Facies architecture and depositional evolution of the middle Eocene mass flow - dominated fan delta complex in the multi-feeder areas: Elazığ Marine Basin (Eastern Türkiye)

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Abstract: A the mass flow-dominated fan delta complex is developed by rapid deposition of coarse-grained materials in front of uplifted areas under the influence active tectonism, important for provide clues about the first opening stages of marine basins. The study aims to shed light on the fact that mass flow-dominated fan delta complexes play an active role in determining the characterization of tectonism controlling basin opening. In the study area, mass flow-dominated the Deliktaş Fan Delta Complex (DFDC) is represented the first deposits of the southern part of the middle Eocene the Elazığ Marine Basin whose development is controlled by normal block faults. The basin consists of the alluvial fan succession, the fan delta succession and the turbidite succession overlying both successions. DFDC is composed of fan delta facies assemblages deposited in the form of shallow water coastal prism in front of the multi-feeder areas controlled by extensional tectonism. Conglomerates and sandstones predominate in the DFDC successions. The system forming the DFDC is a good example for high-energy, mass flow-dominated, multi-feeder fan delta environments with different source areas surrounding the Elazığ Basin from the north and south. Sedimentological studies were carried out from 11 measured stratigraphic sections taken from the DFDC, and three different sequences were defined. These sequences contain the deposits belonging to fan delta plain and fan delta front facies assemblages. The facies architecture of the successions of the DFDC was defined on the basis of measured stratigraphic sections, litho-correlation and field observations, and with the help of the obtained data, the sedimentation evolution of the sequences belonging to it was revealed with three-dimensional basin models. In this way, an approach to the primary geodynamics of the Elaziğ Basin was obtained.

Key words: Fan delta complex, facies architecture, marine basin, primary geodynamics, paleogeographic control

1. Introduction

The most widely known definition of the term fan delta is the deposition of sediments derived from an alluvial fan feeder system as a coastal prism mostly or completely submerged at the interface between the stagnant water body and the active fan (Nemec and Steel 1988). Fan deltas are considered sensitive indicators of climate change and tectonics (Postma, 1978). In particularly mass flow-dominated fan delta deposits typically form in areas with active tectonics and high topography owing to the rapid deposition of coarse-grained material in front of uplifted areas (Surlyk, 1984; Massari and Collela, 1988; Kazancı and Varol, 1990; Postma, 2003). Depending on the flow energy, fan delta sediments are transported as stacks in front of the uplifted area, forming the fan delta complex (Kazancı and Varol, 1990; Postma, 1990, 2003; Deynoux et al., 2005; Wu et al., 2020). They are characterized by the sequences formed by fan delta sediments transported from two or more different tributary areas into a single basin (Colella et al., 1987; Stow et al., 1995; Deynoux et al., 2005; Giraldo-Villegas et al., 2024).

Gilbert-type fan deltas have been the focus of most recent and previous research on the tectonic regulation of marine basins (Colella, 1988; Gawthorpe et al., 1990; Dorsey et al., 1995; Deynoux et al., 2005; Rees et al., 2018; Pavano et al., 2024). However, recently researches are showing up less focus on mass flow-dominated fan delta complexes formed under the influence of active tectonism (Postma, 1978, 2003; Lopex-Blanco et al., 2000; Benvenuti, 2003; Deynoux et al., 2005; Xiong et al., 2023). It is important to find evidence for the first stages of marine basin opening. The purpose of this study is to clarify that fan delta complexes characterized by mass flow are also actively involved in characterizing the tectonism that determines basin opening.

The study area consists of the western part of the Elazığ Marine Basin. The basin developed through rapid deepening in the middle Eocene due to the effects of normal block faulting (Aksoy et al., 2005; Alkaç and Aksoy, 2022). During this time, the well-exposed, mass flow-dominated Deliktaş Fan Delta Complex (DFDC) formed in front of the uplifted areas that bound the basin from the south and north. Fan delta deposits, which are composed of three distinct fan delta sequences, act as a model of the DFDC. This study focuses on the facies architecture and depositional evolution of the sediments belonging to the fan delta complex in question. The DFDC is a good example of developed fan deltas in the multi-feeder areas. The general character of the lithology of the fan delta deposits is the predominance of conglomerates and sandstones. The study aims to define the facies architecture of the sequences of the DFDC based on data from measured stratigraphic sections and litho-correlation, and to show the depositional evolution of the sequences of the complex with three-dimensional basin models. Thus, by defining the clastic facies of the fan delta system, an approach to the basin evolution of the mass flow-dominated fan delta complex is provided. In light of all this data, considering the sedimentological features such as lithology and facies architecture of the DFDC, which represents the initial deposits of the southern part of the Elazığ Basin were evaluated an opinion on the primary geodynamics of the basin.

2. Geological background: Basin stratigraphy and tectonic setting

In the Eastern Anatolia region, which includes the study area, the southern branch of the Neotethys Ocean began to close with northward subduction as part of the N-S-oriented compression regime associated with the convergence of the Arabian and Anatolian plates in the Late Cretaceous (Şengör and Yılmaz, 1981; Yazgan, 1984; Robertson, 2006; Beyarslan and Bingöl, 2014). Due to this compression, many Mesozoic continental margins and oceanic units were deposited on the northern margin of the Arabian Plate over 1000 km from the eastern end of the Mediterranean to Oman (Robertson, 2007; Robertson et al., 2006). The Eastern Taurus Orogenic Belt, which forms the eastern part of the palaeotectonic zone called the Bitlis-Zagros Suture Zone (BZSZ), lies within the boundaries of Türkiye between the Eurasian and the African and Arabian plates. In this orogenic belt, areas of continental uplift and subsiding basins have developed (Sungurlu, 1974; Baştuğ, 1976; Şengör, 1980; Yazgan, 1981; Aksoy et al., 1999; 2005). In the thickened lithospheric region (Bitlis-Pütürge Massif) during orogen formation, a volcano-sedimentary basin (the Maden Basin) with restricted calc-alkaline volcanism developed in the early to middle Eocene (Ertürk et al., 2018). The Elazığ Basin located behind (northern) of the Maden Basin was formed in relation to normal block faulting under the extension regime (Figure 1; Ertürk et al., 2018; Alkaç and Aksoy, 2022;). It was separated from the Maden Basin by a palaeotopographic uplift. The study area is located in the Elazığ Basin, which extends in approximately NE-SW direction in the Eastern Taurus Orogenic Belt.

The DFDC is located in an area of approximately 15 km^2, 40 km southwest of Baskil district of Elazığ province (Figure 1a). The oldest observed unit is the Elazığ Magmatites, which form the bedrock of the basin (Aksoy et al., 1999; Cronin et al., 2005; Beyaraslan and Bingöl, 2010; Çelik and Cronin, 2020; Alkaç and Aksoy, 2022). The unit occurs in an uplifted area of 6 km^2 in the north and southwest of the basin (Figure 1b and Figure 1c). The Elazığ Magmatites are composed of volcanic and plutonic rocks and are considered to be the result of an intra-oceanic arc system (Beyarslan and Bingöl, 2018; Bingöl et al., 2018; Alkaç and Aksoy, 2022). Granitic and diorite rocks are indicative of plutonic rocks, whereas basalts are representative of volcanic rocks. The age of Elazığ Magmatites is between 72 - 84 Ma (Yazgan, 1983, 1984; Lin et al., 2015; Beyarslan and Bingöl, 2018; Sar et al., 2019). Regional compression thrust the Devonian-Jurassic Keban Metamorphites over the Elazığ Magmatites during this unit's formation, transporting them from north to south (Figure 1c). The Harami Formation, which occurs in an area of about 2 km^2, covers the Elazığ Magmatites (Figure 2). In the study area, the lithology of the unit consists of massive conglomerates derived from older rocks at the bottom and grading upward into medium-grained sandstone and sandy limestone with conglomerate interbeds. The age of the formation has been determined to be Late Cretaceous (Perinçek, 1979; Bingöl, 1984; Turan and Bingöl, 1991; Aksoy, 1992; Aksoy et al., 1999, Turan, 2011; Kayğılı et al., 2023). The unit is unconformably overlain by sedimentary deposits known as the Kuşçular Formation. To the east of the basin, the Kuşçular Formation covers an area of roughly 1 km^2 (Figure 2). It consists of poorly sorted conglomerates consisting of pebble to boulder size at the base, grading up into bedded mudstone and siltstone couples in the upper layers (Alkaç and Aksoy, 2022). The Kuşçular Formation aged as early Paleocene in studies (Perinçek, 1980; Koç-Taşgın, 2017; Alkaç and Aksoy, 2022). Massive, medium- to thick-bedded, fossiliferous limestone comprises the Seske Formation, which outcrops in an area of approximately 1 km^2 and unconformably covers the Kuşçular Formation (Figure 2). The age of the unit is late Paleocene–early Eocene (Yazgan, 1984; Türkmen et al., 2001). In the early-middle Eocene, limited calc-alkaline volcanism was active in the thickened lithospheric region of the Eastern Taurus Orogenic Belt, and a volcano-sedimentary basin, the Maden Basin, was formed (Ertürk et al., 2018). The Elazığ Basin opened as a rapidly deepening depositional area by block faulting on the Late Cretaceous Elazığ Magmatites in the extensional area north of the Maden Basin in association with the geodynamic evolution of the basin (Cronin et al., 2005; Alkaç and Aksoy, 2022). Due to the high relief topography of the base controlled by block faulting, the middle Eocene Kırkgeçit Formation, the first sediments deposited in the basin, exhibits uneven and variable stacking (Aksoy et al., 2005). In the Elazığ Basin, block faulting controlled the northern and southern uplifted zones, in front of which DFDC deposits of the Kırkgeçit Formation were stacked (Figure 2). In the early periods when the basin started to develop, the alluvial fan succession in the terrestrial realm was deposited in front of the uplifted zones consisting of the underlying Elazığ Magmatites in the south of the study area. Shallow marine conditions prevailed in the basin, which deepened rapidly as a result of increased tectonic extensional movement in the middle periods of the Middle Eocene. The fan delta successions were deposited unconformably on the alluvial fan succession in the south of the study area and on the Elazığ Magmatites that form the uplifted area in the north (Figure 2). The fan delta succession is characterized by conglomerate, pebbly sandstone and sandstone. The conglomerate clasts consist of grains ranging in size from boulders to pebbles and originate from the uplifted areas at the basin margin. The conglomerates are very poorly sorted and very poorly rounded, indicating a short transport distance. The fan delta complex in the study area is overlain by a turbidite succession that dominated the marine environment due to block faulting and a rapidly developing subsidence that persisted in the middle Eocene (Cronin et al., 2005; Alkaç and Aksoy, 2022). Due to the rapid rise in sea level, the marine area in question shifted northward. Under the tectonic compression regime, which lasted until the end of the Early Miocene, the fan delta complex gained slope and was exposed in its present position (Figure 2).

