancing” cross sections are “Line Length Balancing”, where the bed length before deformation will remain the same after deformation (Hossack, 1979). The bed might be bent by folding or broken by faulting but it should remain the same length. In “Area Balancing” material is conserved and is assumed to not be entering or leaving the plane of the geologic cross section for example via strike-slip faulting (Tearpock and Bischke, 2003). I used both the line length and area balancing methods in restoring my cross section.

The cross section was constructed and restored using a combination of hand drafting and Adobe Illustrator CS5 software. After restoring cross section, the shortening rates along the sections were measured by using an equation;

$$\%\, e = [\,(Lf - Li\,) \div Li\,] \times 100$$

where % e is the percent extension, Li is the original (pre-deformed) length of the section and Lf is the current (deformed) length of the section (Hossack, 1979).

4. RESULTS

4.1. INTRODUCTION

A geological map of the study area and a structural cross section were constructed from integrated field data, satellite imagery, and subsurface data that were acquired during the field study and from the Turkish Petroleum Corporation (Appendix D). The faults that have been measured in the field and interpreted from satellite images (Appendix C) are used to constrain the geometry of these structures in the study area. The displacement along thrust faults was constrained from the cross-section. Then, the cross section was restored using both line length and area balancing methods to test the validity of the cross section and to estimate percent extension along the section.

4.2. RESULT FROM FIELD OBSERVATIONS

The geologic map of the study area showing the locations of major formations, their contacts, and major structures is presented (Fig.4.1). In the study area data were collected along a transect from Esence to Cemberlitas. In the north of study area, the Kocali Complex (Late Cretaceous-Maastrichtian) consists of serpentinite, chert, shale, and interlayered basaltic lavas evolved from the continental platform and slope facies. The contact between the Kocali Complex and the Midyat Group contact is a tectonic thrust contact in the study area. In the north and in the middle study area, the Besni Formation (Late Cretaceous-Maastrichtian) consists of yellow sandstone and yellow white foraminiferous limestone. The depositional environment of the formation is shallow marine. The Germav Formation unconformably overlies the Besni Formation. The Germav Formation (Late Cretaceous-Paleocene) is composed of marls and shale interbedded with thin limestone beds and gray beige marls. The depositional environment of the formation is deep marine to continental slope (Dincer, 1991). The Germav Formation is conformably overlain by the Midyat Group. The Midyat Group (Eocene) consists of white, cream, yellow, light orange colored occasionally silicified, very clayey, fossiliferous limestone and evaporates. The Selmo Formation unconformably overlies the Midyat Group. It was deposited on the carbonate platform (Duran et al., 1988). The Selmo Formation (Late Miocene) consists of various colored polygenic moderately shaly sandstones and yellow colored, soft, silty claystone. Alluvium unconformably overlies the Selmo Formation. The Selmo Formation was deposited in continental environment (Dincer, 1991). Quaternary age alluvium covers the low relief topography and is also found in the river valley. It has coarse, grained sediments, and consists of mainly unconsolidated, uncemented, gravel and sands. Alluvium unconformably overlies the Selmo Formation (Fig.4.1).

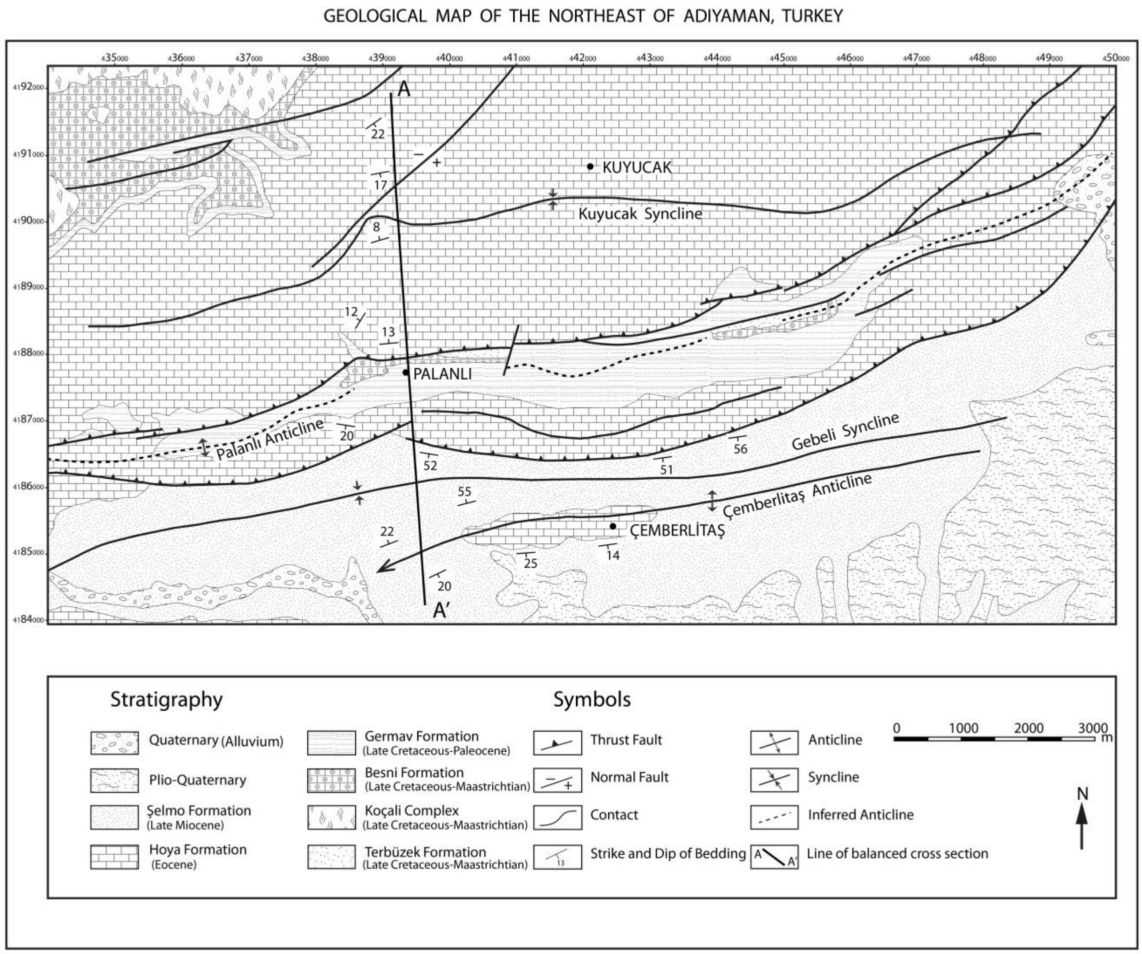


Figure 4.1 Geologic map by Mustafa Tuncer with contributions from Turkish Petroleum Corporation at a scale of 1:50000.

The tectonic structure of the Bitlis Suture shortening is characterized by E-W trending anticlines and synclines (Fig. 4.1 and 4.6). The location of these folds in the hanging wall indicates that they formed in association with the thrust faults as forced folds (Yilmaz, 1993). The Kuyucak syncline (interlimb angle is 165°) is located in the north and its axial surface trends approximately E-W. It has 2375 m wavelength and 50 m amplitude. The Palanli Anticline (interlimb angle is 125°) is located in the center of study area and its axial surface trends approximately E-W. It has 1250 m wavelength and 200 m amplitude. The Gebeli syncline (interlimb angle is 105°) is located in the south and its axial surface trends approximately E-W. It has 2500 m wavelength and 380 m amplitude. The Cemberlitas Anticline (interlimb angle is 138°) is located in the south and its axial surface trends approximately E-W. It has 2670 m wavelength and 290 m amplitude.

The fault planes orientations for the normal fault, and for thrust faults, T1 and T2, are 12/58, 356/55, and 350/56 respectively.

4.3. BALANCED CROSS SECTION

The balanced structural cross section along the section line A-A' is shown in Figure 4.6. The deformed section is displayed at 1:25000 scale of figure 4.6. The location of the balanced cross section and the location of major regional structures are shown on the geologic map of the study area (Fig. 4.1). The cross-section has two distinct parts: 1) The upper part of the cross-section, above ~ -1000 m, is well constrained using surface data (geologic map, field studies, satellite imagery) and subsurface data from drilled wells (Figs. 4.2, 4.3, 4.4, 4.5). 2) In the north, the lower part of the cross-section, below ~ -1000 m, is less well constrained, as noted by question marks, but has been constructed adhering to the geometric principles for construction of cross-sections, the regional geology, and well control. However, in the south, the lower part of the cross-section, below ~ -1000 m, is well constrained by control from well data. The line of balanced cross section is approximately 8930 m long and approximately 3650 m deep.

