2.4.4 Downcurrent evolution in lobe accumulation

The recognition of lobe deposits in proximal and distal locations is based on differing sedimentological character, internal organisation, vertical facies relationships, component associations and position within the fan framework. The studied lobe depositional environments do not represent true downcurrent representatives of each other (fig. 2.42a), their respective up- and/or downcurrent deposits are not exposed and/or not preserved. However, general proximal-distal changes in the lobe depositional environment can be observed. The distal lobes (Lobe C) are located in a more intermediate rather than true distal fan location (fig. 2.42b) as suggested by their high bulk net sand content and relative coarseness of sediments.

The different identified lobe types are characterised by a high net sand content throughout. In a downsystem direction the net sand content gradually decreases (Lobe A/B/C = 93/95/86 %), accompanied by a gradual decrease in grain size (very coarse to medium sand-sized) and bed thickness (ave. 0.6/0.8 - 0.50 m) and a substantial increase in shale content (fig. 2.42b).

Sediment emplacement within the different lobe environments took place by high and low density currents and, at times, sandy debris flows. Shanmugam *et al.* (1995) suggest to regard only normal grading as reliable indicator of deposition by turbidity currents. Thus the amount of "true" turbidite deposits is 45 % in Lobe A, 59 % in Lobe B and 75 % in Lobe C. A clear downcurrent increase in deposition by turbidity currents is present, paired with deposition from increasingly dilute currents, i.e. a decrease in competence, higher relative abundance of Bouma Tc-d structures. The observed non-graded, massive, crudely stratified beds are typically interpreted to represent deposition from high density turbidity currents (e.g. Lowe 1982; Hiscott *et al.* 1997), which some authors assign to sandy debris-flow deposits based on the apparent "non-turbulent turbidity current" flow rheology (e.g. Shanmugam *et al.* 1995; Shanmugam 1996, 2000). The crucial implication of this debate centres on the resultant sand body geometry; sandy debris flows are believed to form less extensive, discontinuous, disconnected sand bodies which are more sensitive to sea-floor topography (Shanmugam *et al.* 1995; McCaffrey in Purvis *et al.* 2002) than high density turbidity flows. Regardless of this, sandy debris flows and/or high density turbidity currents may evolve into low density turbidity currents (e.g. Stow & Johansson 2000; Shanmugam 2000; Purvis *et al.* 2002) thus explaining the downcurrent net increase in turbidites (for further discussion see chapter 5.1).

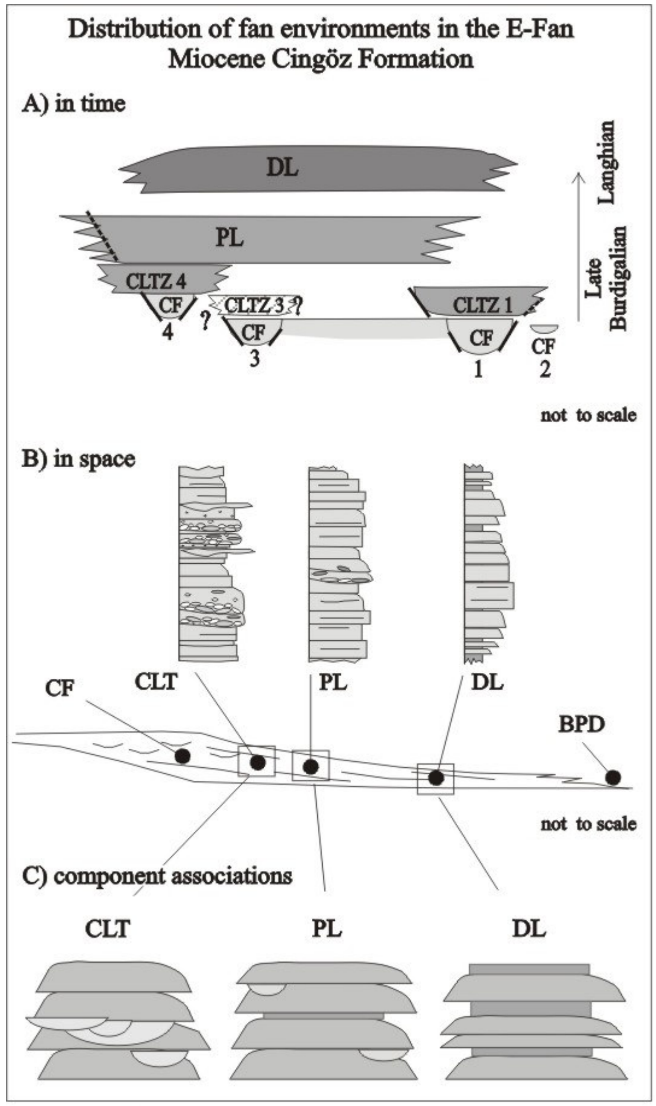

**Figure 2.42: A) Schematic diagram showing the distribution of the channel-lobe transition zone (CLT), proximal lobe (PL) and distal lobe zone (DL) in a time-space matrix.
B) Showing the spatial position of the channel-fill (CF), (CLT), (PL), (DL) and basin plain deposits (BPD) within the E-Fan, Cingöz Formation (modified after Ricci Lucchi *et al.* 1987).
C) Stacking pattern and component association of CLTZ, PL and DL reflecting downcurrent decrease in channelling association, increase in lobe fringe/interlobe deposits and increase in vertical lobe spacing.**

The proximal Lobe A and B deposits are highly amalgamated, composite beds of 10s of metres in thickness are common. Within the Lobe C deposits, shales commonly separate individual sandstone beds and amalgamation is relatively rare (fig. 2.42b). The internal organisation improves from near random and few well-defined asymmetric sequences at bed sub-packet-scale in Lobe A/B deposits to better organised Lobe C deposits. Generally, the significance of vertical arrangements as environmental indicators are questioned (e.g. Hiscott 1981; Millington 1995; Anderton 1995; Chen & Hiscott 1999a; Shanmugam 2000) and are rather believed to represent sensitive indicators of short term fluctuations in both allocyclic and autocyclic controls (Foster 1995). Chen & Hiscott (1999a) doubt the presence of any "organised" lobe development arguing that seismically- or flood-induced turbidites are sporadic events rather than following some sort of organisation. The recorded metre-scale sequences in the various lobe deposits are believed to reflect irregularities of flow volume, sediment supply, topographic compensation etc. (e.g. Mutti *et al.* 1994; Chen & Hiscott 1999a). These smaller-scale sequences are overprinted by the lobe-scale asymmetric sequences believed to be related either to progressive lobe progradation, retrogradation and/or lateral migration or as fining upward and/or random organisation implying aggradation. Anderton (1995) suggests that a more ordered vertical arrangement indicates relative depositional stability. This implies a downcurrent increase in depositional stability from Lobes A/B to C.

Unique component associations characterise the proximal-distal trend. The Lobe A and B deposits are associated with erosive components, i.e. channeling, scouring and/or small distributary channels, reflecting a highly dynamic erosive-depositional bypass environment. The per section lobe representation decreases from 70 % (CLTZ) and 90 % (proximal lobe zone) to 65 % in the distal lobe zone. The associated coarse channelized elements in the former two decrease from the CLTZ (30 %) to proximal lobe zone (8 %). In contrast, Lobe C deposits accumulated in a relatively tranquile depositional environment, underlined by the abundance of preserved bioturbation. Lobes in the CLTZ and partially the proximal lobe zone are poorly defined while in the distal lobe zone, lobes are often clearly separated by associated deposits (fig. 2.42c).

Lobe progradation, switching and overall aggradation result in the observed mixed shingled-compensational stacked Lobe A/B and partially C complexes, representing stable depositional environments (Pickering 1981). The isolated Lobe C deposits within areas of normally fan fringe sedimentation suggest episodic lobe migration into this area, indicative of unstable depositional processes, possibly reflecting source control (Pickering 1981) or lobe switching (this study). The recorded overall grain size decrease in all three lobe depositional environments appears to be related to reduction in grain size in the feeder system or an increase in distance from the input point perhaps due to rising sea level (*see chapter 2.5*). Retrogradation in response to decreased sediment supply and grain size is apparent in the unique Lobe B sequences, i.e. the distinct grain size and textural changes at lobe-scale.

While Lobes A and B developed within a semi-confined space inhibiting much lateral dispersal, the Lobe C deposits appear to be only peripherally restricted by the slope. The proposed elongated sheet-like geometries reflect the restricted environment while some lobate Lobe C geometries were identified.

Distinct downcurrent trends as observed in the lobe deposits of the E-Fan have also been recorded in other ancient deep-water clastic systems (e.g. Macigno Formation: Ghibaudo 1980; Kongsfjord Formation: Pickering 1981; Rocchetta Formation: Cazzola *et al.* 1981) where the decrease in grain size, bed thickness and net sand content are conspicuous. The emplacement mechanism and changing flow competence and capacity play a crucial role in the recorded evolution. Autocyclic controls, such as lobe switching due to lobe build-up, channel migration and avulsion, and allocyclic controls, such as the gradually rising sea level, tectonic activity in the source area and within the basin, govern the development and geometries of the various lobe depositional environments of the E-Fan.

2.5 Controls

Studies of modern and ancient submarine fan systems have shown that a range of auto- and allocyclic mechanisms play an important role in the spatial and temporal development of turbidite systems (e.g. Mutti & Normark 1991; Shanmugam & Moila 1991; Normark & Piper 1991; Reading & Richards 1994; Stow *et al.* 1996; Richards *et al.* 1998; Stow & Mayall 2000; Shanmugam 2000). Some controls including tectonics, climate and eustasy represent "causal" allocyclic factors (Einsele & Ricken 1991; Richards *et al.* 1998) while deposition is subject to modifying local environmental processes, for example, local differences in subsidence, supply and composition of sediments, various hydrographic regimes and autocyclic processes (fig. 2.43). The study of the different lobe depositional environments within the revised fan framework suggests a much more complex development of the E-Fan, Cingöz Formation, than previously anticipated (e.g. Gürbüz & Kelling 1992; Gürbüz 1993).

2.5.1 Basin physiography, basinfloor and depositional topography

During the deposition of the Cingöz turbidite system, the northern margin of the basin was formed by the actively uplifted Tauride orogenic belt, an adjacent narrow (~ 3 km), shallow marine carbonate shelf and a tectonically unstable, steep (~ 35°) foreslope, trending in a general W-E direction (Gürbüz 1993, Cronin *et al.* 2000).

The fans were fed by multiple, incised feeders, which were active at approximately the same time, funnelling sediment into the basin at different localities (Gürbüz 1993; Satur 1999). From west to east the basin deepened (Demircan & Toker 1998), allowing for vast sediment accumulation, particularly in the eastern fan area (Gürbüz 1993; this study), before distinct shallowing towards the extreme east took place (Ünlügenç 1993). Basin extension towards the south is documented by subsurface Cingöz deposits (Naz *et al.* 1991; Williams *et al.* 1995), however, the total southern extent is unknown. Initially, rapid deepening of the basin took place which was then passively infilled by the Cingöz turbidites (Gürbüz 1993; Williams *et al.* 1995).

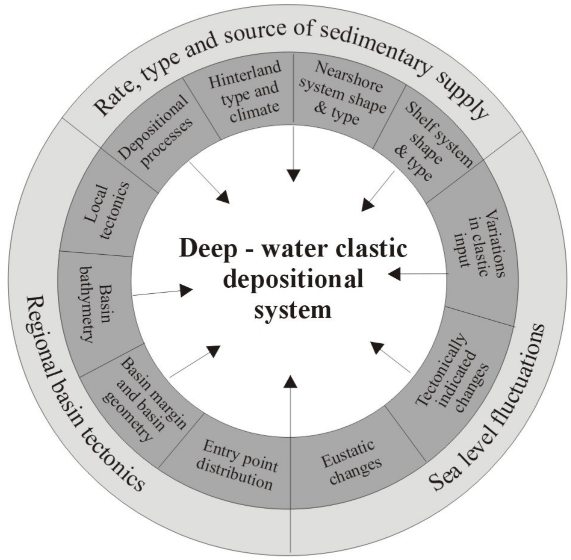

Figure 2.43: Schematic diagram illustrating the range of controls influencing deep-water sedimentation (Richards *et al.* 1998).