3. Materials and methods

The Eocene strata of the first deposits of the Kırkgeçit Formation in the southern part of the Elazığ Basin were the main target of the field investigation. A total of 11 stratigraphic sections were taken from three different outcrops of the fan delta deposits of the Kırkgeçit Formation. These measured sections reflect the depositional characteristics and facies architecture of the fan delta system in the Elazığ Basin based on the fabric features, matrix type, composition, and structural characteristics of the sediments through the identification and stratigraphy of the fan delta deposits. The facies analysis was performed based on the facies and sub-facies classifications of fan deltas (Middleton and Hampton, 1976; Miall, 1977, 1978, 1985; Nemec et al., 1984; Rust, 1984; Shultz, 1984; Kazancı and Varol, 1990; Postma, 1990; Deynoux et al., 2005; Sun et al., 2020). The classifications of Nemec et al. (1984) and Postma (1990) were used for the facies assemblages derived from the interpretations of the facies classifications. Thus, seven facies and two sub-facies were identified and described from the sections of the Eocene units in the southern part of the Elazığ Basin. In addition, a three-dimensional facies model of the Middle Eocene fan delta system was created by analysing and describing the facies based on the data in these sections. The data from the field studies were collected in two steps: in the first step, a detailed geological map was created to determine the relationships and correlations of the conglomerates, sandstones and their associations deposited in front of the uplifted areas that border the basin from the north and south. In the second step, considering the sedimentological features such as lithology and facies architecture of the DFDC, which represent the first deposits of the southern part of the Elazığ Basin, an opinion on the primary geodynamics of the basin was evaluated.

4. Results

4.1. Middle Eocene Elazığ Marine Basin-Fill

The Elazığ Marine Basin-fill is formed in the middle Eocene by the deposits of the Kırkgeçit Formation, which have reached a thickness of 750 m. They are divided into a 200 m thick alluvial fan succession, a 250 m-thick mass flow-dominated fan delta complex succession, and a 300 m thick turbidite succession that unconformably overlies both successions (Figure 3).

4.2. The alluvial fan succession

The alluvial fan succession forms the bottom deposits of the Elazığ Marine Basin and is represented by conglomerates, sandstones, mudstones and gypsum as terrestrial environments (Figure 3). It is characterised from bottom to top with bedded gypsum, nodular gypsum mudstone, red-coloured mudstone, bedded sandstone, massive sandstone and massive conglomerate (Figure 4a). The thickness of the bedded gypsum and the nodular gypsum mudstones is 50 m. The red-colored mudstones are mostly massive and rarely laminated. In some levels, the thickness of the mudstones and sandstones, which are interspersed with interbedded conglomerates, is 60 m. The bedded sandstones are weakly cemented and medium-grained, with a thickness of between 20 m and 25 m. Coarse-grained massive sandstones have a lenticular geometry and a maximum thickness of 35 m. Massive conglomerates with an average thickness of 30 m and well-rounded components are sand matrix.

4.3. The Deliktaş mass flow-dominated fan delta complex succession

Middle Eocene deposits of the DFDC in the basin generally consist of conglomerate, pebbly sandstone and sandstones that were transported from the uplifted areas surrounding the basin from the north and south (Figure 4b). They are overlain by the succession of alluvial fans. (Figure 4c).

4.3.1. Facies analysis of the Deliktaş mass flow-dominated fan delta complex

The facies analysis of the mass flow-dominated Deliktaş Fan-Delta Complex was performed using well-defined fan-delta facies classifications (Middleton and Hampton, 1976; Miall, 1977, 1978, 1985; Nemec et al., 1984; Rust, 1984; Shultz, 1984; Kazancı and Varol, 1990; Postma, 1990; Deynoux et al., 2005; Sun et al., 2020). The identification and stratigraphy of the fan delta complex deposits by the sediments is based on the fabric features, matrix type, composition and structural characteristics. Seven facies and two sub-facies were identified and described from the sections of the Eocene units in the southern part of the Elazığ Marine Basin. The facies and sub-facies were evaluated together and two facies assemblages were defined using facies-assemblage classifications (Nemec et al., 1984; Postma, 1990). These are the conglomerate- and sandstone-dominated 'Fan Delta Plain' and the 'Fan Delta Front', which consists of planar conglomerate, interbedded pebbly sandstone and laminated fine-grained sandstones. Pro-fan delta deposits were not found in the study region and were most likely covered by turbidites. The deposits of the pro-fan delta are often fine-grained lithologies such as mudstone or siltstone. Table 1 summarizes the stratigraphic relationships corresponding to the facies, sub-facies and facies assemblages of the fan delta complex deposits in the study area.

4.3.2. Fan Delta Plain

The Fan Delta Plain facies assemblage are divided into different facies as; (1) channel facies, (2) sandstones and (3) planar-bedded conglomerates. The channel facies and sandstones facies represent the distal part of the fan delta plain assemblage, the planar-bedded conglomerates characterize the proximal part (Kazancı and Varol, 1990). Fan delta plain consists of facies containing conglomerate and sandstone. This facies assemblage deposits are mostly derived from granite and diorite type plutonic rocks and basalt type volcanic rocks of the Elazığ Magmatites, which form the feeder area in the northern and southern parts of the study area. It is also observed to a lesser extent in components derived from recrystallized limestones of the Keban Metamorphites.

Channel Facies

The channel facies is divided into two sub-facies; distributary channel (DC) - conglomerates and plain channel (PC) - sandstones (Figure 5a and Figure 5b). The border relation of the facies to each other is planar, erosional or laterally transitional.

Distributary channel (DC) - conglomerates sub-facies

Description. This facies is usually characterized by conglomerates. Planar-bedded conglomerate levels have also been found. The conglomerate beds become finer towards the top, starting from clast-supported conglomerates at the base, which are supported more by the matrix towards the top, with some fining to medium sandstone. The sub-facies has formed erosional surfaces with the underlying facies, and it has mostly formed flat-bounding surfaces with the overlying facies. It also has an average thickness of 6.6 m and varies between 1 m and 30 m. The rounding and sorting of the components of the sub-facies deposits change from very poor to moderate. Block-sized components with an average grain size of 61.6 cm are generally found in the lower levels of the sub-facies, with a maximum grain size of ≥250 cm. According to the long-axis imbrication observed in the sub-facies conglomerates, the palaeocurrent direction is between 85° and 90° SE.

Interpretation. According to Miall (1977, 1978), the sub-facies were described as massive, matrix- or grain-supported conglomerates (Gms). The fact that the sub-facies components rarely show distinct orientations, have very poorly sorted grain sizes ranging from block to pebble size, and lack a specific fabrication characteristic, indicates subaerial cohesive debris flows that developed under high-density and high-energy flows (Middleton and Hampton, 1976; Miall, 1978, 1985; Lowe, 1982; Nemec et al., 1984; Shultz, 1984; Kazancı and Varol, 1990; Postma, 1990; Deynoux et al., 2005).