Based on the balanced cross section the major structures are the Normal Fault (N1), the Kuyucak Syncline, the Thrust Faults (T1 and T2), the Palanli Anticline, the Gebeli Syncline, the Cemberlitas Anticline, the Blind Thrust Fault (T4), the Kocali-Karadut tectonic contact, the Back-Thrust (T5 and T6), the Basal Decollment (T), and the Unconformities.

The Kuyucak syncline, which has right side limb dipping at about 8º north and the left side limb dipping at about 8º south, is symmetric. The axial surface of the syncline is approximately E-W. The Kuyucak syncline, consists of deep marine and carbonate platform sequences, including the Germav Formation, the Gercus Formation and the Besni Formation, was formed by compressional forces. The asymmetric Palanli anticline is interpreted to have formed above a blind back-thrust. It deforms rocks of the Sirnak Group and the Midyat Group as well as the Kocali Complex. The axial surface trends approximately E-W and the south limb of the anticline dips at about 15º and the north limb of the anticline at about 35°. The symmetric Gebeli Synclinel is interpreted to have formed above a blind back-thrust. It deforms rocks of the Kocali Complex, the Sirnak Group, the Midyat Group, and the Selmo Formation. The axial surface trends approximately E-W and both limbs of the syncline dip at about 35°. The asymmetric Cemberlitas anticline is interpreted to have formed above a blind thrust fault. It deforms rocks of the Karadut Complex, the Sirnak Group, the Midyat Group, and the Selmo

Formation. The axial surface trends approximately E-W and south limb of anticline dips about 8° and north limb of anticline dips about 35°.

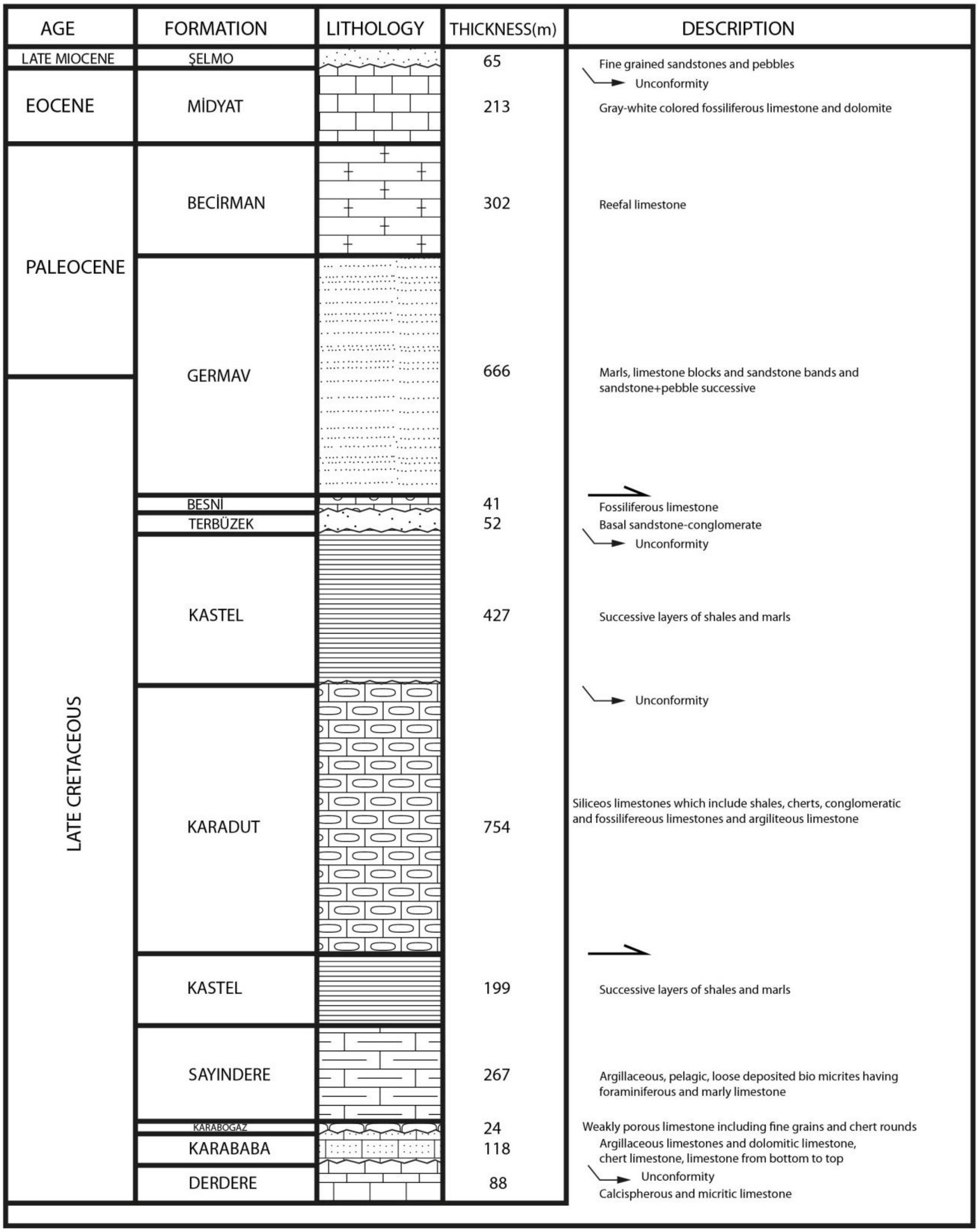


Figure 4.2 Generalized stratigraphic section of Cemberlitas A (Turkish Petroleum Corporation, 2013).

