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# Evidence and implications of massive erosion along the Strait of İstanbul (Bosphorus)

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**Abstract** The Strait of İstanbul (SoI) (Bosphorus) is a narrow valley, which has evolved tectonically from a stream, and in which thick sediment deposits have accumulated in the course of its evolution. Detailed seismic and multi-beam bathymetric data have revealed that the upper parts of the deeper channel deposits consist of parallel strata, which have mostly been eroded subsequently to their deposition. The resulting erosion surface is represented by the present channel floor in the strait, the estimated volume of the eroded material being approximately $2\times10^8$ $m^3$. Erosion rate and seafloor morphology indicate that the flow direction was from the south to the north. This inner channel may have been formed by an abrupt flooding of the Black Sea by Mediterranean waters at the beginning of the latest connection between the Marmara and the Black seas. Subsequently, the Mediterranean bottom current of the modern two-way flow system, which was established at about 5–4 ka b.p., has given the latest shape to the strait floor.

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## Introduction

The Strait of İstanbul (Soİ) is the northernmost gate of the Mediterranean–Black Sea water connection located in NW Anatolia (Fig. 1a). This NNE–SSW-trending channel dissects the ESE–WNW-oriented land belt between the Sea of Marmara and the Black Sea, dividing it into the İstanbul and Kocaeli peninsulas (Fig. 1b). The Soİ is not a simple straight channel, but consists of both meandering and linear sections (Fig. 1c). Due to this complex morphology, the evolution of the Soİ has variously been interpreted as a purely erosional feature (Von Hoff 1822; Phillipson 1898; Andrussow 1900; Cvijic 1908; Penck 1919; Darkot 1938; Pamir 1938; Yalçınlar 1947; Erinç 2000), or a more complex structure having resulted from a combination of tectonic and erosional processes (Hochstätter 1870; Sholten 1974; Eroskay and Kale 1986; Uluğ et al. 1987; Alavi et al. 1989; Yılmaz and Sakınç 1990; Meriç et al. 1991a, 1991b, 2000; Oktay and Sakınç 1991; Yıldırım et al. 1992; Gökaşan et al. 1995, 1997, 2002, 2003; Demirbağ et al. 1999; Algan et al. 2001; Oktay et al. 2002; Akten 2004; Kerey et al. 2004; Yılmaz 2005). Alavi et al. (1989), Gökaşan et al. (1997), Algan et al. (2001) and Kerey et al. (2004) suggested that the strait contains very thick sediment deposits comprising different units separated by unconformities which indicate that the evolution of the Soİ was polihistoric. The latest stage of this evolutionary history started with the confluence of Mediterranean and Black Sea waters at the beginning of the Holocene.

Ryan et al. (1997) suggested that, before the inflow of Mediterranean water, the sea level of the Black Sea was over 100 m deeper than its present level, and that the incursion was fast and abrupt. Demirbağ et al. (1999) and Algan et al. (2002) supported a rapid sea level rise in the Black Sea. On the other hand, a persistent and strong outflow of the Black Sea during the Late Pleistocene–Holocene was proposed by Aksu et al. (1999, 2002) and Hiscott et al. (2002). According to both of these theories, the latest Mediterranean–Black Sea water outflow occurred via the Soİ, implying that a very large volume of

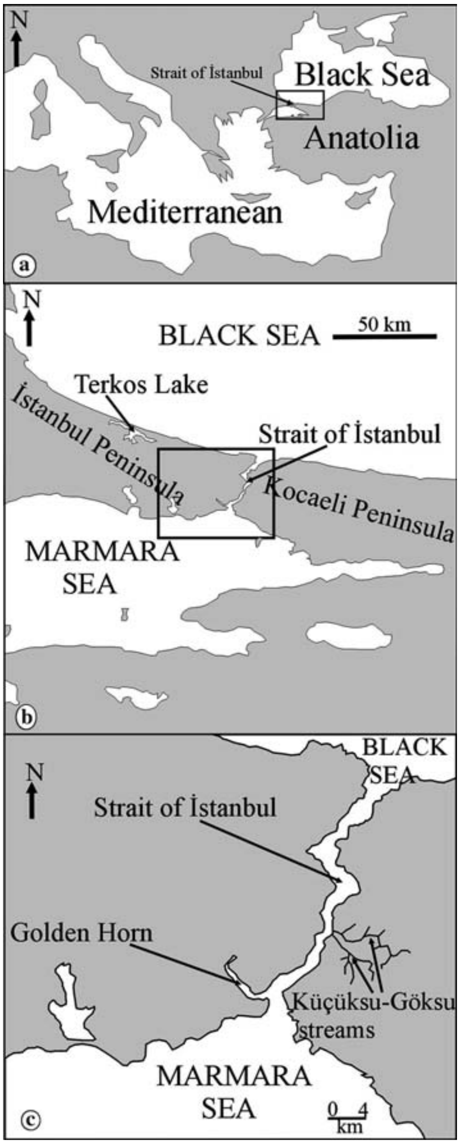



**Fig. 1 a** Location map showing the Black, Marmara and Mediterranean seas. **b, c** Detailed location maps of the study area

water must have passed through the strait. As a result, sustained erosion may have occurred along the floor of the strait. After the initial Black Sea–Marmara Sea (Mediterranean) connection, the present two-way flow system was established by approximately 5 ka b.p. (Algan et al. 2001). Ergin et al. (1991) argued that the velocity of the dominant bottom current of this flow system was capable of eroding and removing finer materials.