While the unique basin physiography is one aspect in controlling the development of the E-Fan, topography, either resulting from basin-floor or depositional topography, additionally influenced the sediment distribution pattern and the geometry of sandstone deposits (e.g. Kneller 1995; Sinclair 2000; Burgess *et al.* 2000). Topographic expression may range from cm to km-scale.

Previous studies suggest that major structural highs influence the overall development of the Cingöz Formation (Gürbüz & Kelling 1992; Gürbüz 1993), restricting fan growth in a western and south-eastern to eastern direction respectively (*chapter 2.1*). Satur (1999) and Satur *et al.* 2000) found the elongated W-E trend of the W-Fan to result from the presence of various submarine highs.

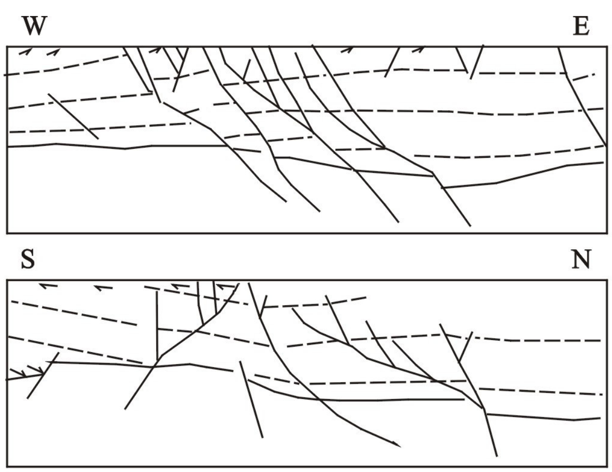

Figure 2.44: Line drawing interpretations of seismic lines flattened on base megasequence 3. Flattened sections show the control on thickness of megasequence 2 by NE-downthrowing extensional faults. No seismic-scale evidence of expansion or growth of sequences in hanging walls (from Williams *et al.* 1995).

The analysis of the sandy basin infill of the E-Fan indicates the presence of basinfloor relief during E-Fan deposition, strongly influencing the sediment accumulation pattern. In the early sandy stage of the E-Fan, Lobe B accumulation of the proximal lobe zone took probably place in an at least partially fault-bounded, intrabasinal depression, resulting in its aggradational, latero-vertical growth pattern akin to Schuppers (1995) confined lobe model of the Arakinthos Sandstone, Greece (*chapter 2.4.2.2*).

During the Orbulina suturalis biozone a 7.8-fold sediment increase over a distance of 6 km from the western to the central E-Fan area was observed. Palaeocurrents in the west and central area point to a general eastern direction, however, the contrasting lithologies, dominantly shales in the west and coarse sandstones in the central area strongly suggest that the deposits in the west record the distal stages of the W-Fan, while the central area was sourced by the E-Fan. Williams *et al.* (1995) seismic analysis shows that numerous

NE-downthrowing extensional faults cut the underlying strata and were active during the deposition of the Kaplankaya, Cingöz and the overlying Güvenç formations (fig. 2.44; note that seismic lines do not cover the actual study area). This synsedimentary extensional fault activity (Ünlügenç 1993) is believed to have led to basin compartmentalisation of relatively closely spaced basin sectors, resulting in a series of fault-controlled, stepped, interbasinal depressions, the lowest area underlying the central E-Fan area.

The resulting fault-scarp topography would have restricted the E-Fan's lateral development to the west while favouring enhanced sediment accumulation in the generated accommodation space in the central basin sector (fig. 2.45b). Differential subsidence driven and/or enhanced by bulk sediment weight may also have led to locally thicker sediment accumulation (Ricci Lucchi & Valmori 1980).

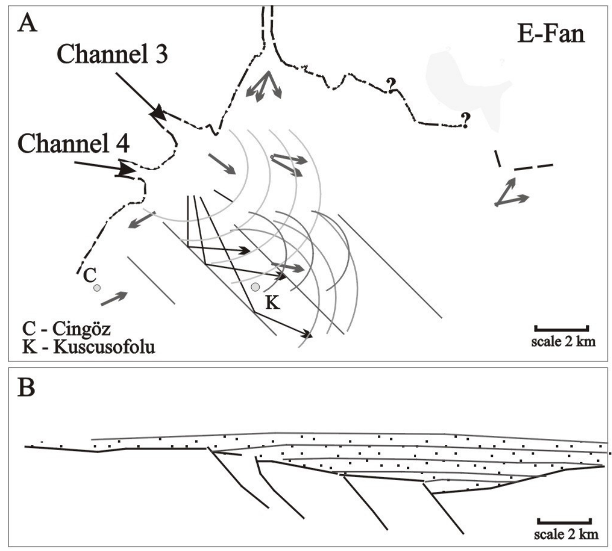

Figure 2.45: A) Schematic diagram illustrating how NE-downthrowing faults could result in eastern deflection of the E-Fan system. Dark grey arrows show measured palaeocurrent pattern in field.
B) Flattened W-E seismic line of Williams *et al.* (1995; fig. 2.45) showing suggested depositional thickening at faults, probably at subseismic scale. Shown seismic line lies approximately 30 km south of feeder channels 3 / 4.

Documented fault trends in the Cingöz Formation range from NW-SE to NWN-SES (45°/30°/15°) (Ünlügenç 1993; Satur 1999; this study), N-S (Satur 1999), E-W (Satur 1999; this study) to NE-SW (Unlügenç, 1993). High degrees of flow deflection have been recognised even on subtle confining topography (Hodgson *et al.* 2002). NW-SE to NWN-SES trending fault-scarps could result in > 90° flow deflection and account for the apparent south-eastern to eastern axial deflection recognised within the central and southern areas of the E-Fan (fig. 2.45a).

Complex, fault-scarp basinfloor topography resulting in basin compartmentalisation has been recognised in a number of deep-water systems (e.g. Claymore Sandstone/North Sea: Kane *et al.* 2002; Neuquen Basin/Jurassic turbidites: Burgess *et al.* 2000; Annot Sandstone/France: Kneller & McCaffrey 1999; Sinclair 2000) resulting in flow deflection subsequently controlling the sandstone distribution patterns (e.g. Marnoso-Arenacea/Italy: Ricci Lucchi 1981, 1985; Miocene Turbidite Systems/San Joaquin Basin:Nilsen *et al.* 2002a; Jaca-Fiscal lobe complex/Hecho Group: Millington 1995). Depositional thickening at faults and lateral restricted dispersal are common features of fault-controlled, restricted basins of tectonically active settings (e.g. Marnoso-Arenacea/Italy: Ricci Lucchi 1981; Gryphon Field/North Sea: Purvis *et al.* 2002; Stow & Johansson 2000). High seafloor topography generated by seamounts and ridges can result in dramatic lateral thickness variations of up to nearly 1000 m (e.g. Monterey and Delgarda Fans/offshore California: Wilde *et al.* 1985).

Depositional topography resulting from the build-up of sediments affects later sediment accumulation. In general, the relative size, shape and orientation of an obstacle determines the degree of interaction between the flow and the topographic feature (e.g. Normark & Piper 1991; Kneller 1995). Succeeding flows need to find a path around the obstacle, seeking even subtle depressions, resulting in enhanced sedimentation rates in the latter relative to the adjacent depositional fan areas (Pickering 1981). All three lobe depositional environments were affected by the depositional relief, partially compounded by the existing structural topography resulting in 10s of metres thick "lobe-to-lobe" compensation cycles (lateral offset stacking) of the Lobe A, B and C deposits (*chapter 2.4*) akin to "compensation cycles" of Normark *et al.* (1993), Chapin *et al.* (1996) and Bouma (2000). This process appears to be common in turbidite systems (examples: table 2.10), modifying the local stacking pattern of individual sandstone beds, bed sub-packets and lobes (Mutti *et al.* 1994).

Proximal deposits of the channel-lobe transition and proximal lobe zone are known to possess distinct, often irregular topographic expression (Normark *et al.* 1979; Mutti & Normark 1991). At m-scale, the irregular topography of particularly the proximal Lobe B deposits (*chapter 2.4.2.1*) has led to bed-to-bed compensation resulting in lenticular or wedging sandstone geometries by infilling small depressions, thus compensating the pre-depositional relief (examples: table 2.10). Even, the position of distributary channels may be determined by relief (Normark *et al.* 1979; *chapter 2.4.2.1*) where distributary channels may have inhibited marginal depressions along the lobe edges. Other, smaller-scale bed-to-bed compensation cycles were observed in the mouth bar facies associated with feeder channel 1 (*chapter 2.2.2.2: Section C: m 170 - 200*).

Topographic control	Result / Dimension	E-Fan	References
Fault scarps and/or local topographic highs	**basin compartmentalisation, locally enchanced deposition (km-scale); system/flow deflection**	**7,8-fold thickness increase over 6 km lateral distance (central E-Fan: *chapter 2.2.2.2*) apparent eastern deflection of E-Fan system**	**e.g. Monteres Fan & Delgarda Fan/offshore Calif. (Wilde *et al.* 1985), Marnoso-Areneacea (Ricci Lucchi 1981, 1985), Claymore Sandstone (Kane *et al.* 2002), Miocene Turbidite Systems/San Joaquin Basin (Nilsen *et al.* 2002a)**
Intrabasinal depression / restricted development	**restricted lateral development, vertical stacking, aggradation (100s m-scale)**	**proximal lobe zone (*chapter 2.4.2*)**	**e.g. Arakinthos Sandstone/Greece (Schuppers 1995), Marnoso-Areneacea (Ricci Lucchi 1981, 1985), Post-Contessa Subinterval/Italy (Ricci Lucchi & Valmori 1980)**
Fault scarp/local highs	**local obstacles (10s m-scale); forced lobe migration "lobe-to-lobe"**	**mouth of feeder channel 1 (north-central E-Fan: *chapter 2.2.2*); proximal and central fan area;**	**e.g. Nicolas Fan/offshore Calif. (Reynolds & Gorskine 1987), Kongsfjord Formation/Norway (Pickering 1981), Peary Land Group/Greenland (Surlyk 1987), Jaca-Fiscal Lobe Complex/Spain (Millington 1995), Pas-de-la-Cuse Lobe/France (Savary *et al.* 2002), Tanqua Karoo/RSA (Sixsmith *et al.* 2002)**
Depositional topgraphy: Debris flow, lobe topography	**compensation cycles; local flow deflection, onlap onto obstacle**	**Lobe B deposits**	
Fault scarp/local highs Depositional topgraphy: Debris flow, lobe and irregular top lobe topography	**relief compensation (m-scale & smaller) wedging, onlapping Onlapping/infilling of irregular top debris flow topography; bed-to-bed compensation**	**proximal lobe deposits (*chapter 2.4.2*), feeder 1 mouth bar facies (*chapter 2.2.2*) Proximaland distal lobe bodies; debris flow #5 (*chapter 2.4.2/3 & 2.2.2*)**	**e.g. Hecho Group/Spain (Mutti & Sonnino 1981, Millington 1995), Laga Formation (Mutti et al. 1987, 1994)**

Table 2.10: Different scales of topography controlling the sandstone distribution pattern, with examples from literature.

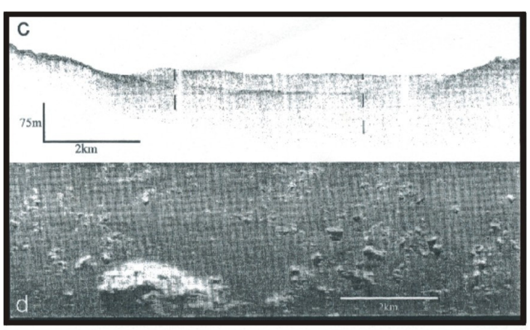

Figure 2.46: (c) 3.5 kHz-profile through a section of the Saharan Debris Flow. The debris flow deposit is the thick acoustically transparent layer lying within the topographic low. (D) TOBI image of a section of the Oratava-Icod-Tino debris avalanche complex north of Tenerife. Note the variation in size of avalanche blocks lying on the surface. Light shades indicate high backscatter, dark shades indicate low backscatter (from Wynn *et al.* 2000).