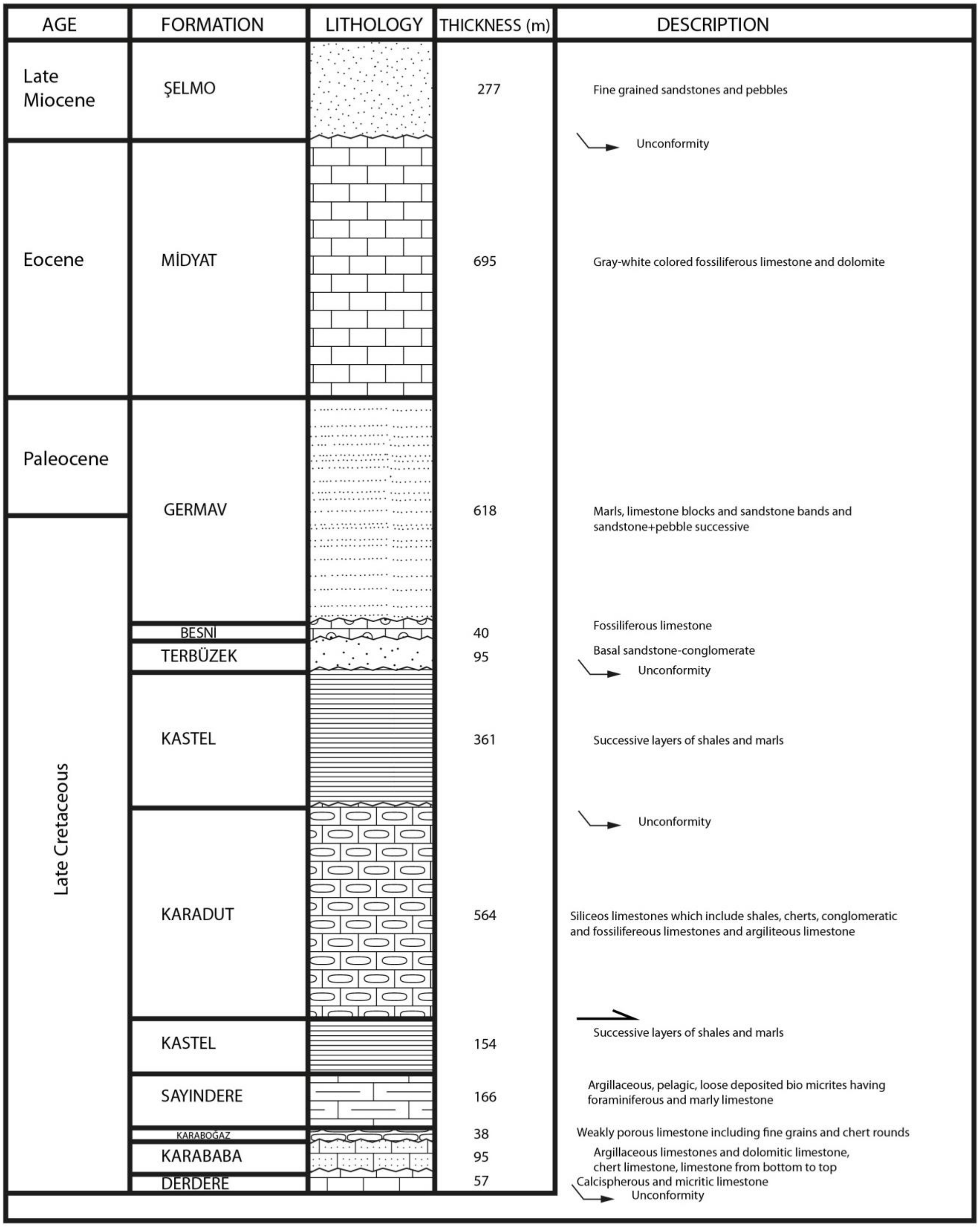


Figure 4.3 Generalized stratigraphic section of Cemberlitas B (Turkish Petroleum Corporation, 2013).

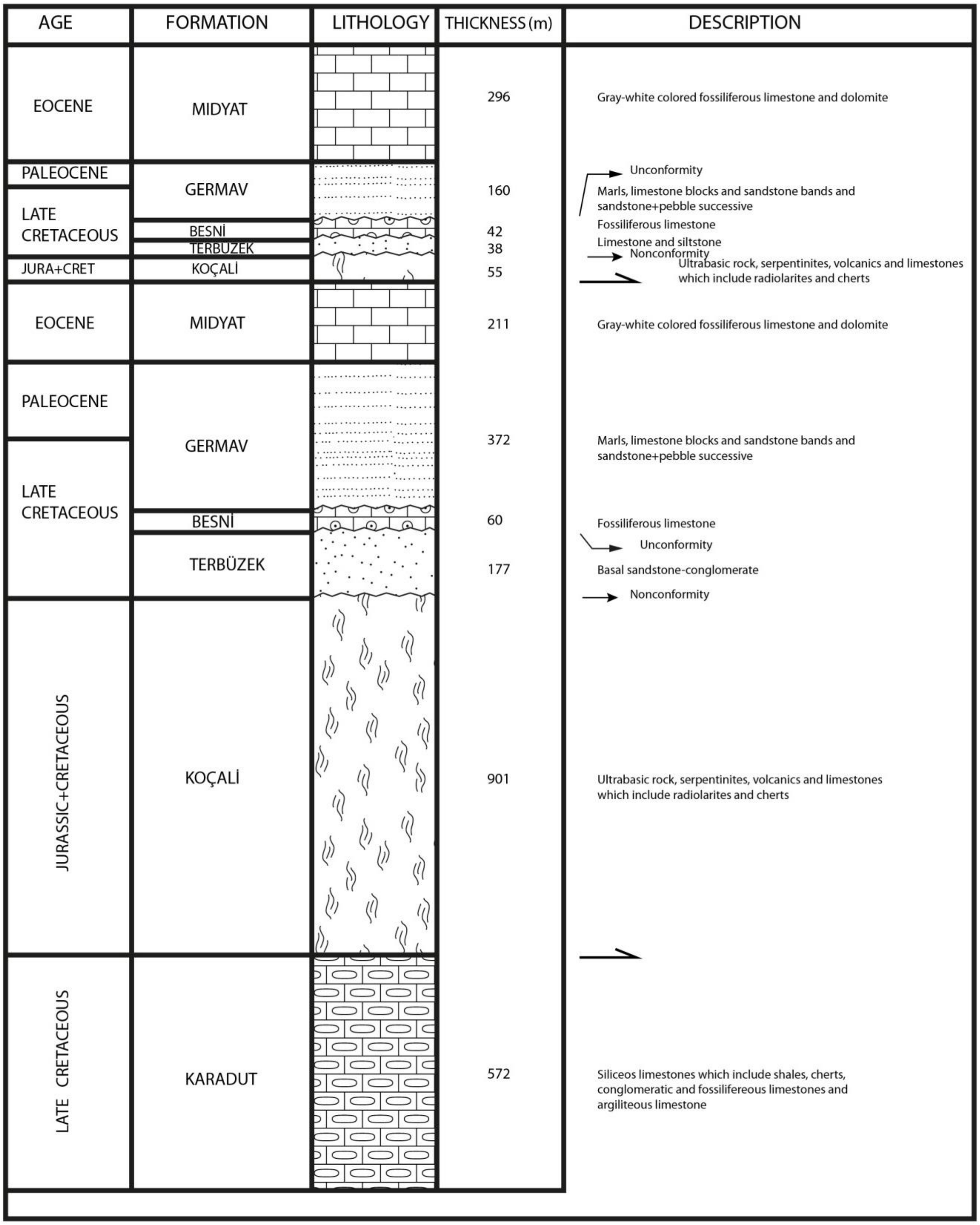


Figure 4.4 Generalized stratigraphic section of Palanli (Turkish Petroleum Corporation, 2013).