Plain channel (PC) - sandstones sub-facies

Description. The facies consists of pebbly sandstones with medium-fine to very coarse grains. Planar bedded conglomerates are also found in the pebbly sandstones at some levels (Figure 5c). The PC sandstone sub-facies has erosional surfaces at the bottom and mostly planar surfaces at the top. The sub-facies varies in thickness from 1 m to 30 m as a plain channel, with an average thickness of 7.3 m. The sandstones contain components ranging from boulders to gravel. The components in the sandstones are very poorly rounded and very poorly to moderately sorted, with an average grain size of 78.8 cm. Block-sized components with a maximum grain size of 170 cm are mostly observed at the base of the sub-facies.

Interpretation. The sub-facies are exactly the same in the literature as identified by Sun et al. (2020) and used with the same name in this study. Sandstone and conglomerate interbedded pebbly sandstones have a pattern stacked along multiple channels that migrate and cut under strong hydrodynamic force (Sun et al., 2020). The presence of randomly distributed components of different sizes in the sandstones suggests that these sediments were carried by high-density subaerial debris flows (Lowe, 1982; Mulder and Alexander, 2001).

Sandstones facies

Description. The sandstone facies is characterized by normally graded, very coarse- to coarse-grained sandstone and has an average thickness of 2 m. At the base of the sandstones, boulder-sized clasts with a maximum grain size of 45 cm can be observed, originating from diorite and granite.

Interpretation. This facies used with same name by Miall (1978), Postma (1978) and Kazancı and Varol (1990). The facies is an upper part of the non-marine realm commonly observed in the uppermost part of the fan delta plain (Kazancı and Varol, 1990). Deposition processes in the fan delta system occurs in environments where the lower fan delta plain has a high sediment flow and the flow energy gradually decreases (Kazancı and Varol, 1990). In addition, it has been noted in the literature (Miall, 1978; Rust, 1984; Marzo et al., 1988) that facies sediments accumulate in small braided streams of the Donjek type flood regime as longitudinal bars or mega-ripples.

Planar-bedded conglomerates facies

Description. The facies consists of mostly planar-bedded conglomerates with grain-supported and/or sand matrix support. It has mostly formed flat and rarely erosional boundaries with the overlying and underlying facies. The thickness of the planar-bedded conglomerate facies varies between 4 m and 12 m. Their average thickness is 7.3 m. The average grain size of the conglomerates is 38.75 cm and the maximum grain size is 55 cm. The grains are also very poorly sorted and very poorly rounded. According to the long axis imbrication observed in a conglomerate level, the palaeocurrent direction is 210ºSW.

Interpretation. The planar-bedded conglomerate facies was first described by Kazancı and Varol (1990) and was also used in this study with the same name. It can be compared with the massive, thick-bedded conglomerate facies (Gm) of Miall (1977, 1978). The planar-bedded conglomerates are a transitional facies between fan delta plain and fan delta front deposits (Kazancı and Varol, 1990), and their deposition processes were probably during the sudden flooding of the tractional transition (Rust, 1984; Marzo et al., 1988).

4.3.3. Fan Delta Front

The sediments of the fan delta front assemblage consist of conglomerate, planar conglomerate with interbedded pebbly sandstone, fine-grained, laminated or thin- bedded sandstones. The components of the sediments of the assemblage originate from the diorite and granitic plutonic rocks of the Elazığ Magmatites and to a lesser extent from the recrystallized limestones of the Keban Metamorphites. The facies of the fan delta are divided into four different facies groups: (1) inner front (distribution), (2) subaqueous distributary channel, (3) subaqueous interdistributary channel and (4) planar stratified conglomerates. The boundary relationship between the facies is planar or erosional. In general, the facies of the assemblage are largely covered by the DC conglomerate sub-facies of the fan delta plain facies assemblage in the basin.

Inner front (Distribution) facies

Description. The facies consists of medium-coarse-grained, planar conglomerate interbedded with pebbly sandstone and has a thickness of 1.6. Interbedded conglomerates are very good rounded and moderately sorted, with an sheet size of 10 cm (Figure 5d).

Interpretation. This facies was first defined by Sun et al. (2020) and was also used in this study with the same name. Distribution channels show the process of transporting less sediment from the source under the decreasing hydrodynamic force from bottom to top. Large sandstones that migrate both upward and downward are a common feature of sediments transported by this mechanism; small-scale sandstones are uncommon (Sun et al., 2020). Sun et al. (2020) found that the planar conglomerate interbedded within the sandstones indicates the presence of periodic high hydrodynamic forces and high-energy currents during migration.

Subaqueous distributary channel (SDC) facies

Description. The lithology of the facies generally consists of weakly cemented, coarse- to medium-grained, pebbly sandstones and rare medium-grained, bedded sandstones. Interbeds of conglomerate were found in some layers of conglomerate. The average thickness of the facies is 2.6 m. SDC is mostly flat-bounded with underlying and overlying facies and was deposited in some levels by erosion on the subaqueous interdistributary channel facies (SIC) (Figure 5e). The components within the sandstones and conglomerate interlayers are medium to very poorly rounded and poorly sorted and have an average grain size of 52 cm.

Interpretation. SDC was described by Postma (1990) as horizontally bedded sandstones. The deposits of these facies are intensively transported from land to the subaqueous by hyperpycnal flow in the form of delta fronts, bedload deposits and traction carpets (Postma, 1990).

Subaqueous interdistributary channel (SIC) facies

Description. The facies represents laminated or thin-bedded, fine-grained sandstone or pebbly sandstone. The thickness of the facies observed as a layer is 1.76 m (Figure 5f).

Interpretation. It was defined by Miall (1977, 1978) with the facies code Sh, which is represented by very coarse to very fine-grained or less pebbly sandstones. As planar bedload in the lower or upper flow regime, the SIC sediments were deposited horizontally with partial or continuous lamination (Miall, 1977, 1978; Postma, 1990). In addition, the sudden transition in the development of the thin-bedded sandstones in the lower and upper layers indicates a rapid and weak change in the depositional environment (Sun et al., 2020).

Planar stratified conglomerates facies

Description. The facies consists of conglomerate-interbedded and sand matrix conglomerates. The average thickness of the facies is 11.5 m. The constituents of the conglomerate are very poorly rounded and moderately sorted, with a maximum grain size of 30 cm.

Interpretation. The facies was named by Kazancı and Varol (1990) with the Cs facies code, and the same name was used in this study. Postma (1984a, b) described this sub-facies in similar studies and stated that the effect of gravity processes was formed by the distal deposition of stratified conglomerates on the subaqueous delta slope steps.

4.3.4. The litho-correlation of Deliktaş mass flow fan delta complex

The DFDC successions are characterized by three different sequences: Fan delta sequence 1 (FD1), fan delta sequence 2 (FD2) and fan delta sequence 3 (FD3). Each sequence can be distinguished from the next sequence by the angular relationship of the layers. The FD1 sequence was spread on the alluvial fan succession and erosionally overlapped the Elazığ Magmatites due to erosion. The FD2 sequence was deposited directly on the Elazığ Magmatites, and the FD3 sequence spread over the Harami Formation (Figure 6). Lateral and vertical litho-correlations of the DFDC are shown in Figure 7, Figure 8 and Figure 9. According to the litho-correlations, the thickness of the Fan Delta Plain facies deposits is 80 m in FD1, 60 m in FD2 and 30 m in FD3. The Fan Delta Front facies is observed in all three fan delta sequences. The thickness of the assemblages was 13 m in FD1, 50 m in FD2 and 54 m in FD3.

4.4. Turbidite Succession

At the end of the middle Eocene, marine conditions formed in the region due to the effective block normal fault and the rapidly developing subsidence. Due to the rapid rise in sea level, the marine environment shifted northwards. As a result of this process, the turbidite succession, which forms the uppermost part of the basin deposits, consists of medium- and fine-grained sandstone and sandstone-siltstone couples of the Kırkgeçit Formation and unconformably overlies the fan delta complex succession (Figure 10). The massive and normally graded sandstone layers (Ta; Bouma, 1962) in the approximately 300 m thick succession have a thickness of 15-20 cm, while the thickness of the sandstone-siltstone couples (Tab, Tabc; Bouma, 1962) is 10 cm.

5. The Sedimentary Evolution and Paleogeographic Depositional Models of the DFDC in relation to the Elazığ Marine Basin

The Elazığ Basin expanded rapidly from the continental uplifted area to the shallow marine environment at the beginning of the middle Eocene due to normal block faulting under the influence of gravity (Aksoy et al., 2005; Alkaç and Aksoy, 2022). During this time, components ranging from boulders to sand, carried into the basin by break-offs from various uplifted areas surrounding and feeding the basin from the north and south, formed sedimentary sequences belonging to the high-energy, mass flow-dominated the Deliktaş Fan Delta Complex (Figure 11a). The sequences of the fan delta complex cannot be transported over long distances due to several factors such as the narrow and long geometry, the irregular basin floor morphology of the restricted basin character and the irregular sorting of sediments (Figure 5a and Figure 11a) in a high-energy environment. Due to back-feeding and/or bypass development in front of the uplifted where they form, sediments transported over short distances are deposited in the channel morphology (Mutti ve Ricci Luchi, 1972; Lowe, 1982; Fisher, 1983; Stow, 1985; Nemec ve Steel, 1984). The channels dip 45–50° to the south (Figure 11b).