Therefore, erosion should be the major process characterizing the latest phase of the polihistoric evolution of the Soİ since the initial Holocene connection between the Mediterranean and the Black Sea. This study aims at documenting the erosion along the strait and discussing the possible reasons for the origin of this erosion, the ultimate aim being a better understanding of the latest Mediterranean–Black Sea connection and the final stage of evolution of the Soİ.

## Materials and methods

The seismic data were collected by the Turkish Navy, Department of Navigation, Hydrography and Oceanography (TN-DNHO), using a Uniboom analog seismic system comprising a 300-J seismic energy source generating a 10-ms pulse, a transducer, a single channel hydrophone streamer, and an analog recorder run of 100–400 ms scan lengths. The vessel speed was about 4 knot. Positioning was achieved by means of a trisponder system. Although the quality of the individual seismic datasets varies, the large number of seismic profiles covering the entire strait and its Marmara and Black sea entrances allows one to reconstruct recent processes in the Soİ (Fig. 2a). A close look at the seismic wavelet on the example shown in Fig. 3 reveals that it is composed of two parts: a primary reflection and a ghost reflection (probably a source-side ghost), which are almost 3 ms apart. This configuration illustrates a thin, youngest parallel layer covering the entire sediments along the seismic profile, which may erroneously be interpreted as a depositional unit. However, in detail the real reflections of the subsurface sediments, which are covered by the ghost, can be partly seen to continue to the seafloor on the profile (Fig. 3).

Multi-beam bathymetric data (Fig. 2b, c) were also collected by the TN-DNHO, using an Elac Bcc MK-2 multi-beam echosounder. This instrument operates with 126 beams at 180 kHz, has a range of 620 m, and reaches a maximum swath width of 970 m at a water depth of 2,200 m. A differential geographic positioning system was used for the positioning of the vessel.

## Results

### Physiography of the Strait of İstanbul

The physiography of the seafloor of the Soİ is described beginning in the south, at the shallowest point (Fig. 2b, c), and continuing northwards to the entrance into the Black Sea.

The shallowest part of the Soİ occurs along the NE–SW-trending section off Üsküdar where an elongated sill formed by a sedimentary deposit reaches a depth of only 27 m (Fig. 4a, b). The sill has previously been described by Darkot (1938), Uluğ et al. (1987), Alavi et al. (1989), Gökaşan et al. (1997), Demirbağ et al. (1999) and Algan et al. (2001). This lens-shaped sill is oriented semi-parallel to the main axis of the strait (Fig. 4b). To the west and the east the sill is bounded by channel-like depressions reaching depths of 40 m. At Çengelköy, the strait bends from its NE–SW orientation to a N–S direction (Figs. 2b, 4a). Whereas the channel along the eastern side of the sill continues northwards along the east coast of the strait, the western channel gradually shoals and eventually disappears south of Defterdar (Figs. 2b, 4b). Between Bebek and Kandilli (Figs. 2b, 5a), the strait