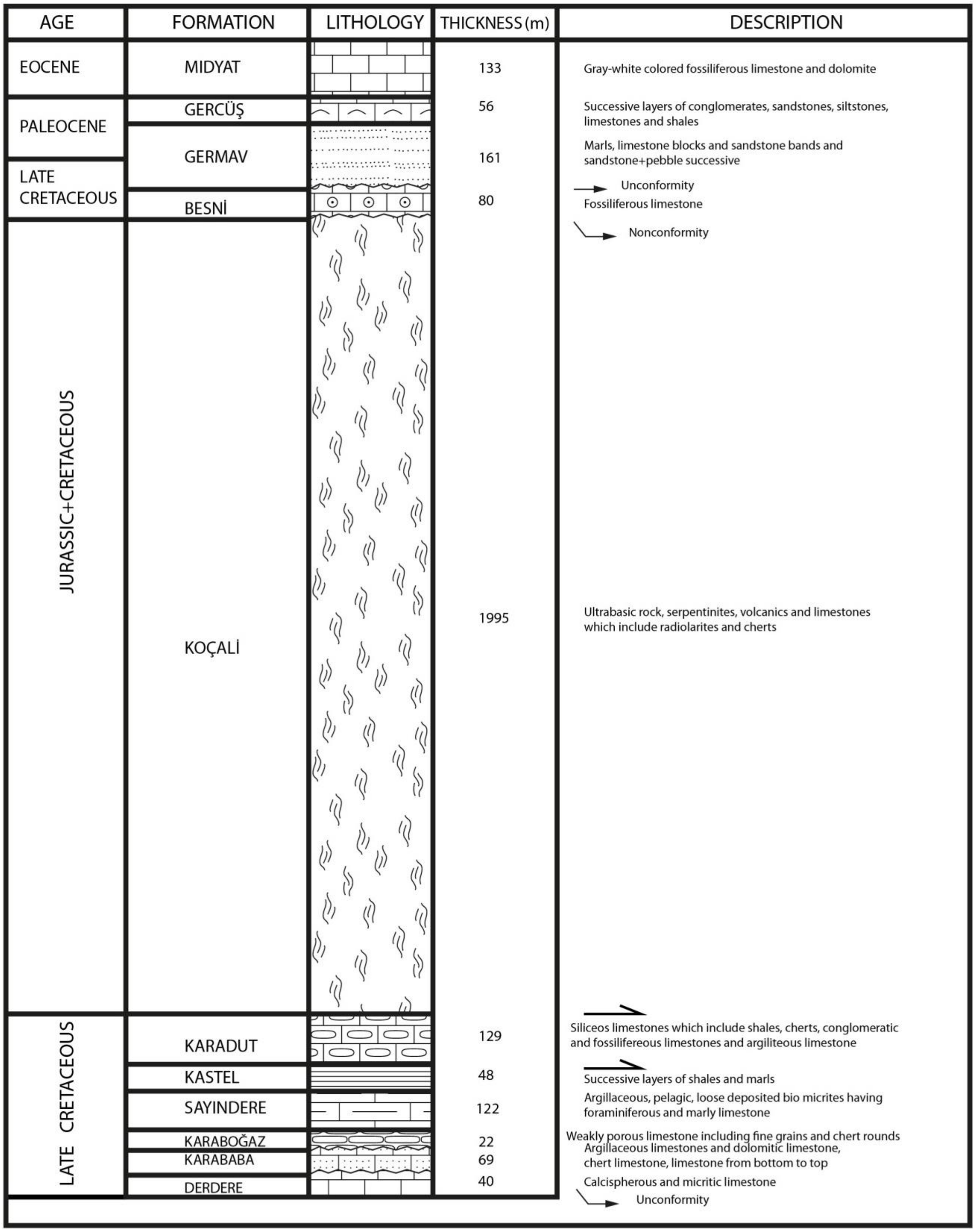


Figure 4.5 Generalized stratigraphic section of Esence (Turkish Petroleum Corporation, 2013).

In the northern portion of the cross section, from Esence (W1), and especially from the Kuyucak Syncline to the Palanli Anticline, the depth to the basement and the decollment surface are extrapolated by using well control data and surface geology including structural measurement. At depths below ~ -1000 m the allochthonous Kocali-Karadut complex was tectonically emplaced on the Mardin Group during the Late Cretaceous (i.e., Maastrichtian) (Coskun, 1996). There is a fault contact between Kocali Complex and Karadut Complex. The Lower Allocthonous Zone consists of a thrust nappe. There are two noticeably different and internally chaotic assemblages separated by a thrust between the Karadut-Kocali Complex. The lower part of the complex is a passive margin sequence including outer shelf and continental-slope deposits and consisting of hemipelagic limestone and calcareous turbidite successions. In thrust contact with the Karadut Complex is the overlying Kocali Complex which consists of ophiolitic rocks. The Upper Autochthonous marine Midyat Group, commonly with neritic carbonate group was deposited without interruption in this succession. The structural cross section (Fig 4.6) shows the geometry of the foreland features. In the study area the Kastel Formation, in the south, and the Terbuzek, Besni, Germav, and Becirman Formations, Midyat Group, and Selmo Formation all display a northward thinning geometry towards the basin.

The balanced cross section was constructed in the N-S direction in the study area. Major shortening in the study area is accommodated by thrust faults and associated forced folds. The thrust faults developed in sequences of interbeded marl and limestone beds. In the cross section several major thrust faults can be identified. These include a basal décollement (T), imbricate splays (T1 and T2) including a blind thrust (T4) and two back thrusts (T5 and T6) (Fig. 4.6).

The Bitlis Suture Zone thrust system consists of a basal sub horizontal to low angle, north dipping master thrust. This basal decollement extends across the entire cross-section at a depth of 2870 meters. It forms the contact between the Karadut Complex is a passive margin sequence including outer shelf and continental-slope deposits and consisting of hemipelagic limestone and calcareous turbidite succession and Adiyaman Group is marine sequence consist of pelagic loose deposited bio-micrites having foraminiferous and marly limestone.

Originating from the basal decollment are imbricate splays T1 and T2. These thrusts are exposed at the surface and are constrained to match geological observations. In the balanced cross section, thrust Faults (T1 and T2) structures are inferred as a listric imbricate splays that merge at depth with the master sole thrust T. Both T1 and T2 propagate through the entire stratigraphic sections and emerge at the topographic surface (Fig. 4.1). At the surface these faults have dip angles of 0 degrees to 55 degrees and from bottom to near the surface. Imbricate splay T4 is a blind thrust and is known from faults intersected by wells W3 and W4. From north to south the amount of displacement on these thrust faults diminishes. Dip separation on the thrust Faults, T1, T2, and T4 as constrained by the cross section are 1550 m, 200 m, and 50 m respectively. The geometry and displacement suggests an “insequence” development of this thrust system where T1 is older than T2, which is older than T4 as the advancing thrust wedge moves toward the south.

The Kocali Complex was tectonically emplaced onto the Karadut Complex along thrust fault T3. Thrust fault T3 is displaced by the imbricate splay T4 originating from the

Basal Décollment and is also truncated by the unconformity developed on the top of the Kocali Complex suggesting that it is the oldest thrust fault in this cross-section.

Thrust faults T5 and T6 are interpreted as blind back-thrusts which have been displacement in the opposite direction of the regional tectonic movement. In addition, back-thrusts may usually form near the end of the evolution of foreland fold and thrust belts. The back thrusts T5 and T6 are speculative as mechanisms to produce smaller folds. Back thrusts can occur in foreland fold and thrust belts and have an opposite vergence with respect to the main thrust system. Also, back thrusts are generally hinterland vergent thrusts. I considered that Palanli Anticline and the Gebeli Syncline both formed because of back-thrusts.

The sub horizontal thrust fault T7 at the structurally high level in the section is interpreted based upon the duplication of the stratigraphic section in the horse block between thrust faults T1 and T2. In this section the Hoya, Germav, Besni, and Terbuzek Formations are repeated at depth requiring the presence of this thrust. However, this repetition of the section is not documented south of thrust fault T2. In addition, this thrust fault T7 would have been removed by erosion north of thrust fault T1. More data is needed to confirm the presence of this low angle T7 thrust fault.

The Normal Fault (N1) is inferred as a normal-slip fault based upon the displacement observed in the cross-section. This fault dips about 56 degrees to the north The dip separation on the Normal Fault (N1) on the balanced cross section is shown 125 m. This fault cross cuts the Midyat, Sirnak Groups and Kocali Complex. In the field this fault shows evidence of thrusting and may have initially formed as a thrust fault to be subsequently reactivated as a normal fault at the end of the orogenic activity.