The Keban Metamorphites overtook the Elazığ Magmatites with a southward advance at the end of the Late Cretaceous (Figure 12a). In the early middle Eocene, the first sediments of the DFDC started to be deposited on the basement rocks consisting of the Elazığ Magmatites and the Late Campanian-Maastrichtian Harami Formation. The boulder, block-sized components in the sediments originate from the Elazığ Magmatites and the Keban Metamorphites at the northern uplifted areas. In the southern uplifted areas of the basin, they began to be deposited on alluvial fans. The fan-delta complex, which is fed by both uplifted areas, represents the early depositional development of the basin (Figure 12b). In the middle and late stages of the middle Eocene, with the increasing extensional tectonic regime, the basin deepened rapidly under the control of normal block faults, and sandstones and conglomerates began to be deposited together (Figure 12c). Due to the rapid rise in sea level and the turbidite sequence deposited as unconformable deposits on the fan deltas (Figure 12c), the basin became deeper during the last stages of the middle Eocene due to block faulting. Thus, the DFDC completed its evolution in a multi-feeder environment in the middle Miocene.

6. Conclusion

This study aims to shed light on the fact that mass flow-dominated fan-delta complexes also play an active role in characterizing the tectonism that controls the opening of marine basins. Therefore, facies analysis studies and interpretations on the depositional evolution of the mass flow-dominated fan delta complexes in the Kırkgeçit Formation in the Elazığ Marine Basin were carried out.

The Elazığ Marine Basin developed through rapid deepening in the middle Eocene under the influence of the normal block faults. During this time, the well-exposed Deliktaş Fan Delta Complex, dominated by mass flows, formed in front of the uplifted areas that bound the basin from the south and north. The succession that started in the basin in front of the uplifted areas due to the rapid deepening of the basin under the influence of normally developed block faults in the southern part of the western Elazığ Basin with the increase of the regional extensional regime in the middle Eocene is a good example of the multi-feeder system deposits for the fan delta complexes. The facies architecture of the DFDC successions was defined on the basis of measured stratigraphic sections, litho-correlation and field observations, and the sedimentary evolution of the fan delta complex was revealed with three-dimensional basin models using the data obtained. In this way, an approach for the primary geodynamics of the Elazığ marine basin was obtained.

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Figures

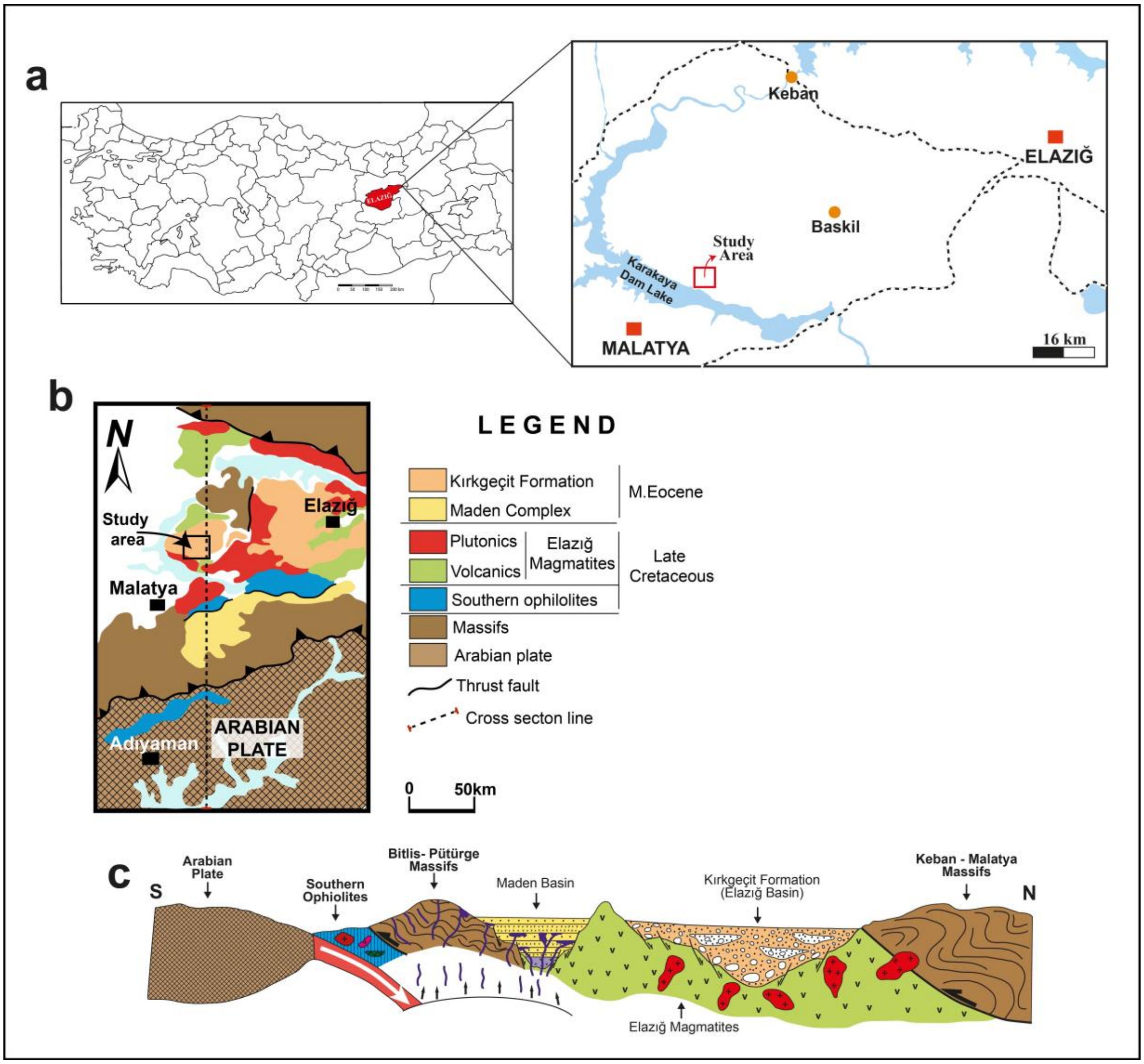

Figure 1. Location map (a) and the simplified geological map (b) covering the study area; (c) The Geotectonic cross-section model of the Elazığ Basin (modified by Alkaç and Aksoy, 2022).

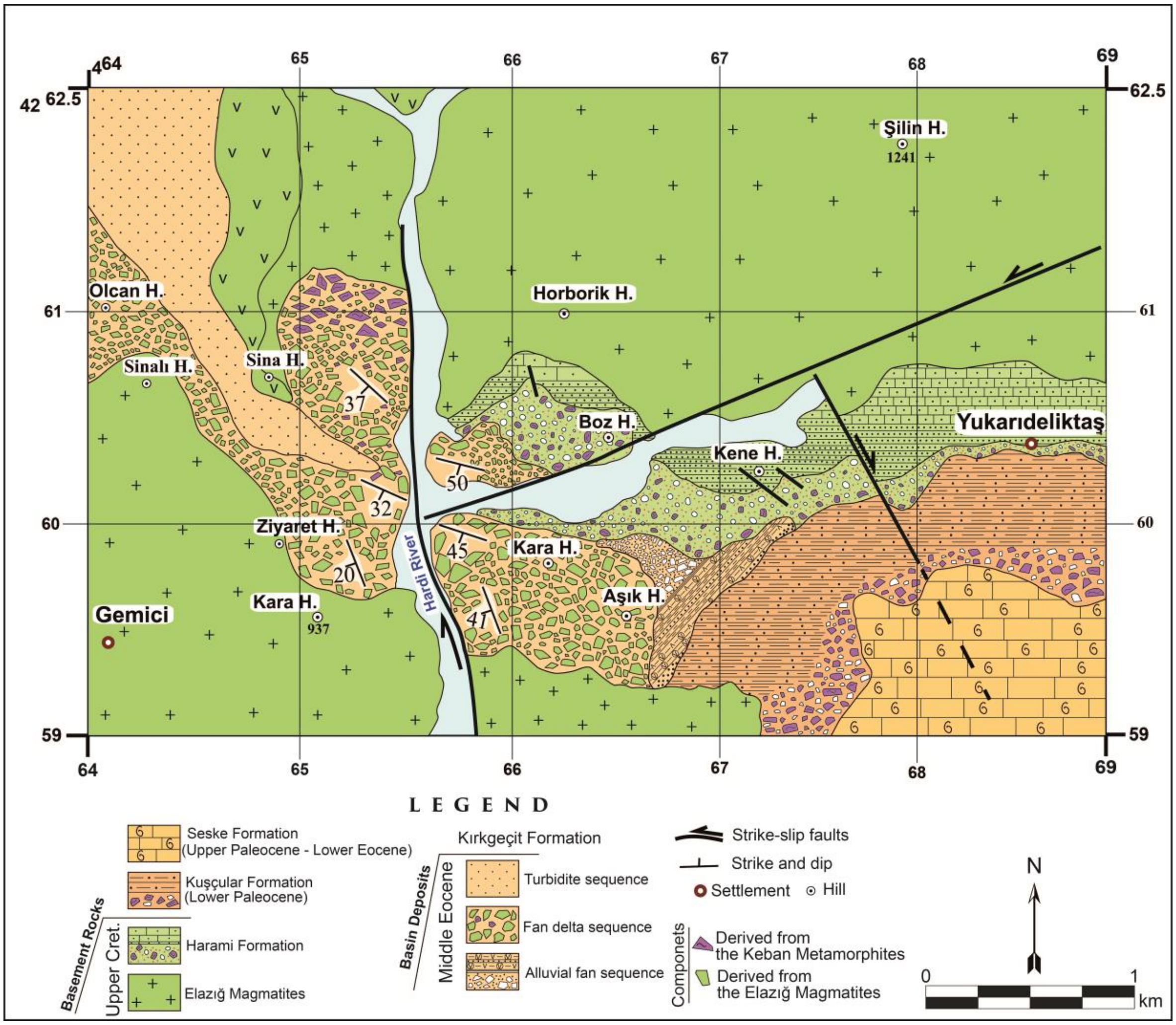

Figure 2. Geological map of the study area.