The thick debris-flow deposits encountered in the western and central E-Fan form 5-80 m thick localised depositional bulges, presenting obstacles to succeeding turbiditic and sandy debris flows *sensu* Shanmugam (1996). Flow interaction through multiple current directions, cannibalisation and incorporation of debris-flow material into succeeding flows may take place (e.g. Kneller 1995).

The wedge-shaped debris-flow deposit just overlying the conglomeratic feeder channel 1 fill is onlapped by sandy mouthbar and associated deposits (*chapter 2.2.2.2*: *Section C: m 130 - 170*). Its emplacement may have temporarily interrupted and/or deflected the flow of channel 1. Reynolds & Gorskine (1987) demonstrate that temporary blockage of one of the main feeder channels of the modern Niclas Fan by debris-flow deposits resulted in a change in flow direction. At the top of the debris flow #5 (Section C: 1900 - 1980 m), overlying thinly-bedded, medium-grained turbidites onlap and infill its depositional topography (table 2.10). Mass flow deposits forming distinct topographic features with great extent (up to 2.5 km width

/ 20 km length) and irregular top relief (10s of metres) are known from other modern fan environments, for example, the Madgalena Turbidite System, Caribbean Sea (Ericella *et al.* 2002) and the Saharan Debris Flow and Oratava-Icod-Tino debris avalanche off Tenerife (fig. 2.46; Wynn *et al.* 2000).
The sand-rich proximal and central E-Fan area possess very little, mostly localised shale deposits. A downcurrent increase in shale content, thickness and areal distribution was recorded. Compaction of these shales through overlying sediment weight will have left localised depressions or irregularities leading to bed-to-bed compensation at meso- to mega-scale (e.g. Laga Formation/Italy: Mutti *et al.* 1978, 1994) or may even modify topography to a great extent influencing the location of later sand bodies (e.g. Frigg Field/North Sea: Heritier *et al.* 1979) or result in oversteepended mould-like geometries (Stow & Johansson 2000). However, potential effects of differential compaction were not observed in the E-Fan at outcrop-scale.
The effects of basinfloor and depositional topography on the reservoir geometry and quality are discussed in chapter 4.

2.5.2 Tectonics

Deep-water clastic systems located on active margins are greatly influenced by tectonics. Tectonic activity of the hinterland controls the number and location of sediment sources, the sediment supply and pathways, the shelf width as well as the duration of fan activity (e.g. Shanmugam & Moiola 1988; Posamentier *et al.* 1991; Trincardi *et al.* 1995; Bouma 2000). Tectonism also controls the size, shape and topography of the host basin (e.g. Mutti & Normark 1987) which has the most profound effect on increasing or decreasing accommodation space (Vail *et al.* 1991). Basinfloor topography can substantially modify sediment dispersal patterns and produce a variable degree of synsedimentary deformation (e.g. Ricci Lucchi 1975a; Trincardi *et al.* 1995; Burgess *et al.* 2000; *see chapter 2.5.1*). When coupled with climate, tectonism controls the type and amount of sediment filling the available accommodation space (Vail *et al.* 1991).
The northern Adana Basin is located in a tectonically active setting. Gürbüz & Kelling (1993) suggested the Adana Basin to fit a Type C turbidite basin (*sensu* Mutti & Normark 1987) representing a structurally controlled, elongate foreland basin underlain by continental crust with a large and long-lived sediment source comparable to, for example, the Pyreneen Basin (Hecho Group: Mutti 1985b, Mutti *et al.* 1985) or the northern Appenine foredeep (Miocene Italian Fans: Ricci Lucchi 1975a; 1981, 1985). However, the Adana Basin exhibits characteristics similar to a Type D basin (Satur 1999) where ongoing tectonic activity resulted in rapid changes in basin shape, short lived sediment sources and the development of a volumetrically much smaller, coarse-grained and short-lived fan. Ünlügenç (1993) and Williams *et al.* (1995) studied the pre- to post tectonism with respect to the Cingöz Formation identifing various structural highs limiting lateral evolution at formation-scale (*see* Gürbüz 1993) and significantly affecting the sediment distribution pattern and geometry of sand-bodies at meso to mega-scale (Satur 1999; Satur *et al.* 2000; *chapter 2.3-2.4*). The existing fault pattern most likely determined the sediment pathways.
In the E-Fan depositional area, the pre- and synsedimentary, extensional fault activity led to basin compartmentalisation resulting in laterally restricted fan development, partially enhanced sediment accumulation in intrabasinal depressions and axial, margin-parallel eastern deflection of the system (*chapter 2.5.1*).
Satur (1999) recognised a shift in the time and activity of the three, structurally controlled main feeder systems (channels 1, 3 and 4). These feeders represent fixed pathways with channel migration only possible within their respective confinements. An apparent westward shift in sediment supply to the basin is documented by the later initiation of feeder channels 3 and 4, while the activity of main feeder channel 1 appears to diminish dramatically (*chapter 2.4.2*). This migration of provenance areas and timing of active feeders has been recognised to result from tectonic activity in the source area (e.g. Paola Basin/Tyrrhenian Sea: Trincardi *et al.* 1995) such as episodic uplift associated with fault systems (Middle Tertiary submarine fan system/San Joaquin Basin: Nilsen *et al.* 2002b) which may control the volume of supplied sediment (e.g. Campos Basin: Bruhn & Walker 1995). Generally, tectonic uplift of the source area is held responsible for an increased sediment supply to a basin (e.g. Vail *et al.* 1991; Stow & Johansson 2000).
Tectonic control on the sandy-basin fill signature in the E-Fan is evident. During Burdigalian and Langhian times, thick debrites were deposited along the western margin and central E-Fan area. Their absence in the east may either be due to a more stable eastern margin or preferential erosion of Kaplankaya-rich debrites by Quaternary conglomerates (*chapter 2.4.3*). Cronin *et al.* (2000) found evidence of considerable tectonic

activity along the eastern margin during pre-Langhian times, however, no pre-Langhian Cingöz sediments are present, either due to non-deposition or burial. Some debrites contain lithified Cingöz channel-fill sediments (e.g. debris flow # 5), suggesting uplift of the basin margin area leading to exposure (?) and subsequent resedimentation of lithified Cingöz sediments. This scenario would involve debris flows being funnelled down the canyons and uplift and erosion of the later potential sandy channel-fill sediments, rather than being generated by mere slope collapse.

A progressive fining in grain size is conspicuous from sand body- to formation-scale. Other trends are rare and likely to be produced by lobe migration and/or progradation. The repeated onset of the distinctly coarse-grained basal Lobe B deposits indicates an episodic supply of coarse sediment to the basin believed to be brought on by uplift in the source area exposing rocks to erosion and/or reworking and the subsequent denudation of this area (*chapter 2.4.2*).

If uplift also resulted in tectonic tilting of the basin is speculative. Potential tilting should have left subtle discordances behind (at seismic or sub-seismic-scale) more pronounced in the proximal, smoothed out in the distal reaches. It might have encouraged the apparent easterly deflection of the E-Fan, however, thick sediment accumulation in the central fan area during the Orbulina suturalis zone as opposed to much lesser thickness in the east, underlines rather a fault-controlled deflection as suggested above (*chapter 2.5.2*). Abundant faulting along the margin is conspicuous (Ünlügenç 1993) and uplift may have effected only the basin margin and hinterland while differential subsidence either tectonically and/or sediment weight-induced acted in the basin (*chapter 2.4.2 / 2.5.1*). That basinfloor gradient can noticeably influence the overall fan geometry is shown by the canyon-mouth lobes off the Corsican and Sardinean shelf, which deviate to the south, following the overall gradient that extends towards the Blearri Abyssal Plain in the south (Kenyon *et al.* 2002). Tectonic uplift has even been shown to be responsible of preventing a fan-like morphology (e.g. Eel Fan: Reynolds & Gorsline 1987).

In combination with other controls, uplift of the source area and the increased sediment supply has been linked to the initiation of submarine fan systems, for example, the Cingöz Formation (Satur 1999) and the Indus Fan (Clift *et al.* 2001).

The effects of post-depositional tectonism on the reservoir geometry and quality are discussed in chapter 4: reservoir characterisation.

2.5.3 Sediment supply and climate

The E-Fan was initiated during late Burdigalian (Nazik & Gürbüz 1992), when significant tectonic activity led to uplift of the Taurus Mountains (Ünlügenç 1993; Williams *et al.* 1995), resulting in an increased sediment flux driving canyon initiation (Gürbüz & Kelling 1993; Gürbüz 1993; Satur 1999). Satur (1999) found the submarine feeder channels to be directly fed from fan deltas and alluvial fans. During its approximately 2.7 million years of activity (Nazik & Gürbüz 1992; Gürbüz 1993), about 3700 m (this study) of E-Fan sediment were accumulated, averaging sediment accumulation rates of 134 cm / 1000 yrs for the sandy basin fill.

The rate of terrigenous sediment input to the deep sea is controlled by mechanisms including sea level, climate and tectonic activity (e.g. Reading & Richards 1994; Bouma 2001; Stow & Mayall 2000). Sedimentation rates between 100 - 1000 m / myr are common in modern submarine fans, higher values may occur nearer the sediment source and in over-supplied basins (e.g. Einsele 1991). Weber *et al.* (1997) found extremly high sedimentation rates in the head of the Bengal Fan canyon with 1 m / yr. Very active ancient systems include the Merquijoq Formation/Greenland (Surlyk 1995) with depositional rates of 60 cm / 1000 yrs and the Fiscal lobes with 1 bed / 500 years (Millington 1995; though no average bed thickness provided). The extremely high sedimentation rates of the E-Fan indicate the availability of large volumes of sediment, with probably higher average sedimentation rates in the proximal than the distal depositional areas. The effect of locally enhanced sedimentation due to restricted sediment dispersal, e.g. in the proximal lobe zone and central fan area, compounds this effect. During the Langhian, sedimentation rates varied from ~ 16 cm / 1000 year in the western to ~ 130 cm / 1000 years in the central area.

The E-Fan is sourced from the Tauride orogen (e.g. Bolkar Mountain area, Inner Taurus belt) representing a tectonically modified combination of arc and recycled orogen provenances and its Palaeozoic and Mesozoic platform carbonate cover with minor contributions of the contemporaneous shelf carbonates (Gürbüz & Kelling 1993). The scattered coalified clasts and wooden fragments found in the channel-lobe transition and distal lobe deposits underline a terrigeneous source area.

The size of the drainage basin as a proxy for sediment input appears to be the most important factor in governing the sediment distribution and the overall architecture of the margin (Kenyon *et al.* 2002), while the amount of available sediment controls the size of a river-fed deep-sea fan (Wetzel 1993). Fan length and depositional rate, i.e. fan volume/age, appear to be highly correlative (0.2 - 0.5 in downcurrent direction) for both river- and shelf-fed fans, regardless of tectonic setting, type of sediment source, time span and epoch of formation (Wetzel 1993).

Small to medium-sized mountainous rivers of tectonic, active settings have shown to play a major role in triggering submarine gravity flows and therefore in turbidite sedimentation (Mutti *et al.* 1996). The connection of the subaerial river system to the submarine feeder systems suggests (semi-) permanent flow discharge. Modern rivers in flood are known to form hyperpycnal flows which may directly transform into submarine turbidites (Mutti 1996; Bouma 2001). Heezen & Hollister (1971) found submarine cable breaks off rivers, for example the Madgalena, Congo and the fan deltas of the Gulf of Corinth, to correlate with times of peak fluvial discharge suggesting that turbidity currents occur at these times. However, the relationship between submarine fan sedimentation and type, volume and density of fluvial flow has been little studied so far (Bouma 2001). Other potential sediment sources for the E-Fan may include river mouth and the subaqueous delta front deposits, the litoral-drift system, sand remobilisation at the canyon heads induced by rip currents during exceptionally strong storms (e.g. Normark & Piper 1991), resuspension of marine sediment at the top of the continental slope and slope failure. The sedimentary discharge of the rivers and other sources would be captured by the three canyons. The gravity flows running through these canyons, together with the slumps and gullies formed on their walls developing into mass flows and/or turbiditiy flows, deposited their load in the compartmentalised basin. The complex palaeocurrent pattern results from the different feeders and the complex basinfloor topography (easterly flow deflection). Only the largest flows reach the distal fan depositional environment (Normark & Piper 1991), the available grain size range dictating the transport distance (Bouma 2000).