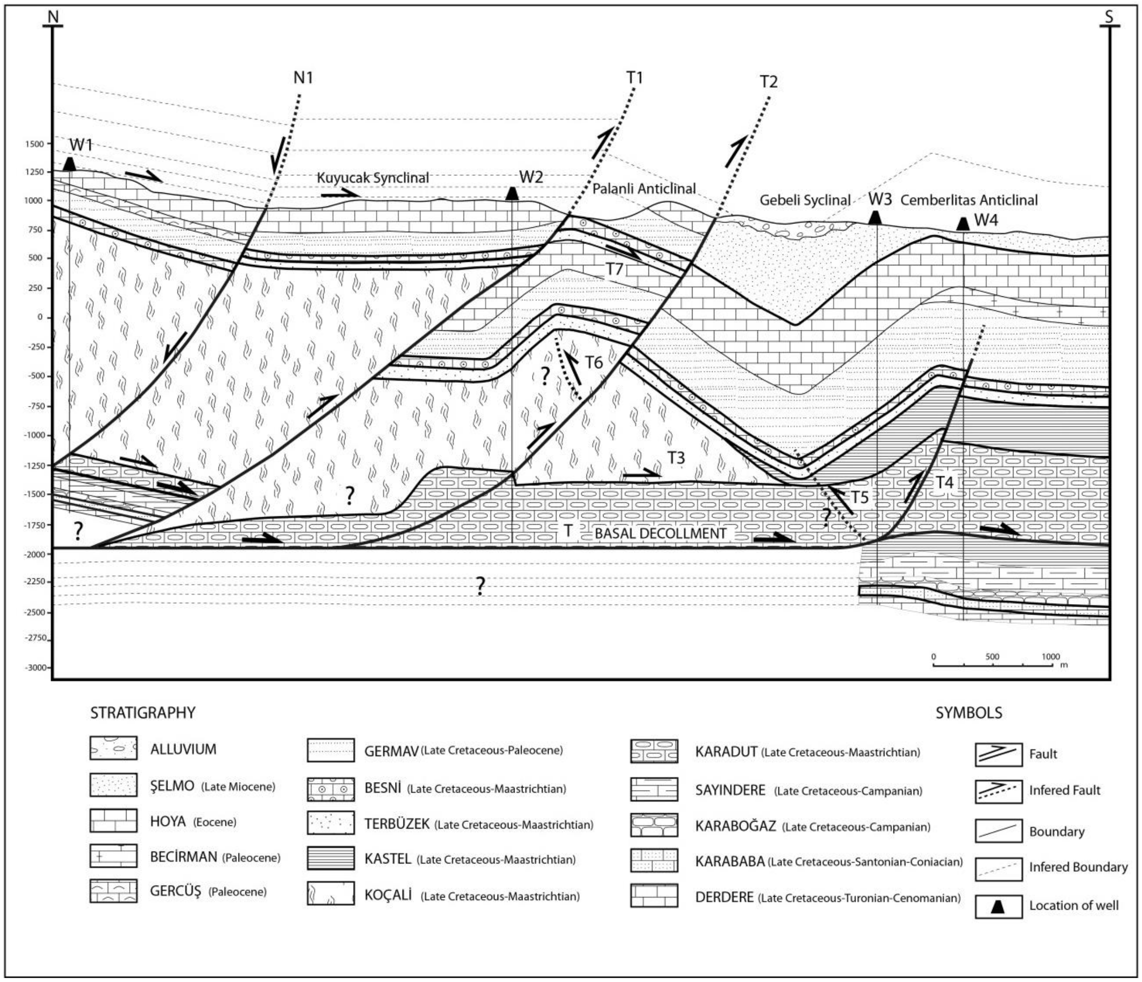


Figure 4.6 A balanced geologic cross section of the study area along section line A-A’.

4.4. PALINSPASTIC RESTORATION

The cross section was palinspastically restored using the line and area balancing methods. The Pin lines were positioned in the north and south of section. After restoring the cross section, the percent extension along the section was measured. The restoration worked well in the central and southern portions of the cross section where there was very good geologic control. However, in the northern portion of the cross section the restoration is less well constrained as seen by mismatch of the Midyat Group along the Normal Fault. This may reflect the more complicated history of this fault, initially starting as a thrust fault and later displaying normal slip. The restoration suggests that the Kocali Complex, Sirnak and Midyat Group acted as ramps where the thrust faults cut up section from the basal decollment.

Estimates of the horizontal and vertical percent shortening from Late Cretaceous to Late Miocene time were constrained by direct comparison between the present-day balanced cross section and the palinspastically restored section. The comparison between the balanced and restored cross sections is straightforward and allows for direct estimations of shortening using the fixed pin lines (P1 and P2). After restoring cross section, the shortening rates and vertical length along the section was measured by using an equation;

$$\% S = [1 - (Lf / Li)] \times 100$$

and

$$\% e = [(ef - ei) \div ei] \times 100$$

Where % S is the percent stretch, Li is the original (pre-deformed) length of the section and Lf is the current (deformed) length of the section (Hossack, 1979) and % e is the percent extension, ei is initial vertical extension of the section and ef is current (deformed) vertical extension of the section. The length of the reconstructed Pin lines (P1 and P2) is 11.85 km whereas the present length of deformed study area between pin lines (P1 and P2) is 8.93 km (Figs. 4.6 and 4.7). The percent S calculated from these results indicates 24.6 percent shortening occurred in the horizontal direction in the Bitlis Suture Zone northeast of Adiyaman as a result of folding and thrusting during Late Cretaceous to Late Miocene time. In addition, the Bitlis Suture Zone northeast of Adiyaman underwent concomitant vertical thickening. The vertical extensions are about 850 m (% e = 36.56) in Esence and 450 m (% e = 11.18) in Palanli respectively with respect to the undeformed section. Hence, vertical thickening is associated with the development of the fold and thrust belt. The area balancing technique indicates a reduction in area of ~11 % between the restored section and the balanced cross section. This difference may be accounted for by loss of material during cleavage formation pressure dissolution of limestone during deformation.

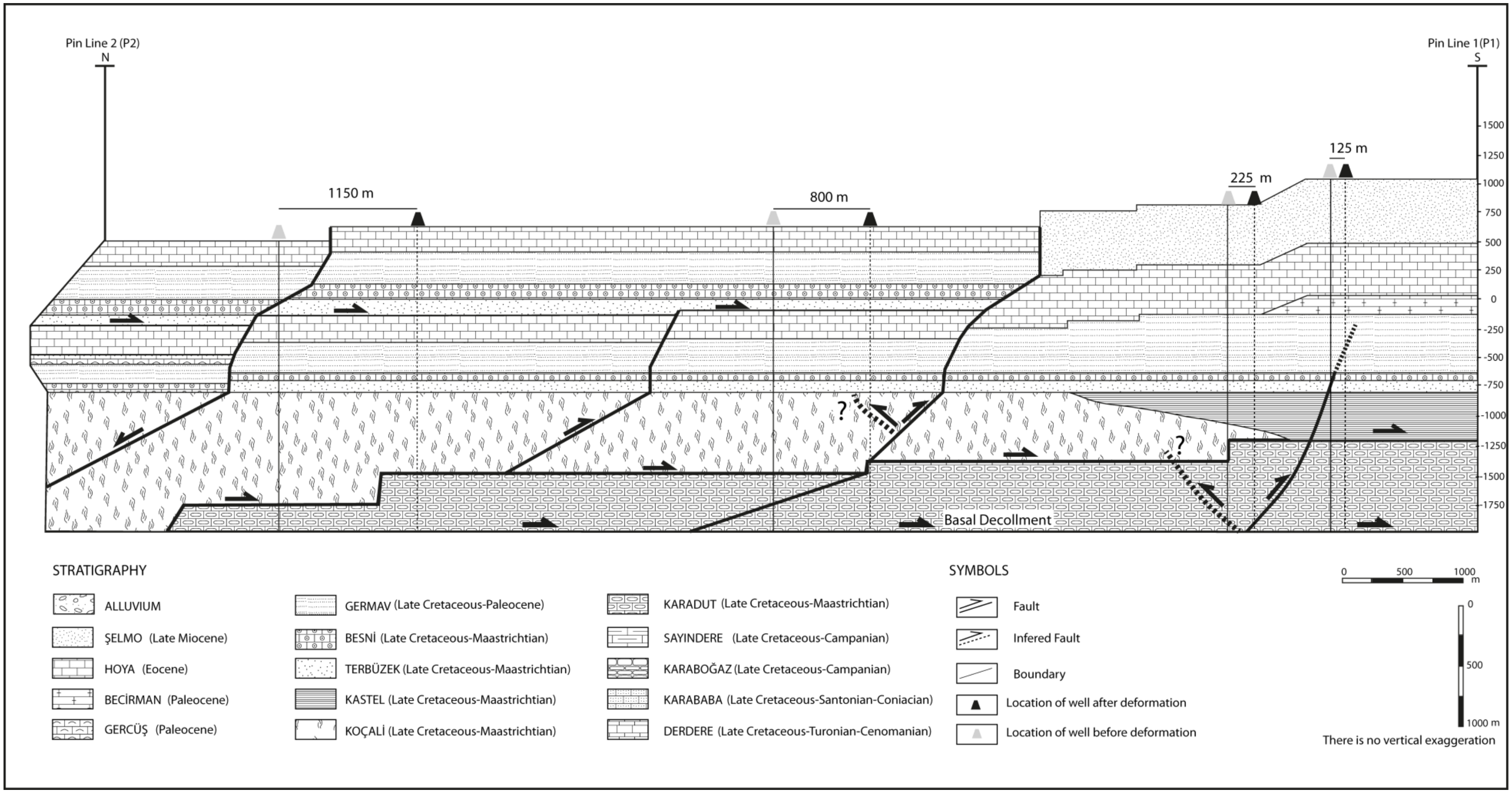


Figure 4.7 Restored cross section of study area.

5. DISCUSSION

5.1. BALANCED AND RESTORED CROSS SECTIONS FOR THE PAST AND PRESENT-DAY STRUCTURE OF THE BITLIS SUTURE ZONE

The following discussion is divided into three parts; first the structural style and geometry of the fold and thrust belt as shown by the geologic map and by the balanced cross section will be presented, then the stain accommodated by the crust during deformation will be discussed and, finally the potential for locating future hydrocarbon prospects within the area will be presented.