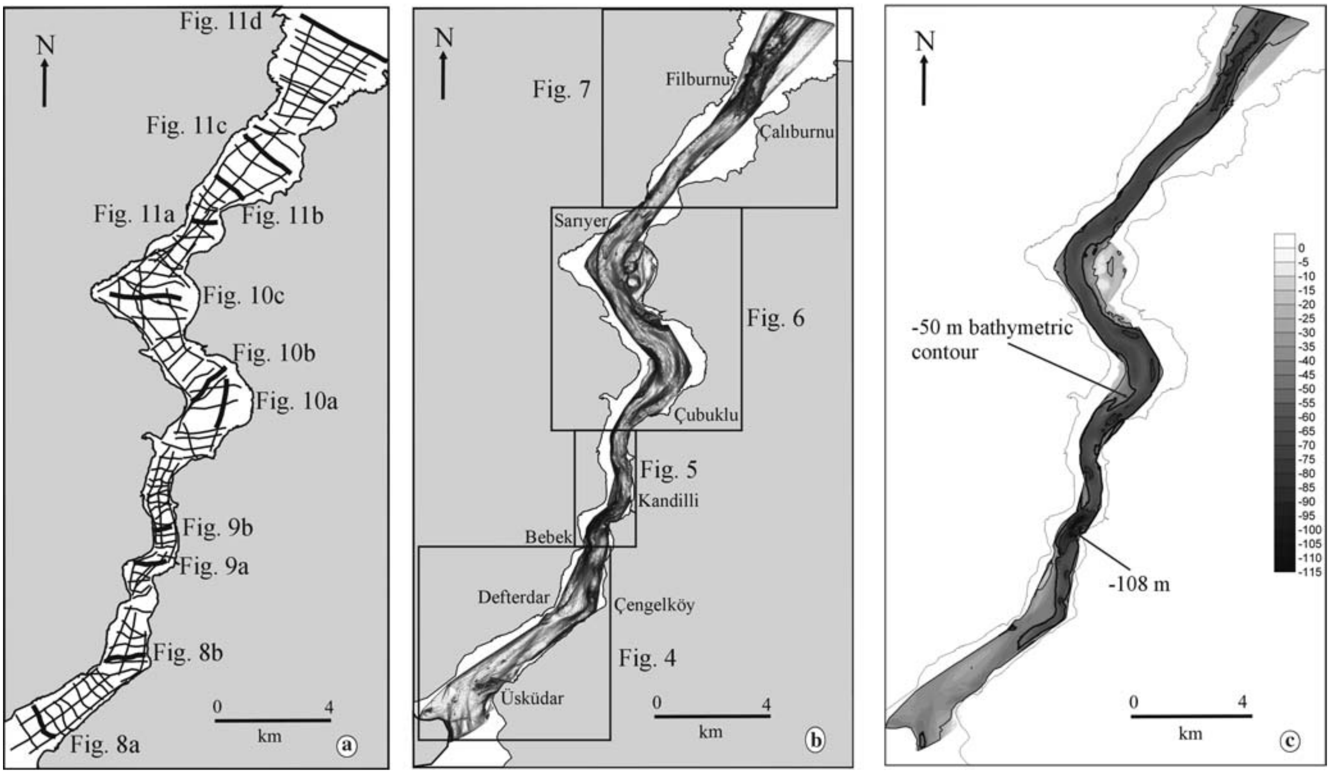



**Fig. 2** **a** Location of seismic reflection profiles obtained along the Strait of İstanbul. *Bold lines* denote the profiles shown in Figs. 8, 9, 10 and 11. **b** *Shaded* relief map of the multi-beam bathymetry of the Strait of İstanbul. **c** Contour map of the multi-beam bathymetry of the Strait of İstanbul. The *bold line* indicates the −50 m contour level

bends towards the NE and the channel progressively deepens to reach 108 m, which is the deepest area in the SoI (Figs. 2b, c, 5b). North of this short section, the strait again turns to a N–S direction, the channel axis beginning to meander along this part of the strait (Fig. 5b).

Off Çubuklu, the SoI widens and the channel meanders more tightly up to Sarıyer (Figs. 2b, 6a). This section of the strait displays the largest basin filled with sediment deposits above the bedrock basement (Gökaşan et al. 1997; Algan et al. 2001). Sediment drift deposits are observed where the strait abruptly enlarges off Çubuklu (Fig. 6b). The channel continues along the east side of the drift deposit, and actually truncates the south-eastern edge of this sediment body (Fig. 6b). Erosion is also observed along the concave sides of the strait to the north of Çubuklu and to the south of Sarıyer, possibly as a result of channel meandering (Fig. 6b).

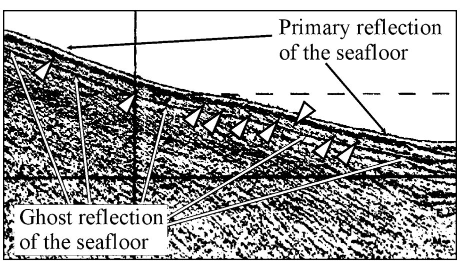



**Fig. 3** An example from the SoI illustrating the artificial reflection (*ghost*) on the subsurface of the sea bottom (for entire profile, see Fig. 10b). *Open arrows* indicate the real reflections of the subsurface strata

The northernmost part of the SoI, i.e. the section between Sarıyer and the Black Sea entrance, consists of a NE–SW-oriented linear channel (Figs. 2b, 7a). The large basin between Çubuklu and Sarıyer is delimited from the north by a buried ridge of Palaeozoic–Upper Cretaceous basement rocks, which are exposed on the seafloor at a depth of 70 m between Sarıyer and Filburnu–Çalıburnu (Gökaşan et al. 1997). Short bifurcations of the channel indicate bypassing on both sides of the basement high (Fig. 7b). To the north of Filburnu–Çalıburnu, the seafloor deepens towards the Black Sea (Fig. 7b), associated with a concomitant deepening of the basement (Gökaşan et al. 1997; Algan et al. 2001).

The multi-beam bathymetric data indicate that the seafloor morphology of the SoI is mainly characterized by erosion. The channel axis within the SoI is defined by the 50-m depth contour (Fig. 2c). This inner channel begins off the sill in the south (off Üsküdar), and continues to the Black Sea entrance of the strait.

## Seismic evidence for erosion in the Strait of İstanbul

Two sedimentary units distinguished by a high-amplitude reflection surface were identified on high-resolution seismic data reported by Gökaşan et al. (1997). The lower one, which is characterized by chaotic reflections, is associated with the Palaeozoic–Upper Cretaceous basement, whereas the upper unit has been interpreted as a channel deposit (Gökaşan et al. 1997). The upper part of the channel deposits shows continuous parallel reflectors indicating a relatively deep environment, suggesting that low-energy conditions prevailed during the latest phase of deposition. After final deposition, however, these parallel-bedded deposits were evidently truncated by renewed erosion, the truncation surface being represented by the modern channel profile along the entire SoI (Figs. 8, 9, 10, 11).