Two distinct sediment types are differentiated: i) the river/fan delta-fed sand-rich sediments forming the lobes and associated fan deposits, conveyed to the deep-sea via the incised canyons and ii) the debris-flow deposits scattered throughout the fan succession mostly resulting from shelf/slope collapse, feeding into the basin from the basin margin.

It appears that uplift of the source and basin margin area freed large volumes of dominantly coarse sediment. Varying sediment supply as, for example, recorded in the sequences of the proximal lobe zone (Lobe B) suggests periodic tectonism, i.e. uplift, bringing on coarser sedimentation, compounded by the presence of repeated mass wasting events throughout the Burdigalian and Langhian. Shanmugam *et al.* (1985) caution that uplift does not necessarily provide the sand- to clay-sized material needed for submarine fan growth since unconsolidated material is not readily available through initial uplift. They suggest that the break-down of coarse debris into finer size by fluvial and shallow-marine processes is required before transport to the deep-water fan by turbidity currents. If a humid climate is present, it favours the rapid break-down of uplifted landmasses whilst water serves as the required transport agent (Shanmugam *et al.* 1985; Ericella *et al.* 1998; Bouma 2000). The Agadir system off the coast of Morocco, for example, experiences progressively diminished sediment input related to increasing aridity and denudation of the hinterland compounded by subsiding continental tectonics thus promoting a landward migration of turbidite sedimentation (Ericella *et al.* 1998). Increasing aridity was also responsible for a decrease in turbidite sedimentation in parts of the Arabian Sea (Indus Fan: Prins & Postma. 2000). Wetzel (1993), however, suggests that uplift and average elevation of the drainage basin to be of greater importance than climate, i.e. mean annual precipitation (Pinet & Souriau 1988). No climatic information for the Adana Basin is available. Waters were described to be warm initially (Toker *et al.* 1998), their gradual cooling related to water influx from the south due to opening up of the Cyprus basin rather than a change in environmental conditions. General subtropical conditions affecting basin sedimentation are suggested.

Initially, the E-Fan appears to be a gravelly system (Satur 1999) with thick conglomeratic sequences present in the distal regions of the basin (Naz *et al.* 1991) before switching to a sand-dominated system during the later (?) Burdigalian (Gürbüz 1993; this study). Satur's (1999) study indicates that the exposed feeder system is older than the exposed sandy basin fill, its coeval deposits presenting an earlier stage of the fan development. The few published borehole and seismic data (Naz *et al.* 1991; Williams *et al.* 1995) infer lobe-shaped bodies in subcrop, but abundant faulting prohibits their direct association with the exposed feeder system. The gravelly phase of the E-Fan might be related to the initial uplift producing very coarse sediments before weathering, erosion, fluvial and shallow marine processes led to a gradual break-down in sediment size initiating the sandy basin-fill phase. The younger feeder channel 4 appears to reach the sandy

stage slightly later than the other feeder channels (Satur 1999), suggesting that its source area may have been uplifted and exposed to erosion later than the source areas of channels 1 / 2 and 3. The shifting source of sediment supply to the basin is directly related to tectonic activity, i.e. uplift in the hinterland and basin margin area (*see above*). This westward shift may correlate with the proposed later initiation of the W-Fan (Satur 1999) and its progradation during late Burdigalian times. However, during Langhian times, the W-Fan retreated (i.e. deposition shifted to its proximal reaches, Satur 1999; *chapter 2.2.2 / 2.5.1*) while sandy deposition was still taking place in central parts of the E-Fan area.
The gradual upward decrease in grain size from gravelly to coarse sand and progressively finer sand size may be related to reduction in grain size in the feeder system and/or denudation of the hinterland and/or subsiding tectonic activity which could have led to a decrease in sediment flux towards the continental shelf or an increase in distance from the input point, perhaps related to rising sea level. Conspicuous fining-upward trends are apparent at different hierarchies of scale indicating higher frequency changes of the above mechanisms (*chapter 2.4*; e.g. Campos Basin, Bruhn & Walker 1995). The grain size of the resultant lobe deposits depends on the size of the subaerial drainage basin acting as the sediment source, the gradient of the drainage basin and continental slope, shelf width and the distance between the source area and the depocentre of the lobe (Kenyon *et al.* 2002). Generally, the overall net sand content and grain size decrease in a downcurrent direction, however, coarse sand deposition took place in thick lobe deposits even in relatively distal reaches of the system (distal lobe zone: this study; well Gülbaş 2: Naz *et al.* 1991) suggesting high flow volume and competence. The unique signatures of the Lobe B deposits (proximal lobe zone) demonstrate the strong influence of source control on lobe accumulation. That the source and textural composition can even control sand body geometries is demonstrated by Normark *et al.* (1998) for the Hueneme and St. Monica Fans.

2.5.4 Sea-level changes

Eustasy is regarded as one of the major controlling mechanisms for fan development. The central assumption of sequence stratigraphic* models is that sedimentation within deep-water systems increases during relative sea-level lowstand (fig. 2.47), while during transgression and sea-level highstand sedimentation diminishes or temporarily halts (e.g. Shanmugam *et al.* 1985; Posamentier & Vail 1988; Posamentier *et al.* 1991; Van Wagoner *et al.* 1990; Vail *et al.* 1991). However, an increasing number of submarine fans which developed during sea-level rise and highstand have been identified such as the Amazon Fan (Flood *et al.* 1991), Navy Fan (Piper & Normark 1983), Mississippi Fan (Kolla & Perlmutter 1993), Bengal Fan (Kuehl *et al.* 1989; Weber *et al.* 1997), Agadir turbidite system (Ericella *et al.* 1998) Campos Basin (Bruhn & Walker 1995), Makran (Prins *et al.* 2000), Porcupine Fans (Kolla & Macudra 1988), Congo and Magdelana fans (Heezen *et al.* 1964), Crati Fan (Ricci Lucchi *et al.* 19884, 1985). Balder Formation/Gryphon Field (Dixon & Pearce 1995; Purvis *et al.* 2002) Frigg Submarine Fan (Helland *et al.* 2002). Deposition during rising sea level appears to be favoured by narrow shelves, incised submarine canyons, shelf-parallel currents and tectonic activity of the basin margin and hinterland, the latter may provide high volumes of sediment (e.g. Reading & Richards 1994; Stow & Mayall 2000; Shanmugam 2000). When submarine canyons are connected with a shelf-edge delta (e.g. Amazon and Mississippi rivers) or directly connect with the river mouth (e.g. Indus and Zaire rivers), sediment may be transported straight into the basin (e.g. Burgess & Hovius 1998). These estuaries with deeply incised canyons may transfer as much as 6 - 8 times more sediment to the deep-sea than other types of river mouth (Wetzel 1993). Shelf-parallel currents may also feed sediment into incised canyons. These factors may result in continued or even increased sediment supply to the basin in spite of rising sea levels (e.g. Reading & Richards 1994; Burgess & Hovius 1998; Eschard 2001).

---

* „***Sequence stratigraphy*** is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities. The fundamental unit of sequence stratigraphy is the sequence, which is bounded by unconformities and their correlative conformities. A sequence can be subdivided into ***system tracts***, which are defined by their position within the sequence and by the stacking pattern of parasequence sets and parasequences, bounded by marine-flooding surfaces. Boundaries of sequences, parasequence sets, and parasequences provide a chronostratigraphic framework for correlating and mapping sedimentary rocks." (Van Wagoner *et al.* 1987). It provides a useful framework for understanding the interplay between accommodation space, subsidence and/or uplift and rate of sea-level change in many sedimentary environments." (Kolla 1993)

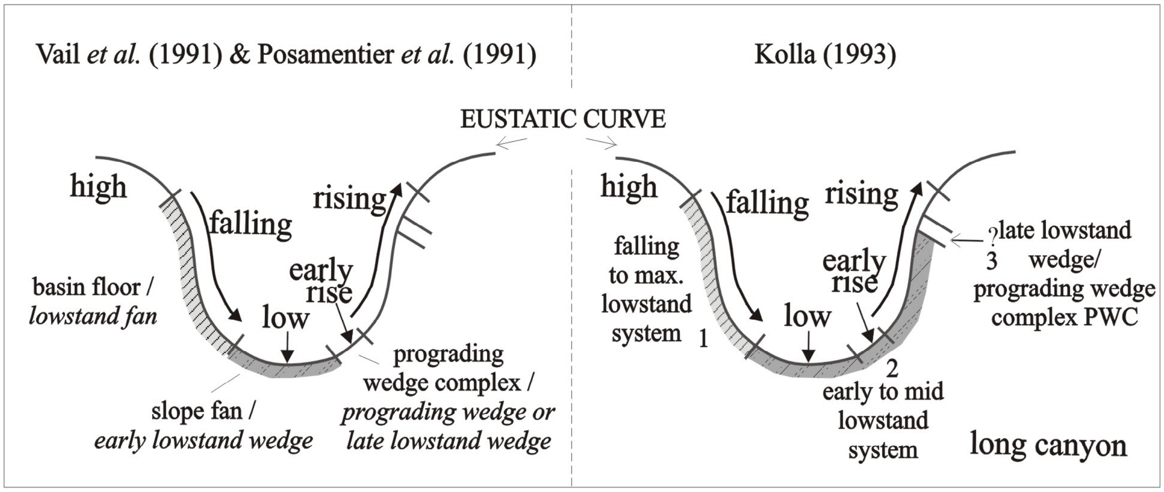

Figure 2.47: Terminologies of deep water system of Vail *et al.* (1991) and Posamentier *et al.* (1991) (*italics*) in comparison to Kolla's (1993) terminology for long canyons. (1 corresponds to basal- to lower, slope to basin system, 2: lowstand - early sea level rise - early Transgressive System Tract (TST), 3: early sea level rise - early TST.)

Previous studies proposed the initiation of the Cingöz fans to result from a fall in relative sea level, suggesting it to be an example of a typical lowstand fan system (Naz *et al.* 1991; Gürbüz 1993). However, more recently it has been proposed that the Cingöz fans present an example of fan systems developed during a transgressive phase (Yetiş *et al.* 1995; Kostrewa *et al.* 1997; Satur *et al.* 1997; Satur 1999). Their initiation is associated with rapid sediment supply into the basin as a consequence of tectonic activity within the source area (Satur 1999), probably related to a previous time of sea-level lowstand.

Sedimentary sequences suggesting rising sea level and/or sea-level fluctuations have been identified at various scales and in different environments within the E-Fan. Satur (1999) found distinct deepening resulting from sea-level rise recorded by initial shallow water sandstones and conglomerates to deeper-water turbidite sandstones within channels 3 / 4 respectively.

The analysis of the sandy basin-fill reveals higher frequency, 4th- and possibly 5th-order relative sea-level fluctuations[*] influencing sedimentary signatures:

i. conspicuous fining upward at lobe scale (m to 10s of m) observed in many individual Lobe A, Lobe B and Lobe C deposits
ii. overall fining upward at lobe-complex scale observed in the transition, proximal and distal lobe zone
iii. gradual upward reduction in overall clast size within the channeling components of the CLTZ
iv. the various channel-lobe transition deposits backfilling (or backstepping *sensu* Mutti & Normark 1987) their respective feeder channels
v. progradation as recorded by the channeling and distributary channel component in the CLTZ and PLZ respectively and the episodic coarse onset of Lobe B deposition in the PLZ

Points i) to iv) record gradually rising sea level, while v) suggests that occasional phases of progradation are perhaps related to a temporary fall in local sea level. Source control, such as overall denudation, may additionally be governing the gradual reduction in grain size (*chapter 2.5.3*) and result in fining-upward sequences (e.g. Campos Basin/Offshore Brazil: Bruhn & Walker 1995). Relative sea-level changes may occur over short time frames (< 100 kyr) in response to both eustasy and tectonism (Normark *et al.* 1993; Posamentier *et al.* 1988) or even be related to the storage and release of continental water generating smaller

*

Eustatic cycles order *	1st	2nd	3rd	4th	5th
Cycle (my) *	200 - 500	10 - 90	1 - 10	0.2 - 0.5	0.01 - 0.2

* Vail *et al.* (1977, 1991); Haq *et al.* (1987a,b)

changes (amplitudes:1 – 10 m; Einsele & Ricken 1991). These higher-order fluctuations influence the distribution of sandstones, i.e. through progradation and retrogradation, and the internal architecture of components of the deep-water clastic system, i.e. fining-upward at various scales, confined geometries of Lobe A deposits resulting from backfilling of the older parts of the feeder system.
The overall retrogradational pattern of the E-Fan and its subsequent blanketing by thick basin plain deposits (e.g. Naz *et al.* 1991; Gürbüz 1993; Yetiş *et al.* 1995) indicates a landward shift of sedimentation in response to the gradually rising sea level. Coarse sediment is probably increasingly trapped on the shelf and coastal areas (e.g. Bouma 2000). The Cingöz fans were active for approximately 2.7 myr (Nazik & Gürbüz 1992), however, different authors give different timing of events (*see chapter 2.7.1*). Gürbüz (1993) suggests the E-Fan to fit a type I fan model *sensu* Mutti (1985a), while Satur (1999) believes that the E-Fan initially developed as a type I, then type II and finally a type III system (table 2.11). He relates this to the context of the sedimentary fill of the Adana Basin representing a full 2nd order eustatic sea-level cycle *sensu* Vail *et al.* (1977) and Haq *et al.* (1987a,b). However, there is no concrete field evidence proving the fan's Type I and Type III stages (*detailed discussion: chapter 2.7.3*).