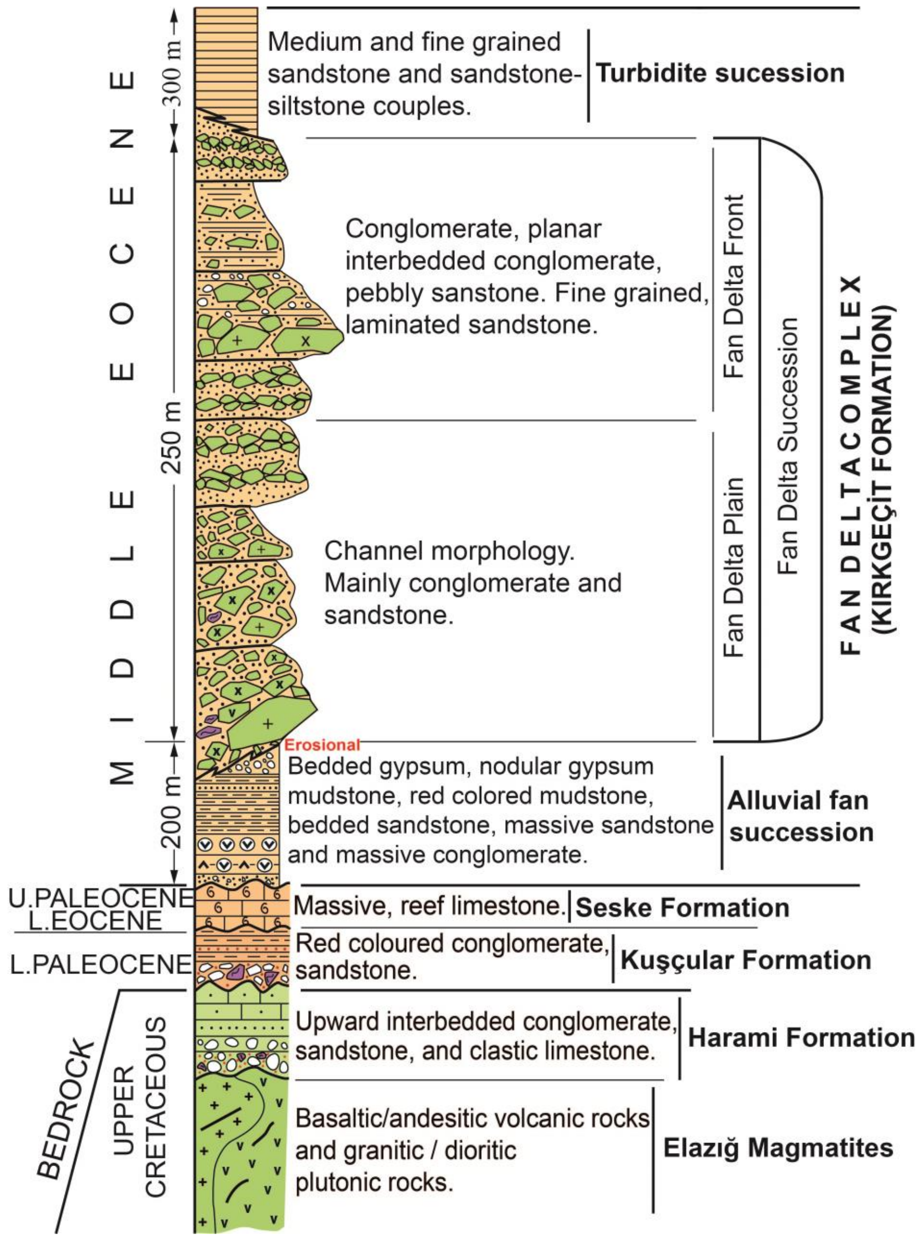

Figure 3. Generalized stratigraphic section through the Middle Eocene basin fill in the study area (prepared using the design of Kazancı and Varol, 1990).

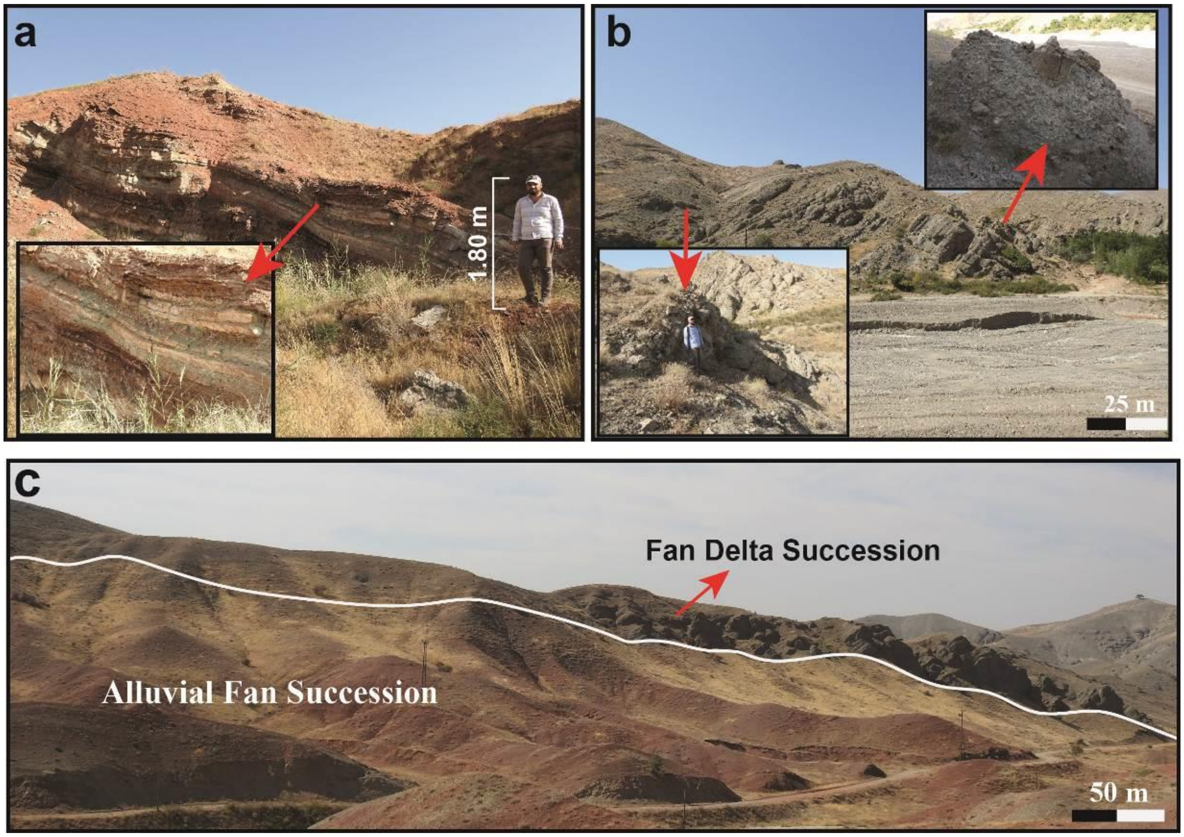

Figure 4. (a) Bedded gypsum, red colored mudstone and bedded sandstone of the Alluvial Fan Succession; (b) General view of the Fan Delta Succession; (c) Boundary relationship between the Alluvial Fan Succession and the Fan Delta Succession.