5.1.1. Structural Style and Geometry. The area balanced and restored cross sections provides insights into the geometry of the fold and thrust system in the study area. I interpreted the subsurface structure beneath the Bitlis Suture Zone as being comprised of an imbricate thrust system with associated force folds developing in the hanging walls of the thrust faults. This structure resulted from continental collision in which the advancing thrusts move progressively over the foreland. As the system developed there was a tendency for new thrust faults to form and branch out from the toe (front) of the master sole thrust and ramp up section to a higher structural level or “in-sequence thrusting”. The similar dip angles (vergence) and sense of displacement on this imbricate thrust system favors the interpretation of it being formed by south directed tectonic transport of the thrust sheets.

The imbricated thrust system is largely controlled by the basal decollment as the subsidiary thrusts that define the imbricate fan geometry merge at depth with this master sole thrust. Branching out from the Basal Decollment (T) are several imbricate thrusts, including T1, T2, T4 and possibly the Normal Fault N1 if it had an earlier history as a thrust fault. This dip on these thrusts (55º-56º) and the sense and magnitude of displacement thrust system favors formation of this tectonic wedge by addition of new material near the toe as progressively younger imbricate thrusts faults form (e.g., T4) to maintain the critical taper necessary for the thrust system to continue advancing. The geometrical style and progressive younging of the imbricate thrusts from north to south is consistent with a southward advancing tectonic located ahead of the main thrust. In addition, interpretations of surface and subsurface data and line length and area balancing of our cross section indicate that the Bitlis Suture zone has some blind and back-thrust faults. These faults may also serve to vertically thicken the overall thrust package and maintain the critical taper of the thrust wedge.

In the study area, around Palanli, the thrust faults shows dublex structure which is marked by a curved triangular thrust slices that converge into a more shallowly dipping sole thrust. In this system, the flat and ramps all tie together.

5.1.2 Shortening of Study Area. The calculated percent S results indicates 24.6 percent shortening occurred in the horizontal direction in the Bitlis Suture Zone northeast of Adiyaman as a result of folding and thrusting. In addition, the calculated e result shows the vertical extensions are about 850 m (% e = 36.56) in Esence and 450 m (% e = 11.18) in Palanli respectively with respect to the undeformed section. Therefore, vertical thickening is associated with the development of the fold and thrust belt. The area balancing technique indicates a reduction in area of ~11 % because of evaporation in Late Cretaceous (i.e., Besni Formation) and cleavage during tectonic deformation. My result compares well with Cater and Gillcrist who calculated the ~ 32 % shortening in the Miocene time for a portion of the orogeny ~50 km to my study area.

5.1.3. Hydrocarbon Prospects. The imbricated thrust system revealed in the geologic map and accompanying cross section provides a framework for hydrocarbon exploration including indicating favorable lower plate structures for exploratory drilling and may also define new trends in exploration for hydrocarbons in the internal parts of the Bitlis Suture Zone.

The structural evolution of this region can be used to predict the development of possible hydrocarbon reservoirs depending on the timing of petroleum migration. In addition, the cross section can identify the position of potential petroleum traps. In the Adiyaman field area, Late Cretaceous to Late Miocene platform strata is generally considered as an oil-prone area because of the deposition of good source rocks and spatially associated reservoir rocks. The approximately 250 m Late Cretaceous strata have potential zones for the generation and accumulation of hydrocarbons. In addition, on the imbrication thrust system, the petroleum migration comes when the thrusts at Cemberlitas Anticline developed. Migrating hydrocarbons could be trapped in this structure. The Palanli Anticline also may represent a potential structural trap for hydrocarbons.

The Mardin Group is composed of the Derdere and Karababa Formations. The Derdere Formation has deep-marine, organic-rich limestone at the base as the source rock, porous primary and secondary dolomites in the middle as the reservoir rock, and micritic, argillaceous limestone at the top as the sealing cap rock (Coskun,1990). This formation is unconformably overlain by the Karababa Formation. The Karababa

Formation is typically comprised of various types of limestone (Yilmaz and Duran, 1997). The highly argillaceous, radioactive limestone is represented at the base the “Karababa-A” is known as a good source rock. The “Karababa B”, argillaceous micrites and sparse dolomite and the “Karababa-C” fossiliferous, fractured micrites are both considered as potential reservoir rocks. The Karababa Formation is unconformably overlain by the Karabogaz Formation (Tuna, 1973; Aksu, 1980; Pasin et al., 1982; Guven et al., 1988).

The allochthonous Kocali-Karadut complex was tectonically emplaced on top of the Karababa Formation during Late Cretaceous (Maastrichtian). The permeability and porosity of the topmost unit of the Mardin Group were increased as a consequence of abundant tectonically induced microfractures that formed as a result of this deformation. The Mardin Group is known as the principal reservoir in number of oilfield near the city of Adiyaman in SE Turkey. Porosity development (collision of Anatolia and Arabia) led to the brittle deformation of reservoir units in oilfields of SE Turkey. In the Late Cretaceous the occurrence of faults and fractures associated with emplacement of the lower nappe thrust sheets has improved the porosity and permeability of these rocks.

Several source rocks exist within the stratigraphic sequence. These include shale, mudstone and carbonate of the Derdere, Karababa and Karabogaz Formations. The primary source rock intervals are the organic rich portions of the Derdere Formation and the Karababa Formations. These Late Cretaceous formations account for approximately 250 m thick strata that have potential zones for the generation and accumulation of the hydrocarbon. Presently oil is being produced out of the Late Cretaceous strata.

6. CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

Deformation during closure of an ocean basin and continent-continent collision in southeast Anatolia Turkey during the Late Cretaceous to Middle Miocene was investigated by construction of a geologic map, structural cross-section and retrodeformed palinspastically restored cross-section. The area of study is a N-S transect across the Bitlis Suture zone of Northeast of Adiyaman. The cross-section was constructed using a combination of surface and subsurface data in order to analyze the structural style, evolution and shortening in the cover strata and hydrocarbon prospects.

During Late Cretaceous to Late Miocene, collision between the Arabian platform and Anatolia plate consumed the intervening oceanic lithosphere by subduction. The collision between these two continental plates resulted in telescoping of the passive margin along thrusts, emplacement of ophiolite nappes by thrusting, and the formation of the imbrication zone. The geologic map and cross section defines the major thrust faults, normal fault and master sole thrust, and major structural elements such folds that formed during this orogenic event.

The balanced cross section shows the thin-skinned nature of the fold and thrust belt at the leading edge of the advancing thrust system. Additionally, the sequence of deformation in the Bitlis suture shortening is older in the inner parts of the thrust system (to the north) and progressively younger in the external parts of the thrust system (to the south). This thrusting occurred during Late Cretaceous to Late Miocene time.

The compressive deformation along the Bitlis Suture Zone is accommodated by the formation of a fold and thrust belt. The thrust system is one in which several imbricate thrusts merge at depth into a master sole thrust. The thrust system follows an "in sequence" evolution where progressively younger thrusts branch out from the leading edge of the master sole thrust resulting in folding and thickening of the wedge – possibly as a means of maintaining the critical taper necessary for the thrust system to continue advancing towards the south. This is consistent with the observation that the vertical thickening was greater in the north, % e = 36.56 in Esence, and decreased towards the south % e = 11.18 in Palanli. The development of the fold and thrust belt resulted in an overall horizontal shortening in this region of 24.6 percent shortening during this continent-continent collision.

6.2. RECOMMEDATION

The recommendations for further study in this area are advised below;

1. Trishear method could be used by computer by Fault Fold program version 4.5 by Richard W. Allmendinger that may help predicting and planning the petroleum potential target areas.

2. This balanced cross-section should be tested and refined by acquisition of 2D or 3D seismic data. This data will assist in refining the subsurface interpretation present in this study and should greatly improve the understanding of the structural development of this area and increase the potential for identifying hydrocarbon reservoirs in the subsurface beneath southeast Anatolia.

APPENDIX A

PREVIOUS STUDIES

1) Temple and Perry (1962) studied oil occurrence in southeast Turkey and they realized stratigraphic possibilities exist for generation and accumulation of oil in the southeast Turkey.

2) Rigo de Righi and Cortesini (1964) who's early work help define the structural setting and stratigraphy of southeastern Turkey.