Sequence Stratigraphic. Model	**System Tract**	**Sea level**	**E-Fan**	**Fan types# Examples in Literature**
Lowstand fan (basinfloor fan*/ Type I#)	LST (= lowstand system tract; most basal stratigraphic unit of LST)	Relative sea-level fall and lowstand	Gravelly growth stage: canyon incision & sediment bypass; sediment transport farthest into the basin, Development of gravel lobes? Or extreme southern downcurrent deposition of thick, sandy lobe successions?	e.g. Chugach Turbidite System/Alaska (Nilsen 1985); Oligocene-early Messinian sand-rich turbidites/Italian Appenines (Cornamusini & Sandrelli 2002);
Early lowstand wedge (slope fan* / Type II#)	late LST to early TST (= transgressive system tract)	Rising sea level	Sandy growth stage: backfilling of feeder channels (inner valley fill), channel-attached lobes	e.g. Rocchetta Formation/ Italian Appenines (Cazzola *et al.* 1981); Macigno costiero (Cornamusini & Sandrelli 2002); Blanka Turbidite System/California (McLean & Howell 1985)
Late lowstand wedge (prograding wedge complex* / Type III#)	TST	Relative sea level approached maximum rate or rise	Muddy growth stage?: Channel-levee complex, small sandy lobe deposition ?	e.g. Delgada Fan (Wilde *et al.* 1985)

Table 2.11: Sequence stratigraphic model for different growth stages of E-Fan after Kolla (1993). Other terminology: * Vail *et al.* 1977, 1991, Posamentier & Erskine (1991) and # Mutti & Normark (1987).

2.5.5 Water depth, contourites and other controls

The study of mainly modern systems has shown that a variety of other controls may affect the sediment accumulation patterns in deep-water turbidite systems.

Water depth: Previous studies of the Cingöz Fan system suggest that fan accumulation in the western part took place under relatively shallow water conditions in the sublitoral zone between 0 - 200 m water depth (Satur 1999). The mixed and Nerities ichnofacies assemblage found in the E-Fan indicate an oligotrophic, less oxygenated and a probably more restricted, relatively deeper water environment (Demircan & Toker 1998). Nereites assemblages are characteristic of the abyssal zone, below 500 - >2000 m water depth (Seilacher 1967; Frey & Pemberton 1984), where they serve as a proxy for the redox boundary depth (Wetzel 2002). Satur (1999) and this study demonstrate that water conditions appear to deepen during the deposition of the E-Fan, however, absolute values cannot be determined. The confining shallow marine Karaisali carbonate platform formed before and just until after the initiation of the Cingöz Formation (Gürbüz 1993), however, it may probably have been drowned and/or burried by the subsequent landward shift of the turbidite system due to rising sea level. Local upward shoaling indicated by the presence of Ophiomorpha (*pers. comm.* Kelling 1998) has been observed in the upper Cingöz in the extreme SE area of the W-Fan western section.

Contourite system: Various modern and subsurface examples exist where submarine fan deposits show reworking by contourite and bottom currents, e.g. Tertiary Sands Frigg Field/North Sea (Enjolras *et al.* 1986), Eocene sands Campos Basin/offshore Brazil (Mutti *et al.* 1980), Ewing Bank Block 826/Gulf of Mexico (Shanmugam *et al.* 1993), Gulf of Cadiz (Gonthier *et al.* 1984; Nelson *et al.* 1993) or primary bottom current deposition (Gulf of Cadiz: Habgood *et al.* 2002). Sandy contourites are generally fine grained, exhibiting typical bedload bedforms such as ripples, sediment waves, planar bedding and ribbons (Mutti & Normark 1987; Shanmugam *et al.* 1993). Resulting vertical sequences are not unlike the Bouma Sequence (Shanmugam 2000). However, intense bioturbation may destroy primary current structures (Mutti & Normark 1987; Nelson *et al.* 1993; Stow & Johansson 2000). These sandy contourites are restricted to particular morphologic and hydrodynamic settings which allow the enhancement of current velocity and for which an adequate sand supply is available (Stow & Johansson 2000). Most preserved ancient turbidite systems formed in collisional and post-collisional basins, which did not allow any significant development of contourite currents (Mutti & Normark 1987; Normark *et al.* 1993). In the E-Fan of the Cingöz Formation, reworking by contourite, bottom currents or even tidal currents was not observed.

Other controls: Submarine fan development in general may additionally be controlled by the overall annual river discharge, sediment concentration, river temperature, seawater salinity and temperature, organic supply, gas production or diapiric movements (e.g. Reading & Richards 1994; Kenyon *et al.* 2002). Seawater salinity and temperature play a crucial role in transforming suspension plumes into hyperpycnal flows by fostering particle flocculation (e.g. Normark & Piper, 1991)

2.6 Evolution of the E-Fan

A review of the E-Fan framework (this study) and detailed analysis of selected areas such as the gravelly feeder system (Satur 1999) and sandy basin-fill (this study), indicate a complex interaction of auto- and allocyclic mechanisms controlling the development history of the E-Fan system. Records of the earliest and latest evolutionary stages are poor, the sand-rich stage is only preserved in parts. The detailed lobe study areas represent unconnected time slices within the system.

Gravelly stage

Stage 1: (late? Burdigalian)

Nazik & Gürbüz (1992) suggest that the E-Fan became active during late Burdigalian. Gürbüz (1993) concluded that the initiation of the Cingöz system was driven by a drop in sea level, however, Satur (1999) believes fan initiation to be related to high sediment availability driven by tectonism in the source area and aided by the direct connection with the subaerial river system and the narrow shelf favouring sediment transport to the basin.
Satur's (1999) study of the feeder system indicates that during its earliest stage the E-Fan developed as a multiple-sourced, gravel-rich fan (fig. 2.48a). The corresponding lobe deposits are not exposed and their size, shape and grain-size therefore unknown. Gravelly channel-fill to sandy fan lobe deposits approximately 40 km to the south of the exposed feeder system suggest great downcurrent extend (Naz *et al.* 1991). Seismic evidence points to convex-upward shaped structures akin to lobe geometries in subcrop (Williams *et al.* 1995). Extensive faulting, however, prohibits any direct correlation with the exposed feeder system (Ünlügenç 1993). The exposed confluence in the NW of the E-Fan indicates that channels 1, 2 and 3 were active at the same time (Satur 1999), at least towards the top of this stage.
The marked gravelly appearance of this first stage may be related to the initial uplift of the Tauride Orogen, when coarse sediment was freed. Naz *et al.* (1991) described the Cingöz gravels in well Gülbaş 2 as "inner-fan valley-fill". Feeder channels 1 and 2 and possibly 3 may initially have formed one large, extensive feeder, which funnelled coarse sediment much farther into the basin. If sand was abundantly available at this stage is unknown, a gravelly fan system similar to Reading & Richards (1994) may have developed forming

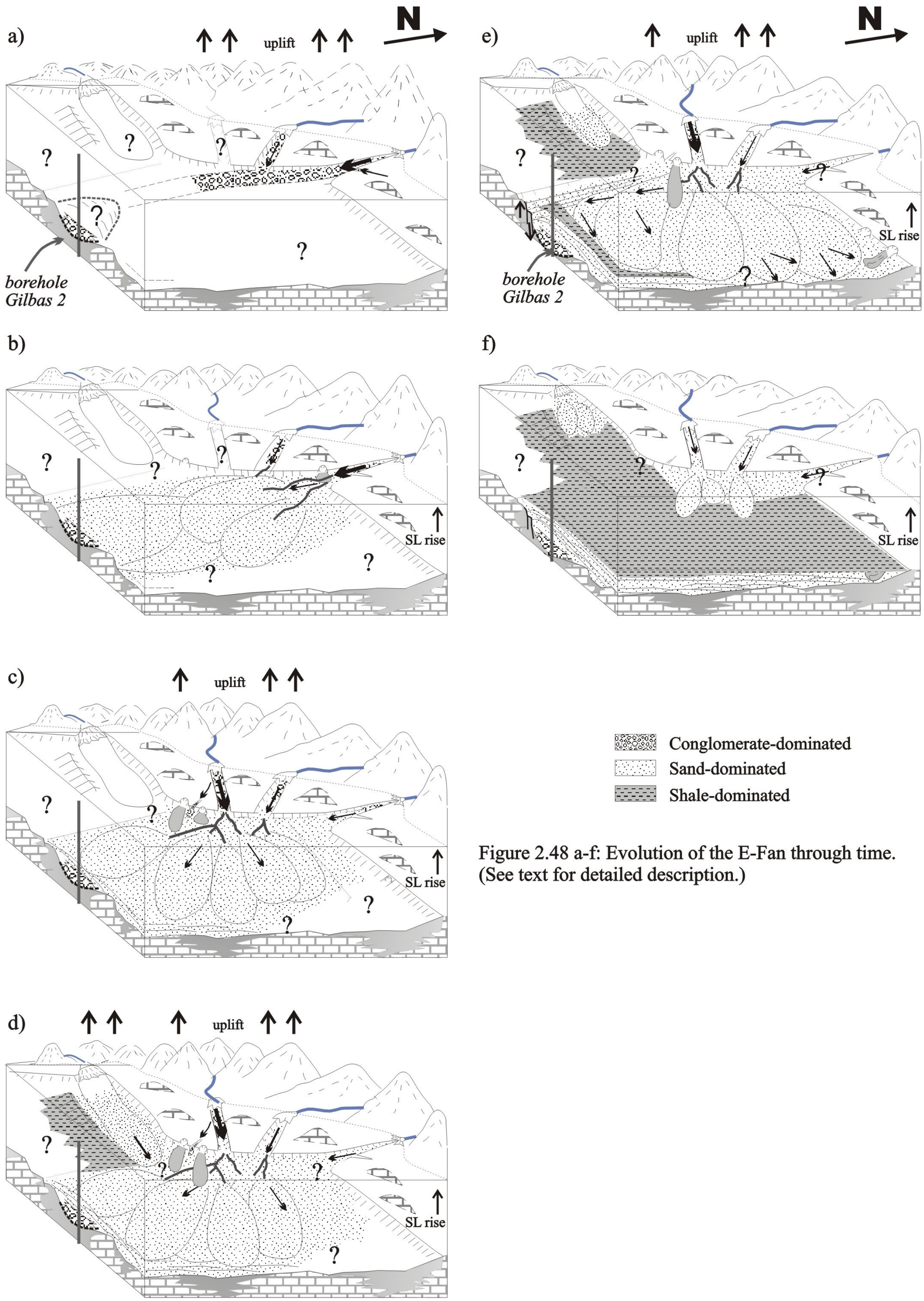

Figure 2.48 a-f: Evolution of the E-Fan through time. (See text for detailed description.)

gravelly lobe at the channel mouth akin to the Var fan lobe (Unterseh 1999) or the Porto lobe (Kenyon *et al.* 2002) at its mouth is possible (fig. 2.48a). The observed conglomeratic channel fill in the feeder system presents the latest stage of the gravelly system indicating backfilling of the conduit due to gradually rising sea level (Satur 1999).