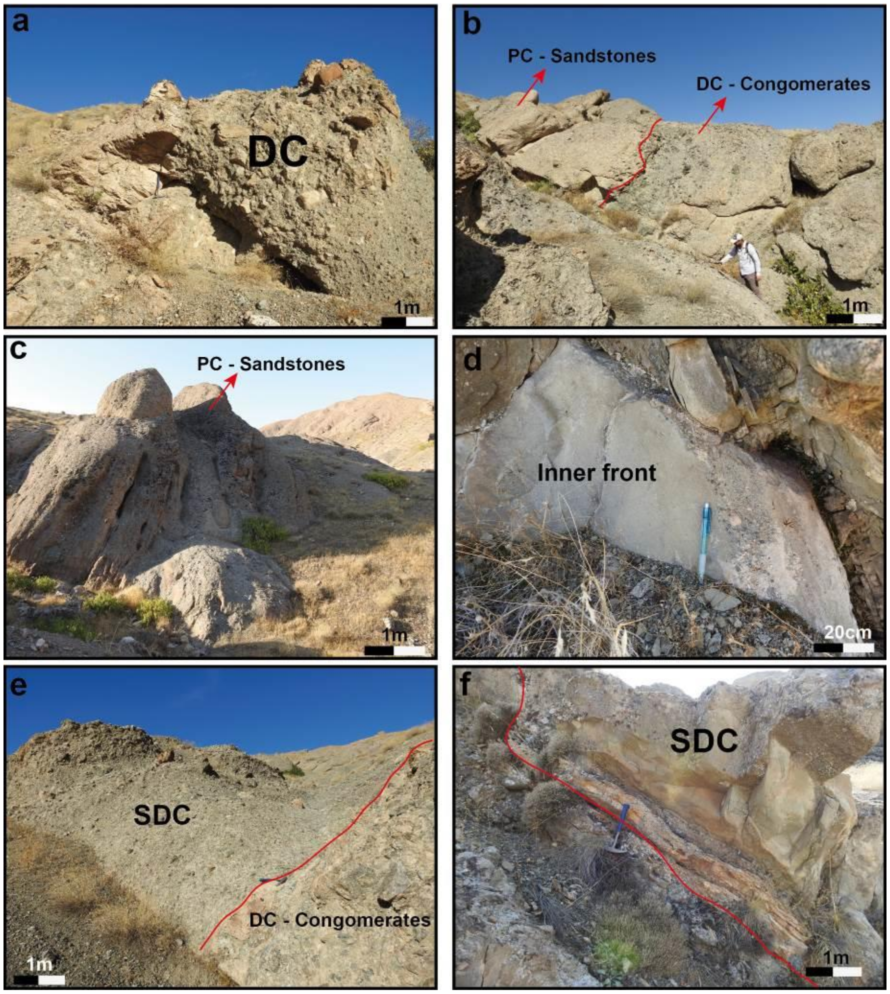

Figure 5. (a) Distributary Channel (DC) – Conglomerates sub-facies of the Channel Facies in the fan delta complex; (b) Boundary relationship between the Distributary Channel (DC) – Conglomerates sub-facies and the Plain Channel (PC) – Sandstones sub-facies of the Channel Facies; (c) Plain Channel (PC) – Sandstones sub-facies observed in the fan felta complex; (d) Inner Front (Distribution) Facies determined in the fan delta complex; (e) Boundary relationship between the Distributary Channel (DC) – Conglomerates sub-facies of the Fan Delta Plain and the Subaqueous Distributary Channel (SDC) Facies of the Fan Delta Front observed in the Deliktaş mass-flow dominated fan delta complex. (f) Subaqueous Distributary Channel Facies in the Fan delta complex.

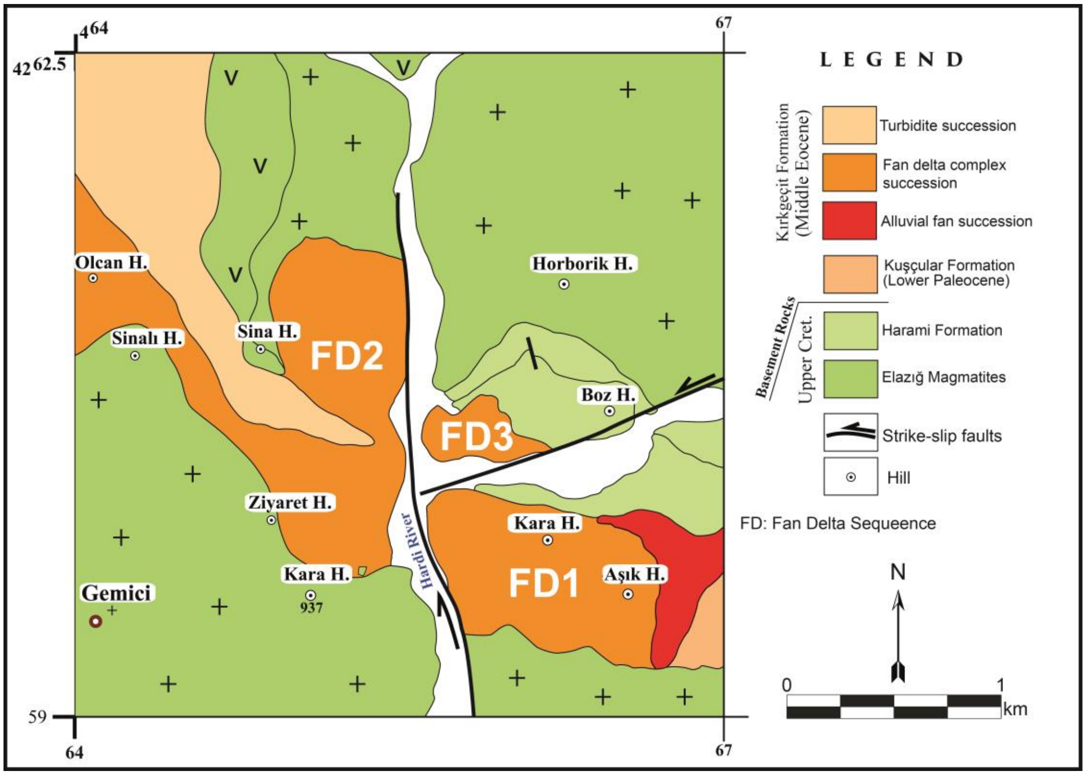

Figure 6. Distribution map of fan delta sequences in the fan delta complex.

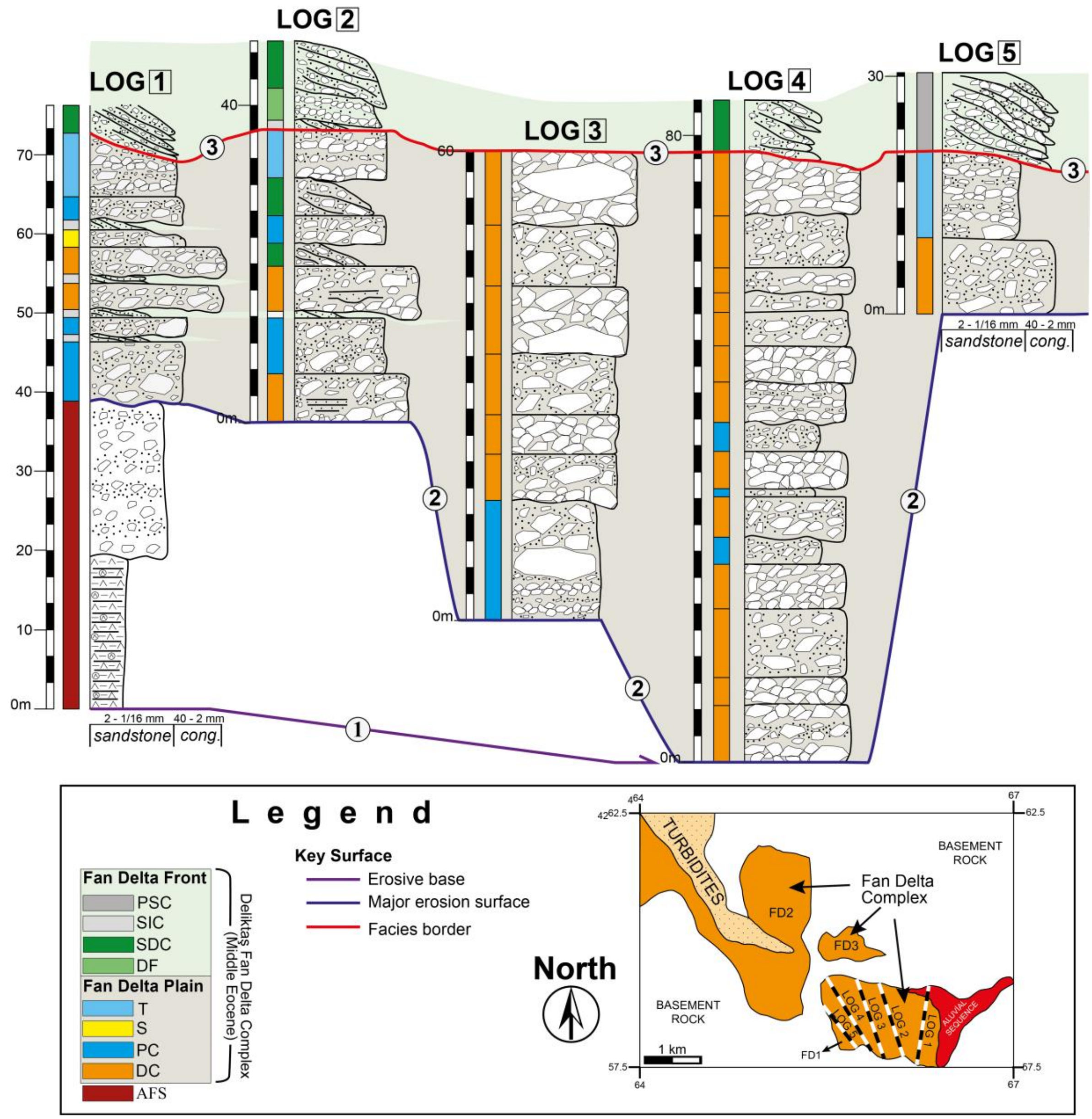

Figure 7. Litho-correlation profile of sedimentary facies of Fan Delta 1 Sequence (FD1) in the Deliktaş Fan Delta Complex (AFS: Alluvial fan succession; DC: Distributary channel; PC: Plain channel; S: Sandstones; T: Planar-bedded conglomerates; DF: Distribution facies; Subaqueous distributary channel; SIC: Subaqueous interdistributary channel; PSC: Planar stratified conglomerates).