In the channel to the east of the sill (Fig. 8a), the parallel-bedded basin deposits are incised to a depth of at least 12 ms (9 m). This erosional incision reaches 26 ms (20 m) off Çengelköy where the strait turns from a north-easterly to a northerly direction (Fig. 8b). Further north, two streams (cf. the Küçüksu and Göksu streams in Fig. 1c) discharging into the strait form a small delta off Kandilli where the strait turns from its northerly course

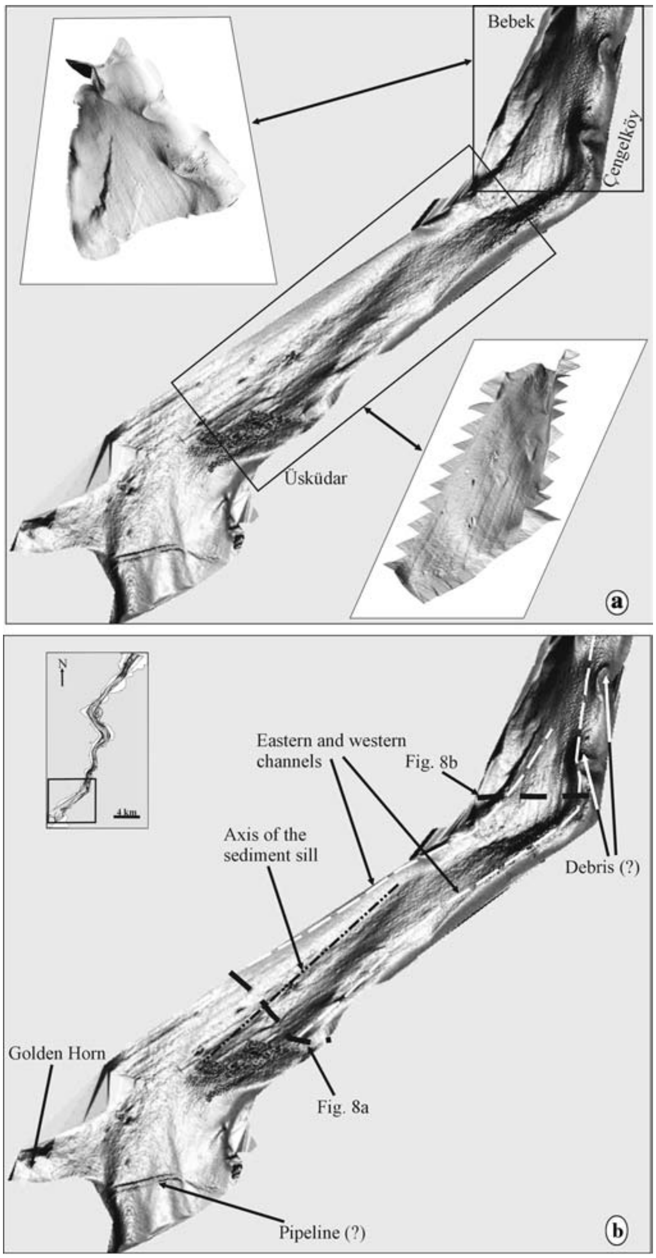



**Fig. 4** **a** Uninterpreted and **b** interpreted shaded relief map of the multi-beam bathymetry of the Strait of İstanbul between Üsküdar and Bebek (*dashed lines* indicate the axis of the inner channel)

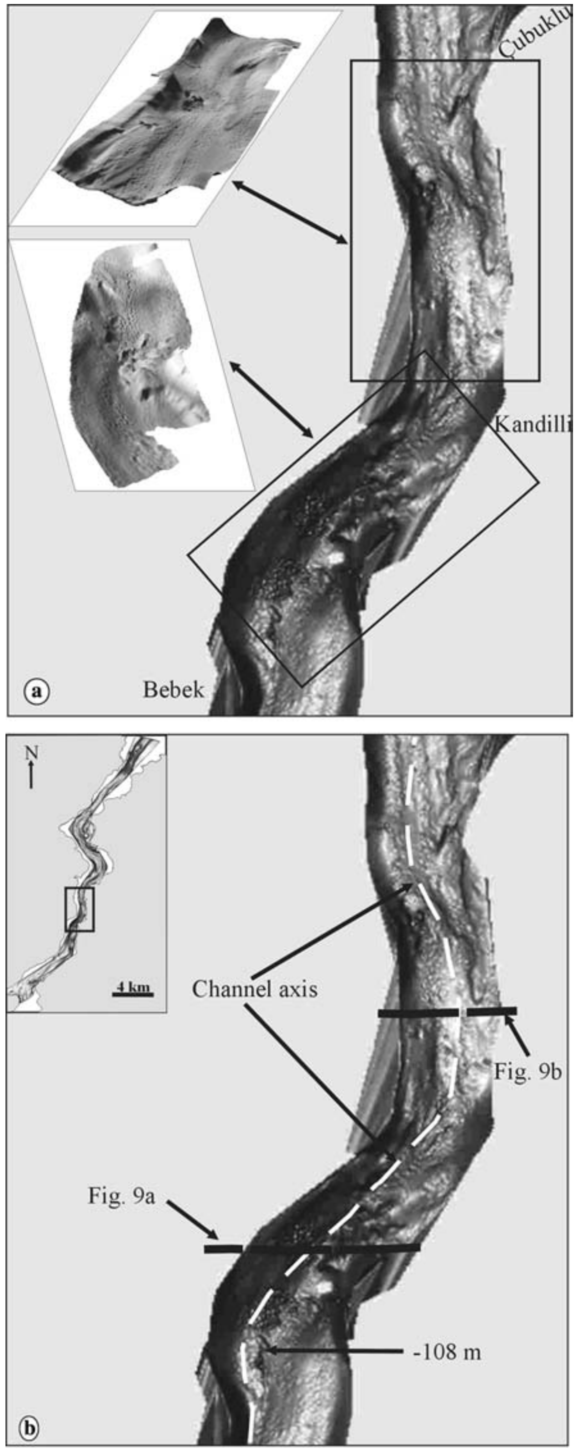



**Fig. 5** **a** Uninterpreted and **b** interpreted shaded relief map of the multi-beam bathymetry of the Strait of İstanbul between Bebek and Çubuklu (*dashed line* indicates the axis of the inner channel)