Sandy stage

Stage 2: (late? Burdigalian)

The transition to the sand-rich phase is marked by the onset of coarse sandy deposition in thick channel-lobe transition (CLTZ) and lobe deposits with an extremely low shale content. They gradually backfill or backstep (*sensu* Mutti & Normark 1987) the conglomeratic feeder channel 1 deposits in the north and channel 3 / 4 deposits in the northwestern area respectively (fig. 2.48b). The palaeocurrent pattern indicates a switch from a mainly northern source (feeder channel 1 / CLTZ 1) to a mainly northwestern to western source (CLTZ 3 / 4). The younger proximal lobe zone was probably sourced from channels 3 and 4. The input from each channel is unknown. Flow mixing at their confluence is likely to have occurred and the subsequent depositional signature within the proximal lobe zone appears to be homogeneous (i.e. no differentiation between the potential sources). Prior to identification of feeder channels 3 and 4, this shift in transport direction was interpreted to result from flow deflection at a submarine high, deflecting sediments funnelled into the basin via feeder channel 1 (Gürbüz 1993; *pers. comm.* Kelling & Gürbüz 1996). No coeval sediments are exposed and/or preserved to the east of the proximal lobe zone and neither was sediment input from the north (channel 1) recorded. However, marginal fan sedimentation took place along the western flank of the E-Fan.

The latero-vertical growth pattern observed in the CLTZ 1 and younger proximal lobe zone (Lobes B) suggests sediment accumulation in a (semi-) confined space. The channel mouth and overlying channel-lobe transition zone associated with feeder channel 1 are partially deposited within the confines of the channel while the proximal lobes appear to have accumulated in an intrabasinal, probably fault-bounded depression. The latter strongly suggests synsedimentary tectonism to affect the accommodation space within the basin. Pre-depositional (fault-scarp) topography and differential subsidence in adjacent basin sectors control the sediment distribution pattern resulting in locally enhanced sediment accumulation (proximal lobe zone), restricted lateral dispersal and preferred (directional) funnelling of sediment further into the basin. Occassional progradation as suggested by the presence of distributary channels was also responsible for sediment transporting further into the basin.

Synsedimentary tectonism also affected the basin margin and source area resulting in frequent shelf/slope-sourced mass wasting events along the north (channel 1) and central E-Fan area as well as along the western margin. The observed west-ward shift in time and activity of the feeder channel system is believed to be controlled by tectonism in the source area. Satur (1999) puts the relative age of channel 4 as younger than channel 3, based on gravelly channel 4 deposits eroding into sandy transition deposits associated with channel 3. Later uplift of the feeder channel 4 source area probably resulted its later initiation and its prolonged funnelling of gravelly material into the basin at a time when feeders 1, 2 and 3 were already sourced by sandier material (fig. 2.48c). The respective source areas of the latter probably having experienced diminished tectonic activity, prolonged denudation and/or coarser sediment trapped in more proximal locations, thus providing overall smaller grain sizes. The apparently diminished sediment input of channel 1 at a later stage may further be explained by this process, resulting in the complete shut-down or a period of quiescence as it had experienced in its earlier development (Satur 1999). Whether uplift in the west may have resulted in a change of basin gradient (tilting towards the east) is unknown. This process might have deflected channel 1 flows to the east along the eastern margin, however, no data are available to support this hypothesis.

The distinct grain size change, sandy backfilling of the conglomeratic feeder systems and the westward shifting sediment source appear to be chiefly controlled by source area tectonism, i.e. differential uplift, and subsequent denudation of the respective sources combined with a gradually rising sea level initiating the apparent landward shift in sedimentation. Synsedimentary tectonism and higher frequency sea-level changes affect the sediment accumulation pattern within the basin. The observed westward shift in source area may be responsible for the later inititiation of the W-Fan as suggested by Satur (1999).

This evolutionary stage of the E-Fan is akin to the low-efficiency fan type II of Mutti (1985a) or the sand-rich submarine fan model of Reading & Richards (1994) where the sand deposition took place in channels and in channel-attached lobes.

Stage 3: (incomplete ?) Praeorbulina glomerosa zone (PN8: late Burdigalian)

During this, probably incomplete, biozone (data from Nazik & Gürbüz 1992 and Gürbüz 1993), 450 m of mainly coarse lobe deposits were deposited in the central E-Fan area and approximately 700 m of granule sediment bodies interbedded with thick very fine-grained successions in the west. No upper Burdigalian fan sediments were recorded in the east. Their absence may either be due to non-deposition or, more likely, due to non-exposure, i.e. burial. The thickness differences between the central and western section may result from the incomplete sampling-range.
Regardless of the uncertain lower timing of this biozone, W-Fan sedimentation is prograding into an area previously occuppied by E-Fan deposition (fig. 2.48d). Already 100 m below the presumed onset of this biozone, W-Fan sediments were recorded. These distinctive granule sandstone bodies, probably downcurrent equivalents of sandstone tongues *sensu* Satur (1999) and Satur *et al.* (2000), are rapidly fining upward into fan fringe sedimentation. Throughout, transport directions persistantly point to the east (75 - 145°). Poor exposure prohibits tracing of the sandstone tongues in a downcurrent, eastern direction, therefore, the exact extent and influence of the western-derived flows are unknown. Flowmixing with channel 3 and 4 flows is likely, resulting deposits probably existing in subcrop (due to the direction and gradient of dip).
The W-Fan progradation is likely to be driven by increased, coarse sediment supply to the basin from the west underlining the proposed westward shift in differential uplift of the source area controlling sediment supply. The granule grain size suggest that the available coarse sediment was funnelled effectively towards the east favoured by the confined, elongate W-Fan subbasin (Satur 1999) at times acting as a channel-like fairway (Stow & Johansson 2000). However, the progradation of the coarse sediment bodies was relatively short-lived, rising sea level and/or diminished input from the west resulting in the retrogradation of the W-Fan giving way to fan fringe sedimentation.
Coarse sand deposition in thick lobe deposits and associated facies sourced from channels 3 and/or 4 is still rife in the central E-Fan area. If lobes were channel-attached and/or sandy channel-fill deposition took place can only be speculated, however, the development as a fan type II *sensu* Mutti (1985a) is likely. Gradual fining- and thinning of deposits and an increase in overall shale content equally suggest source area control (e.g. changing grain size, input and/or flow competence) under an overall rising sea level.

Stage 4 Orbulina suturalis zone (PN9-10: Langhian)

During Langhian times, the sediment dispersal pattern was governed by a complex, fault-scarp basinfloor topography which resulted in basin compartmentalisation leading to tectonic and/or bulk sediment weight, which induced differential subsidence of small, adjacent basin sectors. It favoured enhanced thickness accumulation in the central E-Fan area (~ 2000 m), inhibited lateral (western) sediment dispersal and encouraged flow deflection towards an overall SE to E direction (fig. 2.48e).
Sand-dominated deposition continued in the central and eastern E-Fan areas, accumulating 2000 m and 840 m of primarily sandy lobe and minor associated deposits respectively. (Recorded) deposition in the east sets in slightly above the Langhian/Burdigalian boundary, the encroaching fan sediments gradually aggrading against the slope. Channels 3 and/or 4 provided the bulk of the sediment supply to the basin. If lobes were channel-attached and/or sandy channel-fill deposition took place is unknown, however, source area denudation may have resulted in a mixed sedimentload possibly resulting in a type I fan of Mutti (1985a). In both the central and eastern areas, gradual thinning and fining upward towards the top marks the shift to fan fringe sedimentation probably driven by reduction in grain size due to denudation of the source area, diminished sediment input and/or flow competence and/or subsiding source area tectonism and a gradually rising sea level.
In the west, 250 m of W-Fan fringe sedimentation progressed (previously interpreted to represent deflected E-Fan fringe sedimentation (Gürbüz 1993). It marks the continued retrogradation of the W-Fan due to diminished sediment input and gradually rising sea level (Satur 1999; Satur *et al.* 2000) (fig. 2.48e).
Synsedimentary tectonism continues to trigger mass wasting events resulting in thick debrites interbedded with fan deposition (central E-Fan) and moulding the slope morphology (Cronin *et al.* 2000; this study).

Stage 5: Globorotalia mayeri zone (PN11: early Serravallian)

Rising sea level and diminished sediment input due to subsiding source area tectonisms and denudation of the hinterland lead to overall fan fringe sedimentation during the final depositional stage of the E-Fan system (central area: 80 m; western area: 110 m; eastern area: unknown) (fig. 2.48f). A channel-levee complex (type III fan system) probably developed and sand deposition in smaller lobes may still have taken place in the most proximal fan position. Palaeocurrents (data: Gürbüz 1993) suggest that the western E-Fan area was still sourced from the west, implying much longer W-Fan activity than previously interpreted (e.g. Gürbüz 1993; Satur 1999). Shallowing in the extreme southeast of the W-Fan indicates a local high (*pers. comm.* Kelling 1998).

Stage 6 (late Serravallian)

A combination of subsiding tectonism and denudation of the source area and the gradually rising sea level result in decreased sediment input and/or sediment trapped in the proximal reaches of the shelf which effectively ended E-Fan clastic sedimentation. The Cingöz fans were covered by up to 1200 m thick basin plain deposits (Güvenç Formation; Naz *et al.* 1991).

2.7 Discussion

2.7.1 Biostratigraphic framework

The timing of fan initiation and the length of activity for the W- and E-Fan of the Cingöz system show stark discrepancies among workers. Yetiş (1988) suggests a late Burdigalian to Langhian age for the Cingöz Formation based on lithostratigraphic relationships with the other formations, while Naz *et al.* (1991) indicate an early Langhian to Serravallian age, the fan initiation related to the suggested early Langhian sea-level drop. Toker *et al.* (1998) put the depositional age of the Cingöz Formation from early-middle Miocene (Langhian: Sphenolithus Leterorphus Zone [NN5]) to middle Miocene (Serravallian: Discoaster exilis Zone [NN6]) based on calcareous nanoplankton, the age Satur (1999) appears to have used in his recent study. Nazik & Gürbüz (1992), Gürbüz (1993) and Cronin, Gürbüz, Hurst & Satur (2000) utilise the foraminiferal biozones which place the depositional age of the Cingöz Formation from late Burdigalian to Serravallian (Praeorbulina glomerosa curva [PN8], Orbulina suturalis [PN9-10] and lower? Globorotalia mayeri [PN 11?] zones).

Gürbüz (1993) suggests that the W-Fan was initiated and prograded towards the east already during the late Burdigalian, while Satur (1999) proposes an overall shorter-lived W-Fan sedimentation, its initiation only shortly after the onset of the Langhian. This study, utilising Gürbüz's (1993) biostratigrahpic data, proposes that the W-Fan was active throughout the whole of the Cingöz depositional phase, right up to and including the Globorotalia mayeri zone, and that its occupation of the south-western, former "E-Fan" area persisted longer than previous studies suggested.

2.7.2 E-Fan vs W-Fan

Satur (1999) suggests the E- and the W-Fan to be defined as the eastern and western area of one single Cingöz fan system whose development was only separate during its initial (oldest Langhian: Satur 1999) and later development (Serravallian). He postulates that the western area supplied the bulk of the eastern area and that the marked differences in depositional style between the two "fan areas" are due to the underlying basinfloor topography, the "western area" subbasin being comparatively shallow and well confined.

This study questions the postulated bulk sediment supply from the west and suggests that a complex basinfloor topography resulted in enhanced thickness in the central E-Fan depositional area and the easterly deflection of the turbidite flows.

Satur (1999) postulates the following points:

i. bulk sediment supply to the eastern fan area from the west
ii. western source active slightly later (later early Langhian), separate development during its latest stage and earlier ceasation (Serravallian) than eastern area deposition.

This study proposes that

i. the W-Fan prograded into an area previously occupied by the E-Fan during late Burdigalian times. The magnitude of sediment transfer from west to east is unknown.