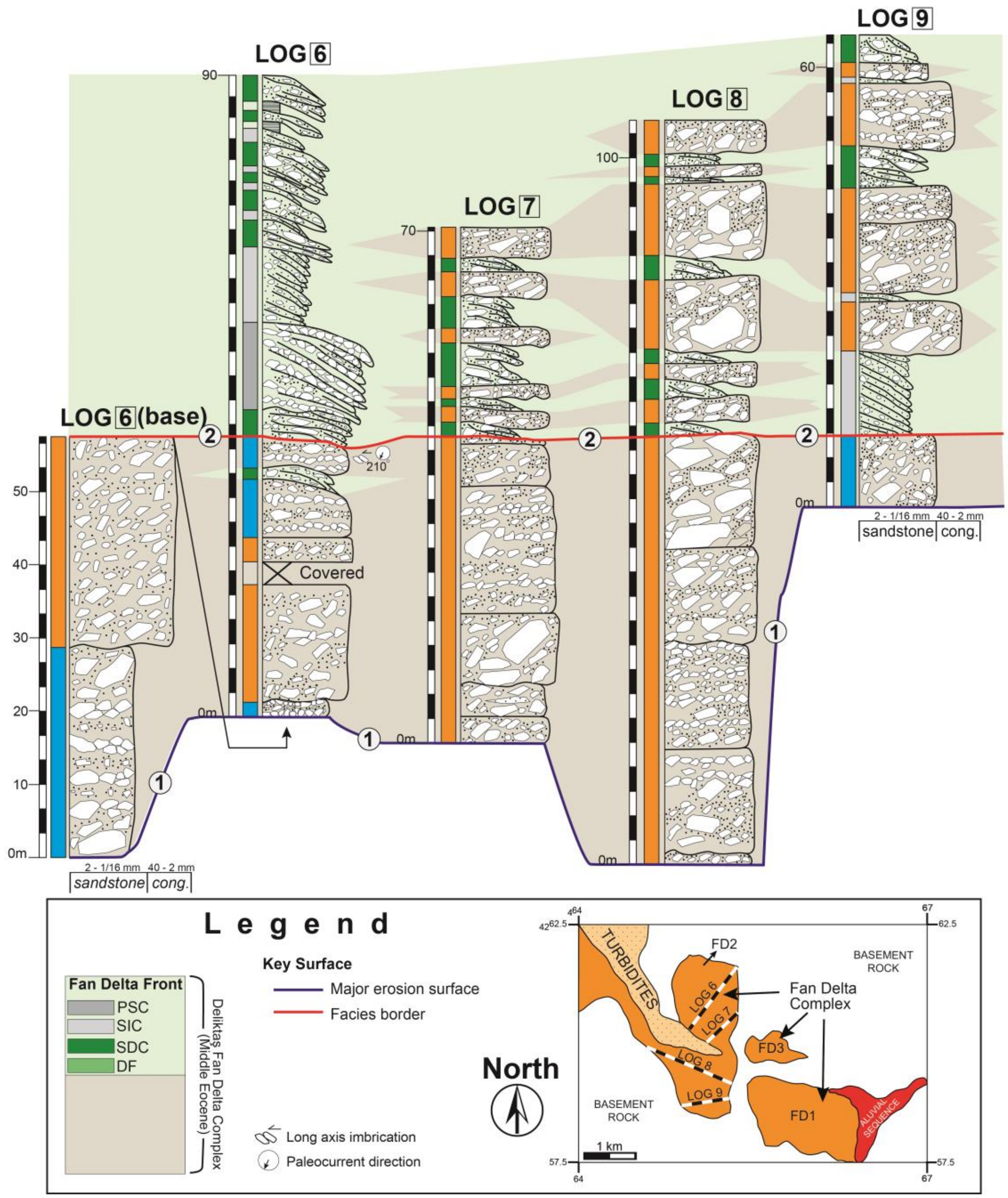

Figure 8. Litho-correlation profile of sedimentary facies of Fan Delta 2 Sequence (FD2) in the Deliktaş Fan Delta Complex (DC: Distributary channel; PC: Plain channel; S: Sandstones; T: Planar-bedded conglomerates; DF: Distribution facies; Subaqueous distributary channel; SIC: Subaqueous interdistributary channel; PSC: Planar stratified conglomerates).

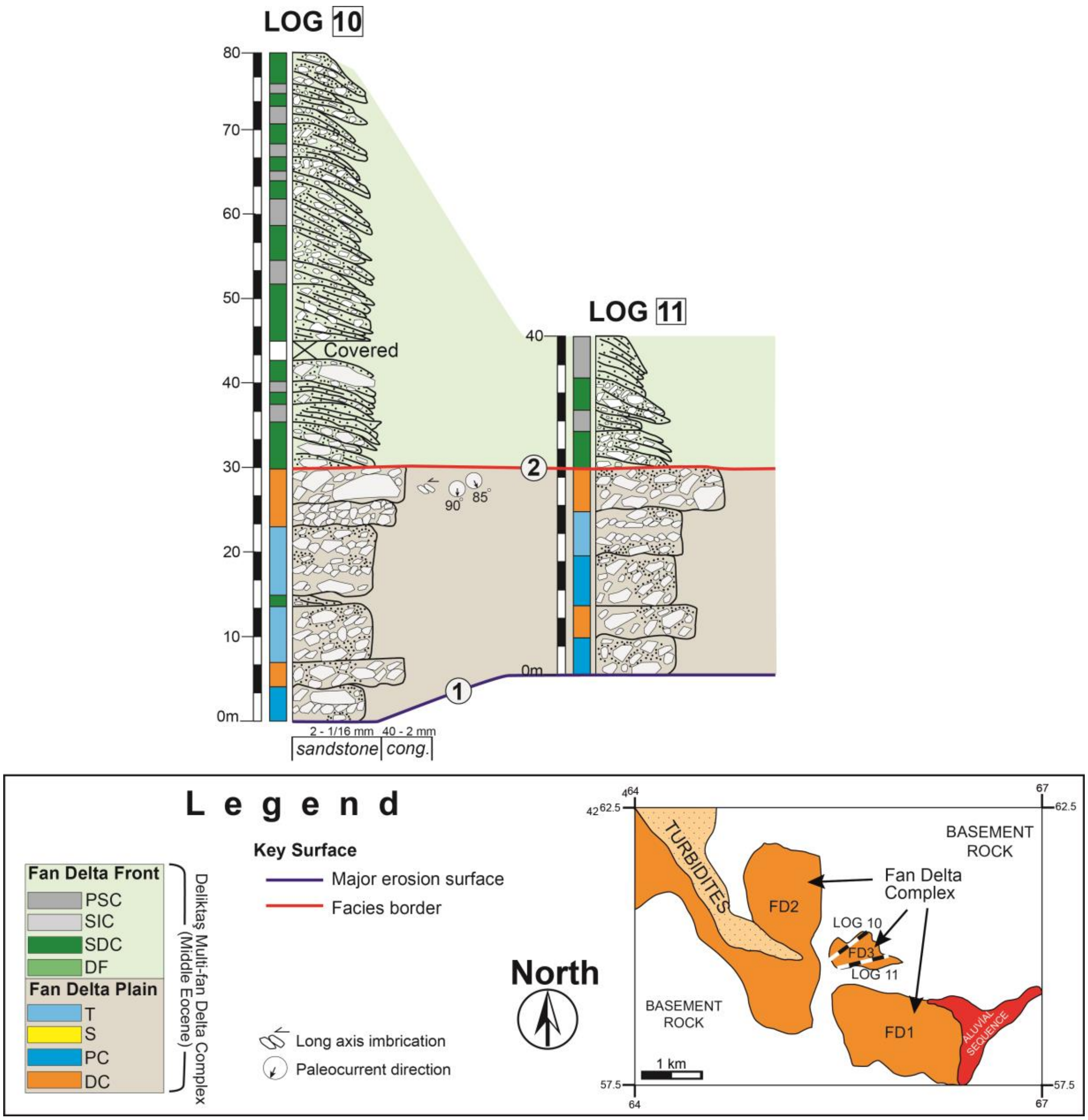

Figure 9. Litho-correlation profile of sedimentary facies of Fan Delta 3 Sequence (FD3) in the Deliktaş Fan Delta Complex (DC: Distributary channel; PC: Plain channel; S: Sandstones; T: Planar-bedded conglomerates; DF: Distribution facies; Subaqueous distributary channel; SIC: Subaqueous interdistributary channel; PSC: Planar stratified conglomerates).