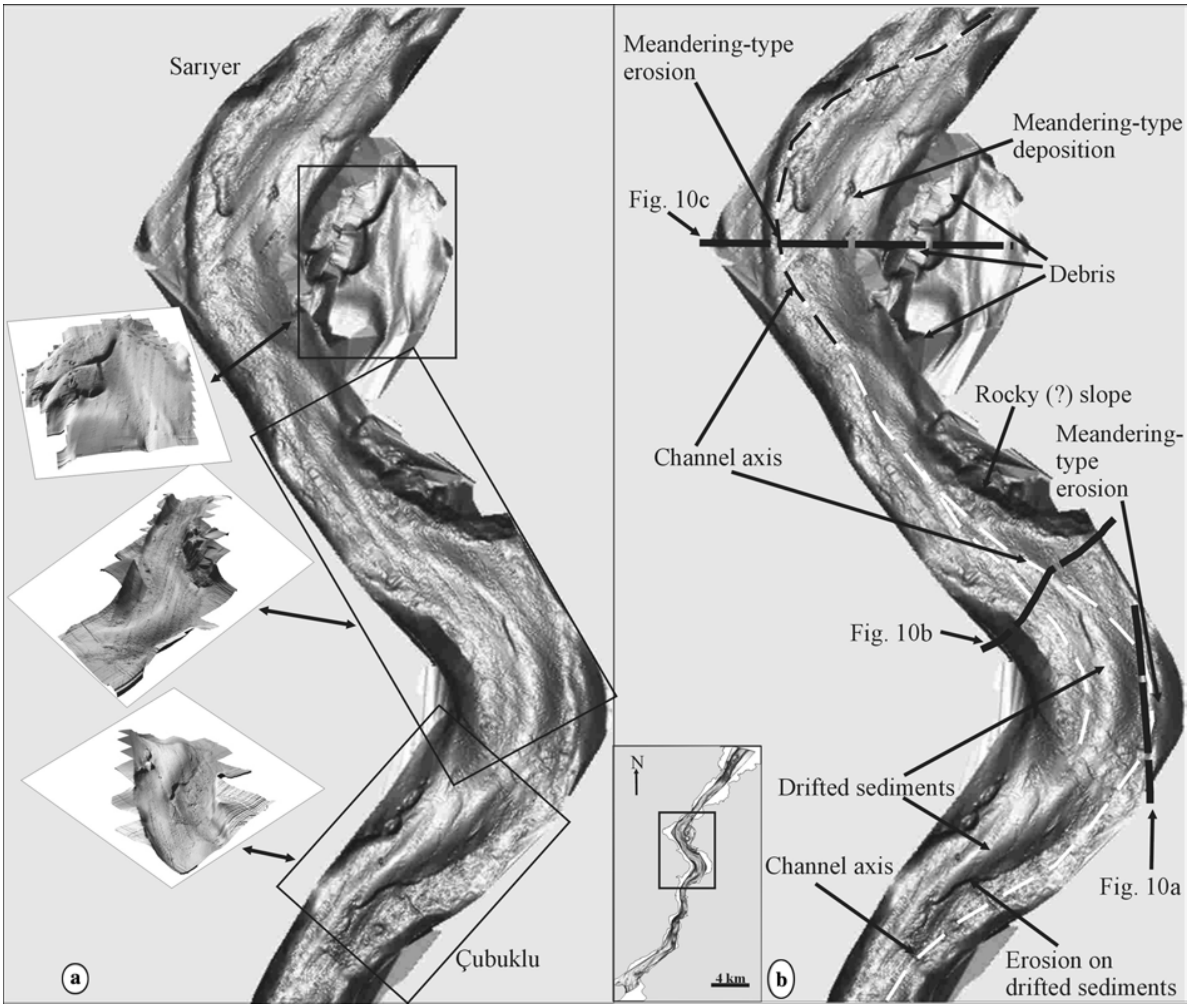



**Fig. 6** **a** Uninterpreted and **b** interpreted shaded relief map of the multi-beam bathymetry of the Strait of İstanbul between Çubuklu and Sarıyer (*dashed lines* indicate the axis of the inner channel)

to an east/north-easterly direction. On the seismic profile of Fig. 9a, the parallel-bedded deposits onlapping on the pro-delta of Küçüksu–Göksu are seen to have been cut down to at least 40 ms (30 m). This depth of erosion reduces to 30 ms (22 m) to the north of Kandilli (inset A in Fig. 9b). The parallel-layered basin deposits are cut down to 40 ms (30 m) on three seismic profiles located in the NW–SE-oriented part of the strait between Çubuklu and Sarıyer (Fig. 10a–c). The sediments are observed to be completely eroded down to basement rock (30 m) in the southern portion of the NE–SW-oriented northern-most section of the strait (Fig. 11a–c). At the Black Sea entrance of the strait, this erosion increases to 45 ms (34 m; Fig. 11d).