3) Sungurlu (1974) who produced the first comprehensive geology and recognized of Southeast Anatolia.

4) Sonel and Sarbay (1988) using seismic methods explored for stratigraphic and structural petroleum traps in the South-Eastern Anatolia region.

5) Yilmaz and Clift (1990) recognized the boundaries of the allochthonous terranes in Anatolia and surrounding region and defined the major tectono-stratigraphic units.

6) Yilmaz (1993) published a tectonic model for the orogenic evolution of southeast Anatolia fold and thrust belt and established the presence of three main tectonic provinces: 1) the nappe zone, 2) the imbricate zone, and 3) the Arabian foreland.

7) Cater and Gillerist (1994) constructed balanced cross sections in SE Turkey of the karst reservoir of the Mid-Cretaceous Mardin Group.

8) Coskun (1994) studied the potential of duplex structures in the SE Turkey as hydrocarbon traps and concluded the main exploration targets are the Upper Cretaceous Mardin carbonates and Jurrassic and Triassic carbonates within the duplex structures.

9) Yilmaz and Duran (1997) identified the location of all major autochthons and allochthons within the southeast Anatolia Fold and Thrust Belt.

10) Bolat (2012) reported on the geology and possibilities for undiscovered petroleum reservoirs north of Adiyaman.

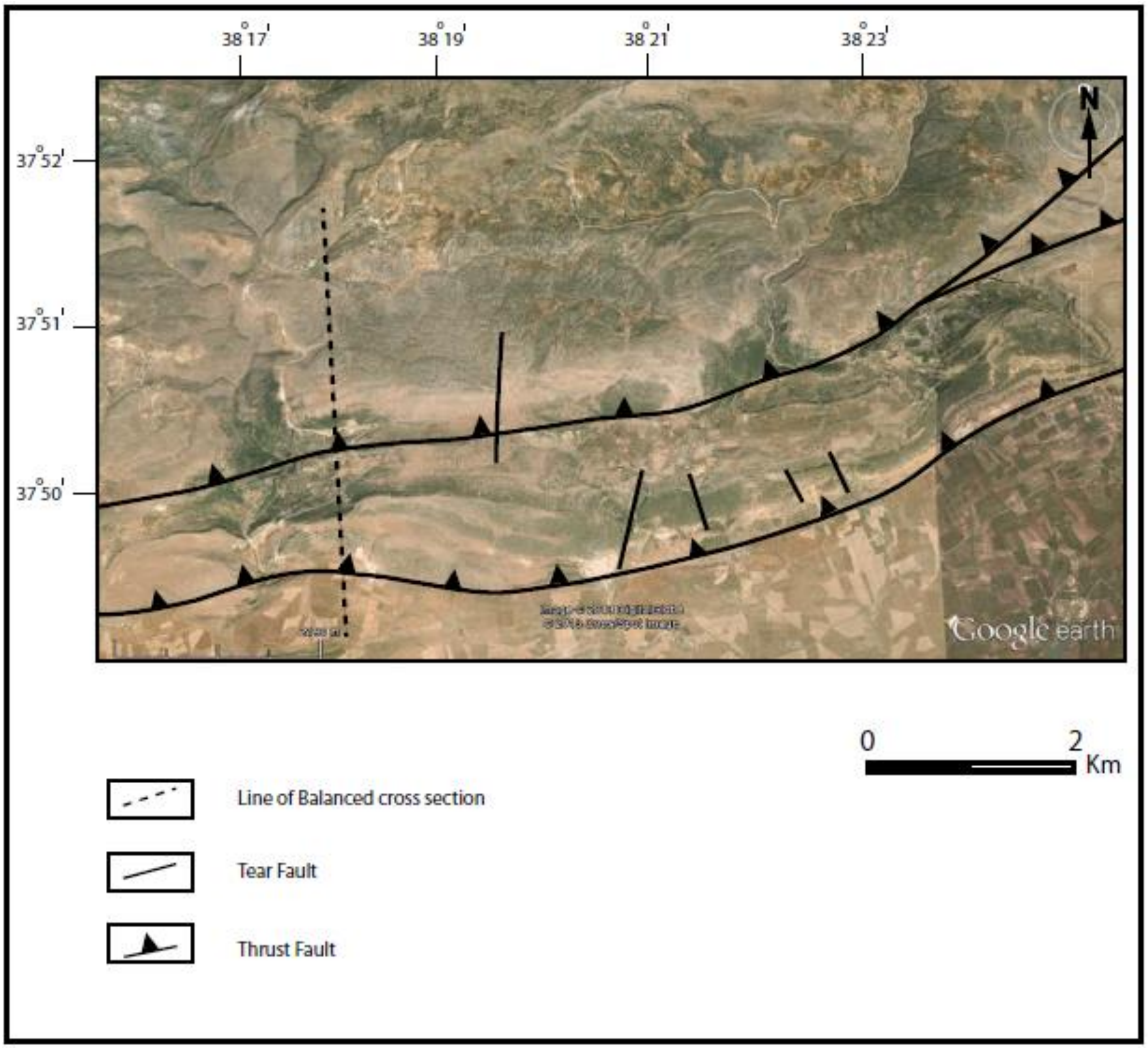
APPENDIX B

DIP-STRIKE MEASUREMENTS OF STUDY

Location	UTM Locations	Outcrop Description	Dip-Strike	Description
1	4192155 439302	Esence well		
2	4191730 439250	Midyat Formation	143/22	gray-white colored limostone
3	4190748 438803	Normal Fault contact	12/58	
4	4190755 438744	Kuyucak Synclinal		
5	4189674 438760	Midyat Formation	331/8	gray-white colored limostone
6	4188410 438830	Palanli well		
7	4188022 439704	Thrust Fault	356/55	
8	4187983 440011	Besni-Terbuzek Formations contact	168/53	limestone-basal sandstone conglomerate
9	4187882 439765	Besni-Germav Formations contact	150/48	limestone-Sandstone bands, marls
10	4187248 438995	Germav-Midyat Formations contact	195/40	sandstone bands marls, gray-white colored limostone
11	4186826 439180	Thrust Fault-Midyat-Selmo Fm contact	350/56	
12	4186577 439296	Selmo Formation	190/52	fined grained sandstone and pebbles
13	4186140 439554	Gebeli Synclinal		
14	4185771 439540	Selmo Formation	330/55	fined grained sandstone and pebbles
15	4185250 439492	Cemberlitas well-B		
16	4185214 439438	Selmo Formation	328/22	fined grained sandstone and pebbles
17	4185015 439518	Cemberlitas Anticlinal		
18	4184880 439425	Selmo Formation	135/20	fined grained sandstone and pebbles
19	4186470 441248	Midyat-Selmo Formations contact	190/52	gray-white colored limostone- fined grained sandstone and pebbles
20	4186510 442726	Midyat-Selmo Formation contact	95/51	gray-white colored limostone-fined grained sandstone and pebbles
21	4186765 443732	Midyat-Selmo Formation contact	168/56	gray-white colored limostone- fined grained sandstone and pebbles