Thus its influence, i.e. eastward depositional extent, can only be speculated upon in absence of any concrecte depositional evidence. Potential sediments in the central E-Fan area recording W-Fan progradation and/or flow mixing with E-Fan feeders, may exist in subcrop. During Langhian, W-Fan sedimentation retrograded, leaving fringe sedimentation in place, while coarse sand deposition was still rife in the central and eastern E-Fan area. Satur's (1999) geochemical pilot study points to an E-Fan source for the Langhian Lobe C deposits.

ii. the W-Fan was active for a much longer time than both Gürbüz (1993) and Satur (1999) suggested. W-Fan fringe sedimentation was still conspicuous during the Globorotalia mayeri zone (early Serravallian), deposits which were previously interpreted to represent deflected E-Fan sediments. One argument was the deeper-water fauna encountered, which is characteristic of the E-Fan depositional environment (Gürbüz 1993; *pers. comm.* Gürbüz & Kelling 1996). However, with rising sea level, conditions deepened and thus may account for the deeper water assemblage in this (W-Fan) area (Demircan & Toker 1998). Only towards the extreme top, shallowing was recorded.

Satur's (1999) suggested new nomenclature appears to be rather semantic. Regardless of it, he acknowledges that one Cingöz deepwater clastic system consits of two, more or less coeval depositional entities sourced from separate, distinct sources (W-feeder *versus* E-Fan feeder system). Their development was initially separate (Gürbüz 1993), then interfingered and was ultimately separate again (Gürbüz 1993; Satur 1999).

The former and current Cingöz fan models are clearly biased towards over-emphasising the outcropping, relatively proximal conglomeratic and sandy deposits. The unknown dimension of the Cingöz systems' southern extent as indicated by borehole and seismic data (Naz *et al.* 1991; Williams *et al.* 1995) presents problems in understanding the greater picture of the Cingöz development. The considerable thickness of conglomeratic "inner-fan valley-fill" deposits (Naz *et al.* 1991) has not been adequately addressed in their existence in relation to the outcropping Cingöz deposits by any later study (e.g. Gürbüz 1993, Ünlügenç 1993; Williams *et al.* 1995; Yetiş *et al.* 1995; Satur 1999; this study). Clearly, problems exist with tying the borehole data into the fan models due to absence of (unpublished?) lithologic and biostratigraphic data, basin-wide marker beds and abundant faulting.

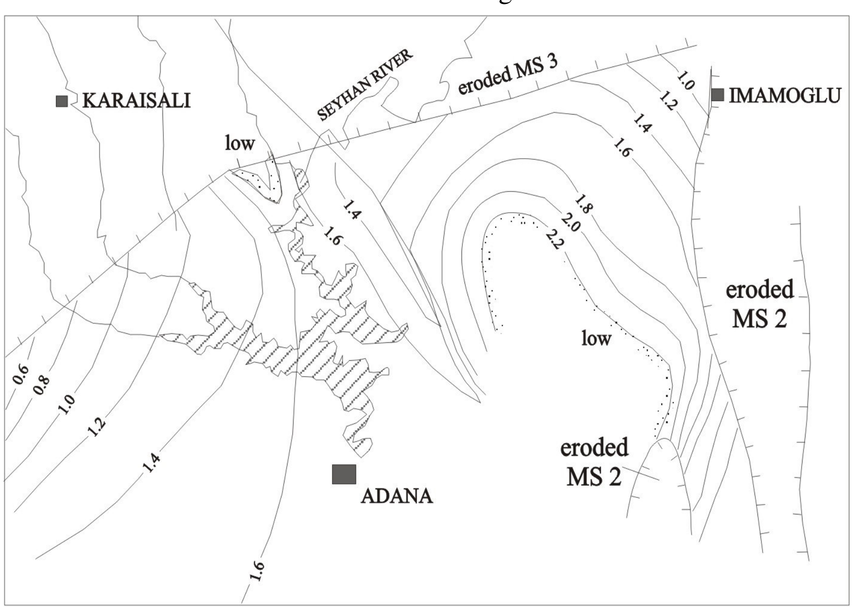

Figure 2.49: Isochron (thickness in seconds TWTT) for megasequence 2. The map show an area of thick megasequence 2 between Adana city and the Imamoglu Fault Zone (eroded MS 2 on map; from Williams *et al.* 1995)

Naz *et al.* (1991) interpret the cored section to represent the downcurrent extend to the E-Fan (their Ayva Hill Fan). This study agrees, especially since the W-Fan appears to be strongly confined to a W-E trending subbasin. Williams *et al.* (1995) show a great, almost radial extent in a southern direction with a depositional thickening between Adana and the Imamoglu Fault (fig. 2.49), lying in the direct southern extension of the exposed E-Fan. However, their described Megasequence 2 includes Kaplankaya, Cingöz and Güvenç deposits, all of unknown thicknesses and geometries.

2.7.3 Dynamic depositional model

The E-Fan represents a relatively small, coarse-grained and short-lived deep-water clastic system deposited in a Type C basin *sensu* Mutti & Normark (1987), with some elements of a Type D basin. Its initiation is believed to result from high sediment availability within the source area (Satur 1999), perhaps during a time of lowered sea level (e.g. Naz *et al.* 1991; Görür 1992; Gürbüz 1993). Basin aggradation met with rapid sediment discharge from the uplifted Taurus Orogen and restricted sediment dispersal due to complex fault-scarp basin topography. It resulted in thick, locally extensive sediment accumulation, restricted (lateral) western dispersal and the eastern axial deflection of the E-Fan system during the sandy growth stage. The observed landward shift of the system resulted from a combination of subsiding source-area tectonism, denudation and a gradually rising sea level.

However, no single encompassing model can fully describe the spatial and temporal changes observed within the E-Fan, the changes from a gravel-rich to sand-rich and subsequently mud-rich? submarine fan system* (*sensu* Reading & Richards 1994) or the evolution through type I to III stages (*sensu* Mutti 1985a) as proposed by Satur (1999).

For the described gravelly-growth stage during late? Burdigalian times, which is solely known from the exposed conglomeratic northern feeders and the inner-fan valley-fill of Naz *et al.* (1991), the question of if and how much sand was available is crucial for its classification. If sand was abundantly available, it was probably deposited in sandy lobes downsystem of the recorded conglomeratic channel-fill deposits, thus being comparable to a type I system of Mutti (1985a) (fig. 2.50). However, if rapid tectonic uplift provided the sediment to the basin, it probably yielded very little sand-sized material at first. Than the E-Fan would initially have developed as a gravel-rich type of Reading & Richards (1994) where "smallish" gravel lobes form at the mouth of a channel similar to the modern gravelly systems such as the Porto canyon-mouth lobe (Kenyon *et al.* 2002) and the Var fan lobe (Unterseh 1999). Seismic data do not indicate channel-incision far to the south as suggested by Naz *et al.* (1991), but the apparent fault-scarp topography (Williams *et al.* 1995) probably controlled the channelized and/or non-channelized conglomeratic accumulation. Due to the overall lack of data neither model can be verified to correctly represent the gravelly-growth stage.

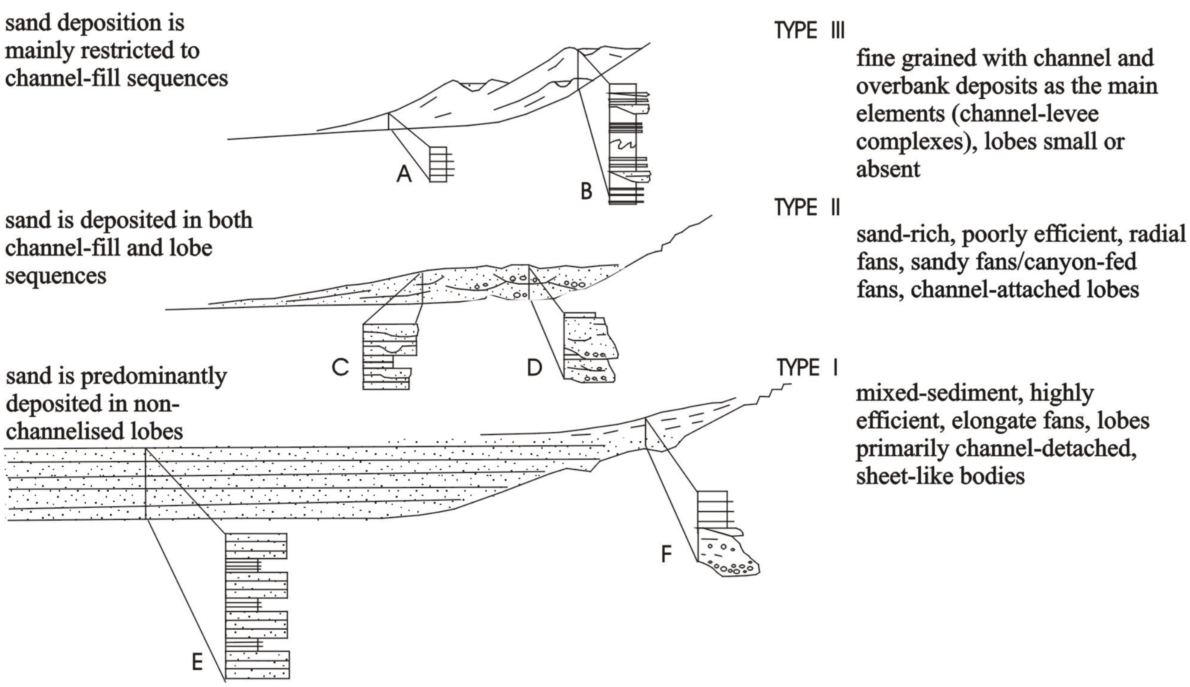

Figure 2.50: Schematic representation of three main types of turbidite deposits as characterised by relative amount of and position within the deposit of the sandy component (from Mutti 1985a).

The sand-rich phase of the E-Fan is marked by the onset of thick sandy sheet-like deposits backfilling the feeder system. Gürbüz (1993) rather too simplistically suggested that the whole of the E-Fan represents a type I system *sensu* Mutti (1985a), where sand is predominantly deposited in non-channelized lobes. Type I systems are synonymous with the highly efficient fans characteristic of elongate foreland basins (fig. 2.50).

* submarine fan systems *sensu* Reading & Richards (1994) are characterised by a single feeder, while multiple sourced systems should be classified as 'submarine ramp'. However, the E-Fan feeders are clearly defined and do appear to be active at slightly different stages thus the 'non-conforming classification' of multiple-sourced submarine fan is retained.

However, the sandy basin-fill of the E-Fan is more akin to sand-rich, poorly efficient systems, where coarser sand is deposited in smaller, channel-attached lobes and channel-fill sequences, such as the Lobes A and B backfilling the feeder channel during the late? Burdigalian. Conglomerates characterise the channeling component in the transition zones, but if during this stage sandy channel-fill deposition took place is unknown. The deposition of the thick, sand-rich Lobe C deposits during Langhian times took place in the eastern, more distal reaches of the system. It is not known if they are channel-attached lobes and if sand deposition took place in the feeders as the sequence stratigraphic approach would favour. If continued grain size reduction driven by source control resulted in a more sand/mud-rich system *sensu* Reading & Richards (1994) it might have favoured sand transport farther into the basin in spite of the rising sea level thus changing to a type I (?) system. Even very large, mud-rich systems such as Amazon Fan, for example, records 20 to > 100 m thick sand complexes of at times medium- to coarse-grained sand in the lower fan area (Flood *et al.* 1995).
Fan fringe sedimentation during the late Langhian and early Serravallian indicates a continued landward shift in the sand deposition probably driven by continued source-area denudation and rising sea level, resulting in a proposed channel-levee complex with probably no or few small sandy lobes developing in the proximal reaches (Satur 1999). No proximal fan sediments are preserved representing this stage.
Satur's (1999) model is driven by the sequence stratigraphic approach regarding sea-level rise as the most important factor controlling the evolution of the Cingöz system rather than integrating potential source control, i.e. changing sediment availability and grain size, which this study believes to be an important factor in governing the E-Fan evolution. That a switch in fan system *sensu* Mutti (1985a) may be independent of sea level, is documented by the sand-rich turbidites systems of the northern Appenines. They initially developed as type I system (late Oligonece to early Messinian) and changed to type II systems (Late Messinian to Pliocene) resulting from changes in the shape, geometry and dimension of the basins due to the emersion of a mountain chain that strongly altered the palaeodrainage pattern combined with tectonic fragmentation of the basin (Cornamusini & Sandrelli 2002).