## Submarine canyons at the Black Sea and Marmara Sea entrances

On multi-beam bathymetric (Di Iiorio and Yüce 1999) and seismic data from the SW Black Sea shelf, a NE–SW-oriented submarine canyon is clearly observed as the northern extension of the SoI (Fig. 12a–f). Along this channel section, up to 25 ms (19 m) of sediments has been removed, indicating that erosion continued along the northern extension of the strait on the SW Black Sea shelf (Fig. 12c–f). On Fig. 12b, the channel is observed to turn sharply to the NW before diminishing towards the shelf edge. Some secondary channels accompany the main channel where it shallows (Fig. 12b). The main channel and one of the secondary channels are clearly visible on the seismic profile of Fig. 13a. The main channel appears to follow the axis of an anticline, whereas the subsidiary channel has been cut into the parallel layers (Fig. 13a). However, the seismic data show that the erosional surface truncating the upper part of the anticline is overlain by a thin sedimentary unit (inset of Fig. 13a). This indicates that the erosion forming the inner channel has been replaced by deposition in this area. Figures 12b and 13b show that the channel of the SoI does not reach the large canyon, which commences on the SW slope and extends

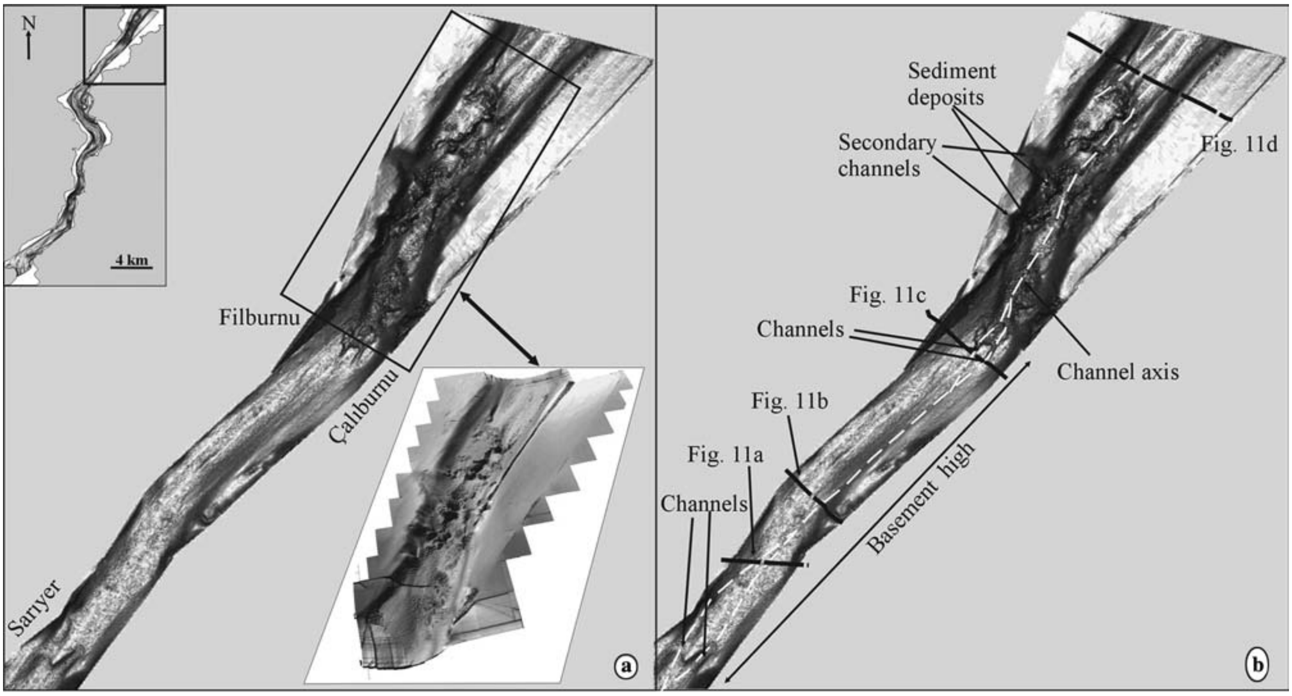



**Fig. 7** **a** Uninterpreted and **b** interpreted shaded relief map of the multi-beam bathymetry of the Strait of İstanbul between Sarıyer and the Black Sea entrance of the strait (*dashed lines* indicate the axis of the inner channel)

down into the abyssal plain of the Black Sea (Ross et al. 1974).

The channel at the southern entrance to the SoI situated on the north-eastern shelf of the Marmara Sea has been studied in greater detail than is the case for its northern counterpart (e.g. Gunnerson and Özturgut 1974; Ergin et al. 1991; Gökaşan 1998; Hiscott et al. 2002; Oktay et al. 2002). Multi-beam bathymetry indicates that the Marmara Sea extension of the strait forms a wide, shallow trough at the southern exit, which extends to the shelf edge at −70 m (Fig. 14a). The seismic data show that the eastern slopes of the trough are characterized by offlapping of delta deposits subsequently covered by marine onlaps, whereas the western slope is controlled by faults (Oktay et al. 2002; Fig. 14b). The whole trough is draped by recent shallow-marine deposits (Fig. 14b). The NE slope of the Marmara Sea is cut by several small canyons (inset map of Fig. 14a), none of, which however, attain the size of the SoI valley.