APPENDIX C

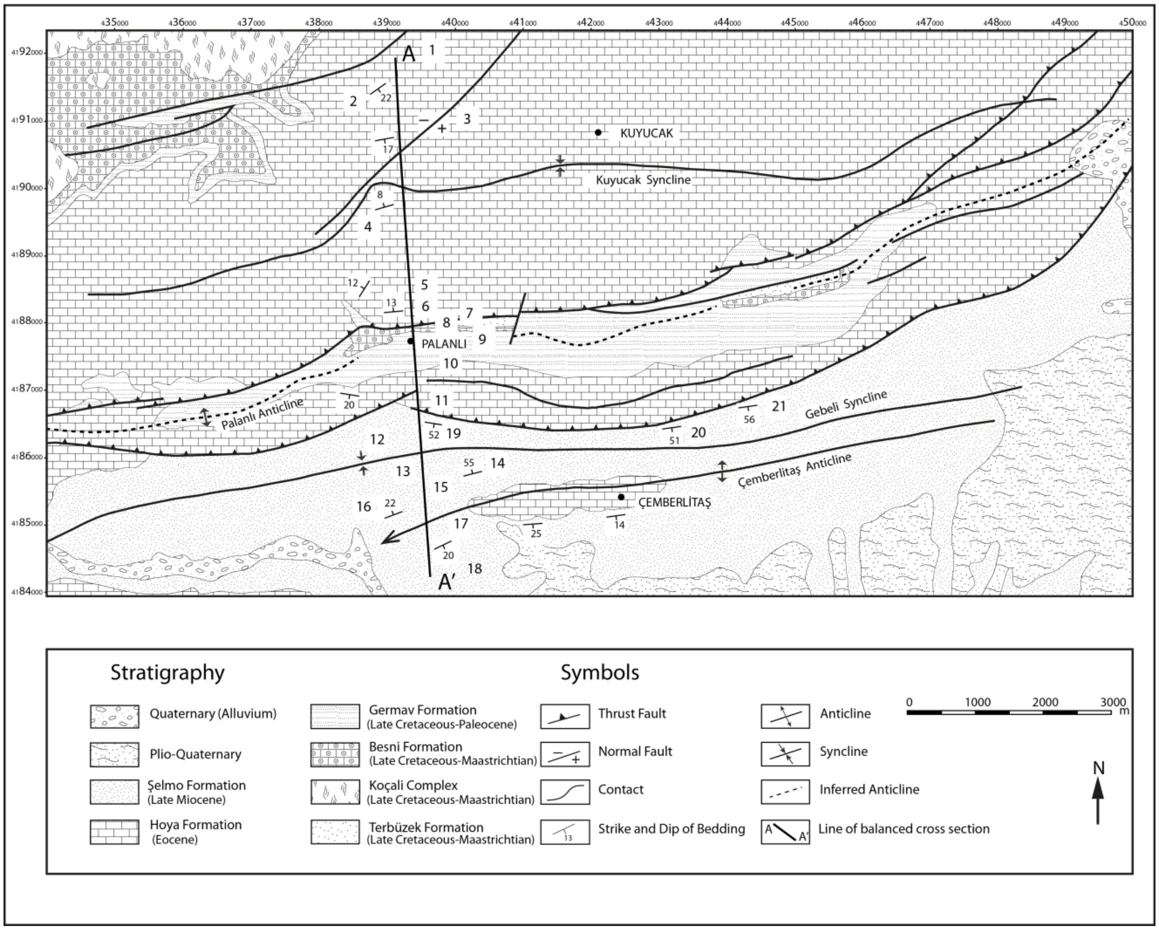
SATELITE IMAGE OF STUDY AREA


38°17'
38°19'
38°21'
38°23'
37°52'
37°51'
37°50'
N
Google earth
0
2
Km
Line of Balanced cross section
Tear Fault
Thrust Fault

APPENDIX D

LOCATION OF MAJOR CONTACTS

GEOLOGICAL MAP OF THE NORTHEAST OF ADIYAMAN, TURKEY



BIBLIOGRAPHY

Ala, M, A and Moss, B, J, 1979, Comparative Petroleum Geology of Southeast Turkey and Northeast Syria: Journal of Petroleum Geology 1, 4, p. 3-27.

Bolat, A, 2012, Adiyaman ili Kuzeyinin Jeolojisi ve Petrol Potansiyeli.

Cater, J, M, L and Gillcrist, J, R, 1994, Karstic Reservoirs of the Mid-Cretaceous Mardin Group, SE Turkey: Tectonic and Eustatic Controls on their Genesis Distribution and Preservation: Journal of Petroleum Geology, v. 17(3), p. 253-278.

Coskun, B, 1996, Tectonic Controls on the Evolution of Porosity in the Cretaceous Mardin Group Carbonates, Adiyaman Oilfields, SE Turkey: Journal of Petroleum Geology, v. 19, p. 445-460.

Davis, G, H, Reynolds, S, J and Kluth, C, F, 2011, Structural Geology of Rocks and Regions: USA, Jay O'Callaghan, 839 p.

Demirel, I, H and Guneri, S, 2000, Cretaceous Carbonates in the Adiyaman Region, SE Turkey: An Assessment of Burial History and Source-rock potential: Journal of Petroleum Geology, v. 23(1), p. 91-106.

Demirel, I, H, Yurtsever, T, S and Guneri, S, 2001, Petroleum system of the Adiyaman region, Southeastern Anatolia, Turkey: Marine and Petroleum Geology 18, p. 391-410.

Kardoon, I, A, K, Lawrence, R, D and Lillie, R, J, 1994, Seismic data, Geometry, evolution and shortening in the Active Sulaiman Fold-and-thrust Belt of Pakistan, Southwest of the Himalayas: The American Association of Petroleum Geologists, v.78, p. 758-774.

Long, S, Mcquarrie, N, Tobgay, T and Grujic, D, 2011, Geometry and crustal shortening of the Himalayan Fold-thrust belt, eastern and central Bhutan: Geological society of the America Bulletin.

McDougall, J, W and Hussain, A, 1991, Fold and Thrust Propagation in the western Himalaya based on a balanced cross section of the Surghar Range and Kohat Plateau, Pakistan: The American Association of Petroleum Geologists Bulletin, v.75, p. 463-478.

Okay, A, I, 2008, Geology of Turkey: A synopsis.

Righi, M, R, D and Cortesini, A, 1964, Gravity Tectonics in Foothills Structure Belt of Southeast Turkey: Bulletin of the American Association of Petroleum Geologist, v.48, p. 1911-1937.

Rungsai, M, K, 2006, Restoration of the geological structure using geologic and seismic data in the Saveh block, Iran.

Sage, L, Mosconi, A, Moratti, I, Riva, E and Roure, F, 1991, Cross section balancing in the central Apennines: An application of Locace: The American Association of Petroleum Geologist Bulletin, v.75, p. 832-844.

Schelling, D, Cater, J, Seago, R and Ojha, T, P, 1991, A Balanced cross-section across the central Nepal Siwalik Hills: Hitauda to Amlekhganj: Jour.Fac.Sci, v.23, p.1-9.

Seyrek, E, 2008, Post Miocene Tectonic Evolution of Alidag Anticline Adiyaman, Turkey.

Sonel, N and Sarbay, N, 1988, Definition of Petroleum traps around Narli (K.Maras) using methods: Commun.Fac.Sci.Univ.Ank.Serie C, v.6, p. 257-287.

Tasgin, C, K, Orhan, H, Turkmen, I and Aksoy, E, 2011, Soft-Sediment deformation structures in the late Miocene Selmo Formation around Adiyaman area, Southeastern Turkey: Sedimentary Geology 235 p. 277-291.

Tasman, C, E, 1949, Stratigraphy of Southeast Turkey: Bulletin of the American Association of Petroleum Geologist, v. 33, p. 22-31.

Tearpock, D, J and Bischke, R, E, 2002, Applied Subsurface Geological Mapping: USA, A Simon&Schuster Company, 822 p.

Temple, P, G and Perry, L, J, 1962, Geology and Oil Occurence Southeast Turkey: Bulletin of the American Association of Petroleum Geologist, v. 46, p. 1596-1612.

Verges, J, Saura, E, Cosciello, E, Fernandez, M, Villasenor, A, Jimenez-Munt, I and Garcia-Castellanos, D, 2011, Crustal-scale cross sections across NW Zagros belt implications for the Arabian margin reconstruction: Geol.Mag.148, p. 739-761.

Wickham, J and Moeckel, G, 1997, Restoration of Structural cross sections: Journal of Structural Geology, v. 19, p. 975-986.

Yilmaz, Y, 1993, New Evidence and model on the evolution of the southeast Anatolian Orogeny: Geological Society of American Bulletin, v. 105, p. 251-271.

Yilmaz, Y and Clift, P, D, 1990, Allochthonous Terranes in the Tethyan Middle East: Anatolia and the surrounding Regions (and Discussion): Philosophical Transactions of the Royal Society, p. 611-624.

VITA

Mustafa Tuncer was born in Elazig, Turkey. He graduated in 2008-2009 Education period by qualifying as being the highest ranking student and received his B.S. with Honors in Geological Engineering from the Firat University, Elazig, Turkey. In 2009, he is awarded a scholarship by Turkish Petroleum Corporation. In December 2013, he received his M.S. degree in Geology&Geophysics from the Missouri University of Science and Technology, USA.