2.7.4 Lobe accumulation

During the sandy-growth stage (late Burdigalian – Langhian), the sand deposition took place in thick, non-erosive, laterally extensive sheet-like deposits, some of which appear to be of lobate geometry. The transition zone (Lobe A) and proximal lobe (Lobe B) deposits do not fit the classical lobe definition *sensu* Mutti & Normark (1987), while Lobe C deposits of the distal lobe zone are more akin to it. The location and nature of the resultant lobes are primarily governed by the topograhic restraints.
The use of the term "lobe" is ambiguous. A lobe *sensu strictu* refers to non-channelized depositional bodies of lobate geometry, however, different data sets, ie. modern to ancient (outcrop/subsurface), yielded a greatly differing application of the term (*see reviews* in e.g. Shanmugam & Moiola 1991; Shanmugam 2000). Confusion and non-transferability of results are the consequence.
A detailed discussion on depositional lobes and related bodies, for example their definition, recognition, controls, reservoir characterisation and the potential problematic application of the term, are presented in chapter 5 with emphasis on the studied outcrop and subsurface examples (*chapter 3*).

2.7.5 Controls

A deep-water clastic system developing in a tectonic active setting is controlled by a complex interplay of the local and regional tectonism, relative sea-level variation, climate and the sediment supply pattern (e.g. Normark *et al.* 1993; Reading & Richards 1994; Stow & Johansson 2000). The retrogradational pattern of the E-Fan is striking and indicates the gradually rising sea level to be the fundamental control on its development as suggested by Satur's (1999) sequence stratigraphic-driven model. However, this study has shown that tectonism plays an important role in governing the E-Fan evolution and ultimately of the Cingöz Formation.
Source-area tectonism has been shown to influence the i) timing and spacing of sediment supply by activating different sources at different times probably through differential uplift, ii) resulting in the apparent westward shift in the supply transfer pattern through structurally controlled feeders and iii) in conjunction with probably a more humid climate, it controlled the available sediment grain size, flow

competence and capacity. Tectonism also controlled the geometry and topography of the host basin which strongly influenced the spatial and temporal development of the sediment accumulation. This in turn resulted in the observed locally enhanced deposition during late? Burdigalian and Langhian, the (western-) lateral restricted dispersal and the apparent easterly, axial flow deflection of the E-Fan during Langhian times. Through time, basinfloor topography was probably increasingly subdued through depositional smoothing of the relief.

The longitudinal, landward shift or retrogradation of the E-Fan system is expressed by the gradual reduction in grain size and the retrogradational pattern, i.e. the backstepping of more distal facies (e.g. channel-lobe transition zone) over more proximal facies (e.g. channel-fill sequences). This is likely to result from a combination of i) gradually rising sea level, ii) a tectonically driven decrease in the gradient of the continental margin, iii) gradual basin infilling and onlap and/or iv) a change in the energy, volume and load of sediment gravity flows building the turbidite system. The change in the energy, volume and load of the sediment gravity flows is probably related to the interplay of continental tectonics and climate overprinted by the gradually rising sea level. The rising sea level results in a greater transition area between the source and the basin, allowing sorting and deposition of coarser fractions there (e.g. Stow & Johansson 2000; Bouma 2000; Kenyon *et al.* 2002).

Tectonic control, i.e. source-area tectonism controlling sediment supply, rather than eustasy has been recognised in a number of transgressive systems to be the fundamental control resulting in the accumulation of thick deep-water massive sandstones (Stow & Johansson 2000), distinct fining-upward sequences (e.g. Campos Basin/offshore Brazil: Bruhn & Walker 1995), or landward shift of the system in combination with increasing hinterland aridity (e.g Agadir turbidite system/offshore Morocco: Ericella *et al.* 1998). Even clastic progradation is not necessarily related to a fall in sea level but, in case of the deep-water clastic strata in the Carboniferous Culm Basin/Czech Republic, to changes in drainage basin size and/or climatic fluctuations within the source area (Hartley & Otava 2001). Sea-level changes are recognised to modify effects of longer-term changes in sedimentation driven by tectonic activity in the source area (e.g. Paola Basin/Tyrrhenian Sea: Trincardi *et al.* 1995) or may even be the reason for switching sediment supply patterns to a basin rather than tectonism (e.g. Monterey Fan: Normark & Piper 1991).

The temporal and spatial turbidite accumulation in the distinctively retrogradational E-Fan system appears to be controlled by source-area tectonism and the overall transgression taking place in the Adana Basin. Additionally, the direct connectivity with fan deltas made the eustatic signature less significant than sediment supply, which aided the direct and substantial supply of coarse-grained clastic material into the basin.

2.8 Conclusion

Through extensive field work focusing on the sand-rich, proximal basin fill of the eastern fan, investigation of the fan-slope contact and a detailed revision of the existing framework, reveals new insights into the sandy growth phase and factors controlling sediment accumulation through time.

I) Time-stratigraphic changes indicate that the E-Fan system evolve from a gravel-dominated system during late? Burdigalian to a sand-dominated one in late Burdigalian – Langhian times. Initial source-area uplift resulted in the availability of very coarse sediment, probably feeding the gravelly growth stage, where small gravel lobes may have developed at the mouth of the feeder system. Progressive sea level rise and denudation of the hinterland led to the initiation of the sandy growth stage, where the bulk of the sand accumulated in thick, laterally extensive depositional lobes. During late Burdigalian, it initially developed as a type II fan *sensu* Mutti (1985a), however, continued source-area denudation probably resulted in a more mixed sediment supply, leading to a type I ? system during Langhian times. During early Serravallian a channel-levee system (type III) developed with small or no lobe deposition.

II) The changing spatial and temporal distribution and nature of the turbidite deposits suggests tectonism as a fundamental control, overprinted by the transgression in the Adana Basin. Source-area tectonism controlled the westward migration of the source area, the sediment supply pattern and in combination with climate resulted in a gradual grain size reduction. Tectonism also controlled the geometry and topography of the host basin, resulting in locally enhanced deposition, (western-) lateral restricted dispersal and the apparent eastern deflection of the E-Fan. The overall retrogradation is driven by the rising sea level and progressive denudation of the Taurus Orogen.

III) During the sandy growth stage, the bulk of the sand accumulated in laterally extensive, thick, coarse-grained, sheet-like bodies of channel-lobe transition (Lobe A), proximal (Lobe B) and distal (Lobe C) depositional zones. Lobes A and B do not fit the classical lobe definition *sensu* Mutti & Normark (1987, 1991), while Lobes C are more akin to it. The size, geometry and vertical stacking of the lobes reflects to some degree their restricted spatial, aggradational development. Unique component associations characterise the various depositional environments: transition zone (Lobe A: 70 %, channeling 30 % with scours 5 %), proximal zone (Lobe B 90 %, distributary channels: 8 %, lobe fringe 2 %) and distal lobe zone (Lobe C: 65 %, lobe fringe 22 %, interlobe 4%, fan fringe 9 %). Conspicuous fining upward at lobe and zonal scale reflect the gradually rising sea level while sporadic phases of progradation and/or coarse clastic sediment supply suggest a combination of higher frequency sea-level fluctuations and tectonic control.

IV) The studied lobe depositional environments do not represent true downcurrent representatives of each other. However, conspicuous, general downcurrent changes can be observed. Throughout, the different lobe types are characterised by a high net sand content. This is decreasing in a downcurrent direction, accompanied by a gradual decrease in grain size, bed thickness and amalgamation. In a downcurrent direction, deposition from turbidity currents increases along with the overall shale content. The internal organisation at bed sub-packet- to lobe-scale becomes more ordered, while lobe stacking becomes increasingly less.

V) Thick debrites were identified in the western and central E-Fan area which previously had been interpreted to represent levee and/or mid-fan channel deposits. These debrites indicate major tectonic activity, e.g. uplift, in particularly the basin margin area triggering large shelf/slope failures. Their frequency and great size probably posed some major obstacles resulting in flow deflection and/or cannibalisation by the canyon-derived sandy flows. Major remobilisation (slumping) of Cingöz deposits was observed along the north-eastern margin.

VI) During a short timespan in late Burdigalian times, granule W-Fan sediments prograded towards the east. The magnitude of sediment transfer from west to east is unknown, ditto any depositional evidence. Rapidly, W-Fan fringe sedimentation persued, its sedimentation only ceasing during the Globorotalia mayeri zone (NP11, early Serravallian). Thus, the W-Fan was active for much longer than previous studies had suggested.

2.9 Further work

A number of areas would require further work to permit an even better understanding of the development of the E-Fan and the Cingöz Formation as a whole, fostering a greater understanding on factors governing the evolution of relatively small, sand-rich deep-water clastic systems.

I) A complete detailed biostratigraphic framework for the E-Fan / Cingöz Formation is needed to aid understanding the spatial and temporal development of the system. Incomplete and/or absent dating of especially the older evolutionary stages hinders complete reconstruction of the system's development. This is especially important in the light of the differing ages of fan initiation and cessation provided by different authors.

II) The previous, field-based studies are clearly biased towards the channelized and non-channelized proximal fan deposits. Little seismic and borehole data are published, but their integration is needed in much more detail to fully understand the nature of the Cingöz Formation and factors controlling its evolution.

III) The evolution of the Cingöz Formation has to be seen in the context of the evolution of the Neogene fill of the northern Adana Basin. Revision and/or more details of the biostratigraphic and lithostratigraphic framework are necessary to gain a fuller picture of the formations' relationships. Especially with regard to the subsurface data set, the suggested presence of, for example, Karaisali reefal and Kaplankaya slope, needs to be addressed.

IV) Geochemical provenance studies as tested in a pilot study by Satur (1999) may further help to determine i) the distal extend of W-Fan progradation and ii) help tying borehole data into the existing data set. This geochemical stratigraphy might help differentiating the various and changing sources (channel 1 - 3 and/or 3 / 4) and counteract problems arising from faulting or missing biostratigraphy.

V) No information on climatic conditions during the Middle Miocene is presently available. Climatic data would further enhance the knowledge of possible and/or changing controls of the Cingöz Formation.

2.10 Summary

The E-Fan of the Miocene Cingöz Formation, southern Turkey, represents a small, coarse-grained multiple sourced deep-water clastic system whose evolution was fundamentally governed by tectonism and the gradually rising sea level. Initially source area uplift resulted in the initiation of the fan system and the formation of a gravel-dominated system, depositing thick coarse clastics far into the basin.

Gradual denudation of the source area in combination with rising sea level led to a sand-dominated system. Sand was deposited in coarse-grained, aggradational channel-lobe transition zones and thick lobe deposits (akin to type II and later type I ? system *sensu* Mutti 1985a), backfilling the feeder system. Basinfloor topography played a crucial role in influencing the temporal and spatial sandstone distribution pattern resulting in locally enhanced deposition, (western-) lateral restricted development and the apparent eastern deflection of the E-Fan, while basin-margin and source-area tectonism controlled the timing and activity of the source-area supply. During its final stage (early Serravallian), the E-Fan probably developed as a channel-levee complex (type III system).

The marked retrogressional signature of the E-Fan is produced by a combination of gradually rising sea level, probably subsiding source-area tectonism and denudation of the hinterland. Episodic tectonic activity resulted in influx of coarse sediment into the basin, while higher frequency sea level fluctuations resulted in occasional progradation of the deep-water system. Clastic deposition is eventually shut off and thick basinal shales blanket the Cingöz Formation.

3 CHARACTERISATION OF SUBSURFACE LOBE DEPOSITS: S10 INTERVAL, SCAPA SANDSTONE MEMBER, SCAPA FIELD, BLOCK 14/19 NORTH SEA, UK

3.1 Geological background

3.1.1 Location

The Scapa Field is located in UK Block 14/19 in the Scapa-Highlander subbasin ("Scapa syncline") of the Witch Ground Graben (WGG), Outer Moray Firth, 112 miles (~ 175 km) north east of Aberdeen in a water depth of 385 feet (120 m). The field was discovered in 1975 by appraisal well 14/19-15 (McGann *et al.* 1991) and consists of the Main Scapa Field and the West Scapa Field, divided by the West Scapa Fault (fig. 3.1).