## Discussion

### Erosional and depositional history of the Strait of İstanbul

Interpretation of the evolution of the Bosphorus can be made only by using morphological and seismic data, as no continuous sedimentary record is available from the deep basins in this region. To date, boreholes have penetrated only the upper portion of the sedimentary fill at the basin margins, and this only at a few localities (Yılmaz and Sakınç 1990; Algan et al. 2001; Kerey et al. 2004). According to previous studies (Pamir 1938; Gökaşan et al. 1997) and our own observations, the evolution of the strait commenced with a river developing at an erosional surface formed around the SoI in the Upper Miocene–Pliocene (Cvijic 1908; Pamir 1938; Perinçek 1991; Erinç 2000). The morphological effects of this erosion are still traceable with a mature horizontal surface on Palaeozoic–Mesozoic bedrock (Fig. 15a). The horizontal surface is inclined at low angles at opposite directions on both sides, and is cut by the modern slopes of the SoI. When these incline surfaces are projected, they join each other above the present sea level, yielding the profile of a mature river valley (Fig. 15a). This morphology indicates that the ancient river valley developed simultaneously with the mature erosion surface, as noted previously by Pamir (1938). On the basement palaeo-topography map in Fig. 15b, a fragment of this valley with a similar mature morphology can be traced within the SoI along the palaeo-high of Palaeozoic–Upper Cretaceous bedrock. Thus, the evolution of the strait possibly started with an erosional phase (Fig. 15c, stage 1). Subsequently, tectonic events deformed this valley and its southern side became a depositional basin (stages 2–4, Fig. 15b, c). The effects of tectonic activity were also observed on the seismic profiles used in this study (Fig. 16). Since the strait was deepened by incision of the southerly flow of the ancient river, and subsequently collapsed as a result of tectonic activity, it then became a narrow basin downhilling to the Marmara Sea (south), and thick sediments were

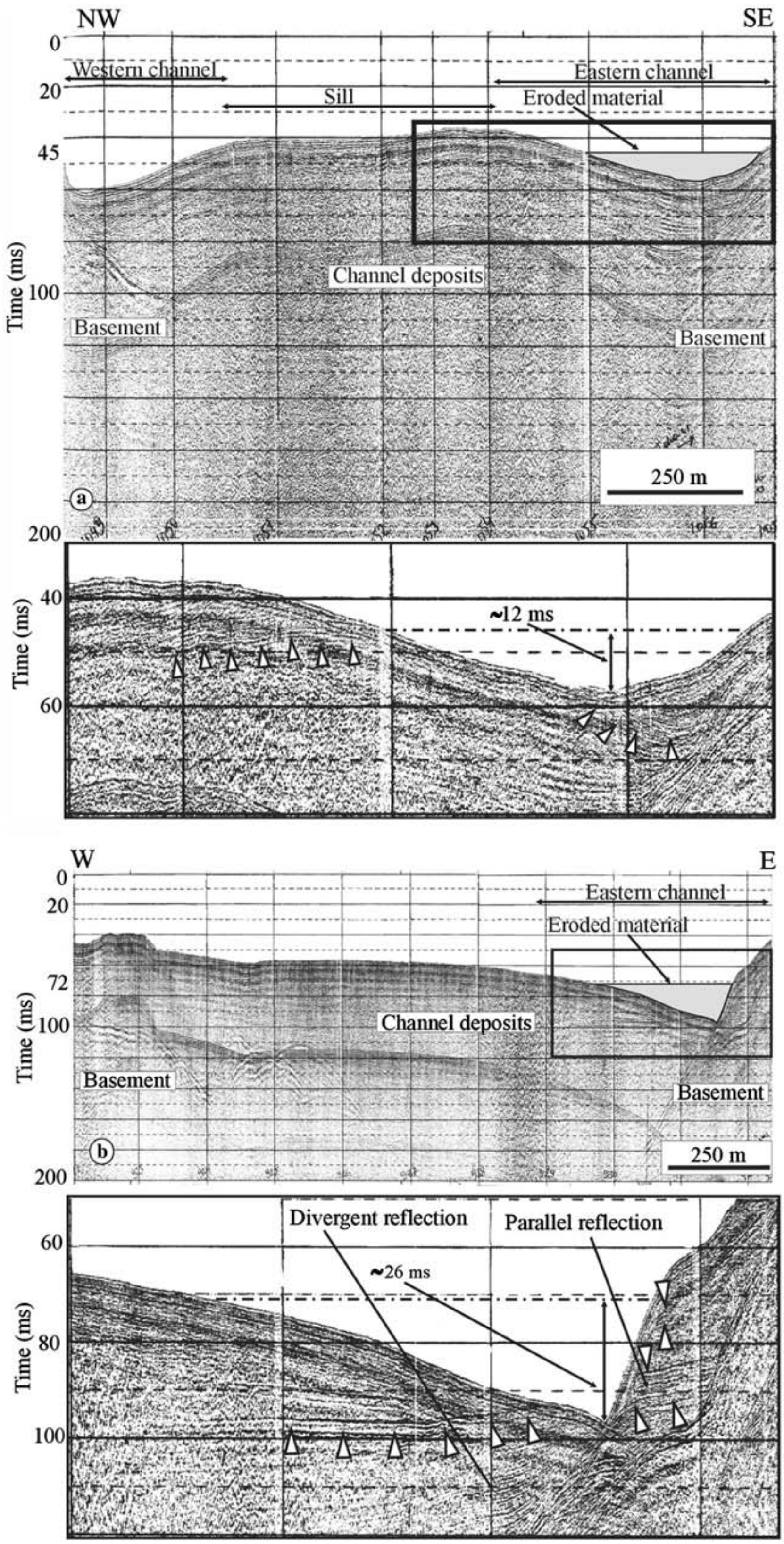
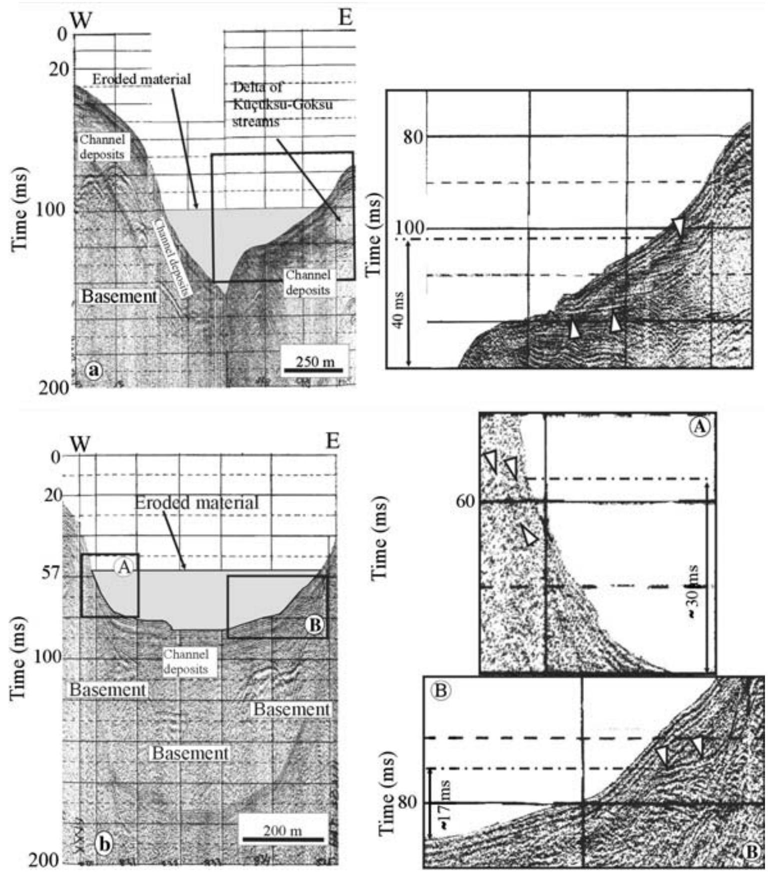