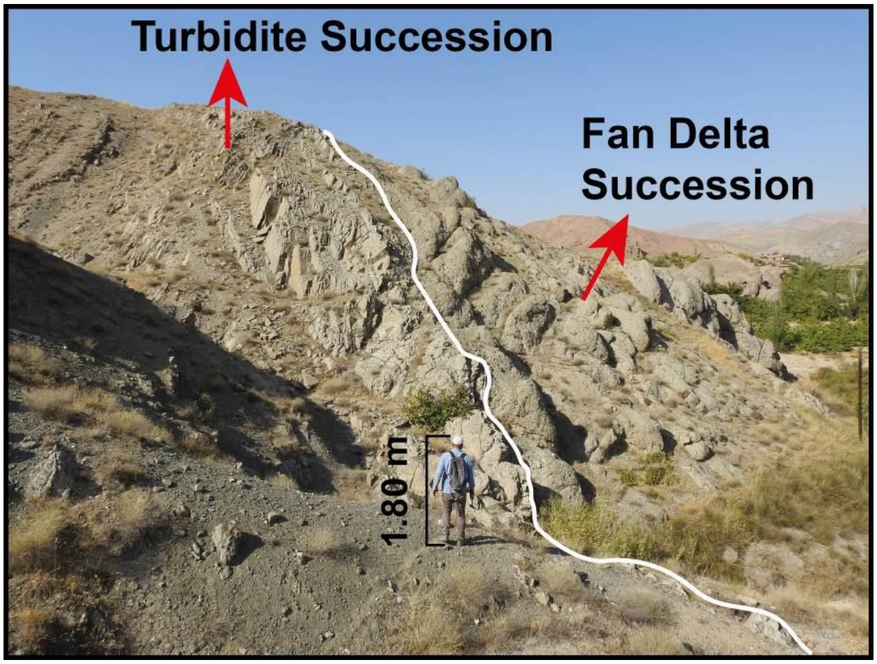

Figure 10. Boundary relationship between the Fan Delta Succession and the Turbidite Succession.

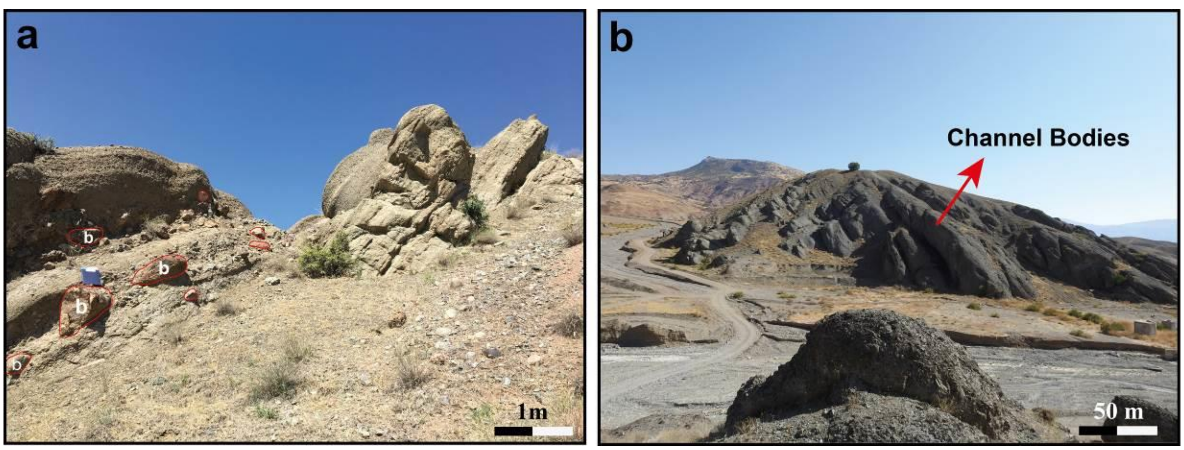

Figure 11. (a) Boulder - block sized components (indicated as b) observed in the sediments of the Fan Delta Succession; (b) General view of the channel morphology in the Fan Delta Succession.

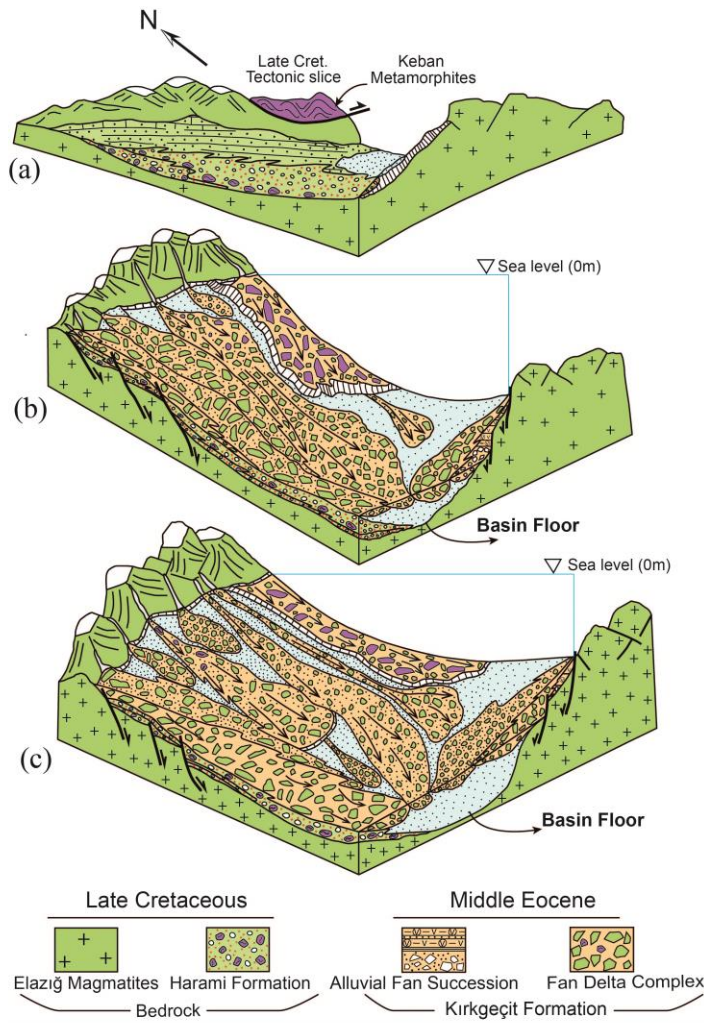

Figure 12. (a) Late Cretaceous paleogeography of the study area, (b) Pre-mature middle Eocene depositional model of the Deliktaş Fan Delta Complex, (c) Mature middle Eocene depositional model of the Deliktaş fan Delta Complex.

Tables

Table 1. Summarizes of the sedimentary facies architecture of the Deliktaş Fan Delta Complex.

Facies Assemblages	Facies	Sub-facies	Brief Description	Brief Interpretation
Fan Delta Plain	channel	distributary channel	Conglomerate, sandy matrix and grain supported. At the basement, grain supported conglomerates and upward sandy matrix conglomerates in the same layer.	Subaerial cohesionless debris flow Cohesive debris flow. Middleton and Hampton (1976); Miall (1978, 1985); Lowe (1982); Nemec et al. (1984); Shultz (1984); Kazancı and Varol (1990); Postma (1990); Deynoux et al. (2005).
		plain channel	Medium to fine, medium, coarse, very coarse to coarse grained sandstone. Pebbly sandstone with planar stratified conglomerates.	Debris flow Subaqueous debris flow. Hyperconcentrated density flow. Lowe (1982); Mulder and Alexander (2001); Sun et al. (2020).
	sandstones		Normal graded, very coarse to coarse grained sandstone.	Donjek type flood regime. Miall (1978); Rust (1984); Marzo et al. (1988). Lower delta plain. Kazancı and Varol (1990).
	planar bedded conglomerates		Grain supported and/or sandy matrix supported, planar bedded conglomerates.	Flash foods from tractional transport. Rust (1984); Marzo et al. (1988); Kazancı and Varol (1990).
Fan Delta Front	distribution		Coarse to medium grained, pebbly sandstones with planar conglomerates.	Inner Front, distribution migrating and incising frequently. Sun et al. (2020)
	subaqueous distributary channel		Medium to fine, medium, coarse to medium, coarse grained, pebbly sandstone or medium grained, layered sandstone.	Bedload deposition and traction carpet. Postma (1990).
	subaqueous interdistributary channel		Fine grained, laminar or fine layered sandstone and/or pebbly sandstone.	Lower and upper flow regime. Miall (1977, 1978); Postma (1990); Sun et al. (2020).
	planar stratified conglomerate		Sandy matrix, conglomerate with interbedded conglomerate.	Subaqueous delta slope. Postma (1984a, b); Kazancı and Varol (1990).