**Fig. 8 a, b** Seismic reflection profiles **a** near Üsküdar and **b** near çengelköy (modified partly after Gökaşan et al. 1997). *Grey-shaded areas* show the possible volume of the eroded material. *Open arrows* in the insets indicate truncated layers. Incision values are shown in the insets (see Fig. 2a for locations)

**Fig. 9** **a, b** Seismic reflection profiles **a** near Bebek and **b** near Kandilli. *Grey-shaded areas* show the possible volume of the eroded material. *Open arrows* in the insets indicate truncated layers. Incision values are shown in the insets (see Fig. 2a for locations)




deposited in the basin (Fig. 15b). Thus, an erosional stage was followed by deposition in the evolutionary history of the Soİ. Timing of initiation of the depositional phase of the Soİ is unknown due to the absence of sedimentary data. The sediments deposited in the channel may have been emplaced as alluvial fans, judging from the divergent reflection pattern of the deeper sedimentary layer (inset of Fig. 8b). However, the continuous parallel-bedded sediments of the upper succession (insets of Figs. 8b, 9a, 10a–c, 11a–d) indicate that a relatively deep condition must have prevailed during the latest phase of deposition. Depositional conditions persisted until the latest connection between the Mediterranean and the Black Sea (Gökaşan et al. 1997; Demirbağ et al. 1999; Algan et al. 2001; Kerey et al. 2004). Once the Mediterranean–Black Sea connection was established, an initial higher-energy situation was formed by the outflow of either Mediterranean (Ryan et al. 1997) or Black Sea waters (Aksu et al. 1999, 2002; Hiscott et al. 2002). This was subsequently replaced by the present, less vigorous two-layered current system in the strait (Ergin et al. 1991; Algan et al. 2001). Algan et al. (2001) and Kerey et al. (2004) detailed the last 26 ka of the history of the Soİ, using a borehole traverse between Selviburnu and Tarabya. The borehole data indicate that neo-euxinian lacustrine sediments were overlain by sedimentary deposits containing the Mediterranean forms dated at 5.3 ka b.p., and that the boundary of these two units was erosional. Kerey et al. (2004) interpreted that the upper deposits start with coarse, shell-rich sediments becoming finer upwards, and covered by green clay deposits indicating a relative rise in sea level. However, the presence of two coarsening-upward sequences in the upper part of the stratigraphy indicates that a higher-energy condition was re-established in the Soİ as a latest event (Kerey et al. 2004).

## Physiography of the inner channel

According to the seismic data, the shallow sub-bottom reflectors cropping out at the seafloor (Fig. 16) indicate recent erosion in the Soİ. Therefore, it is interpreted that the strait was originally filled by deposits up to the level of the shallowest eroded layer. The depth of this shallowest eroded layer varies from 41 to 100 ms (Figs. 8, 9, 10, 11), with an estimated average of 55 ms. This average value is inferred to have been the upper surface of the channel fill before erosion started (cf. ancient seafloor of the Soİ). Thus, the sector between the average depths of erosion and the deepest point of the present seafloor is assumed to have been filled by material before the erosion event (Figs. 8, 9, 10, 11, 17). The estimated volume of the eroded material amounts to ca. $2\times10^8$ m$^3$.

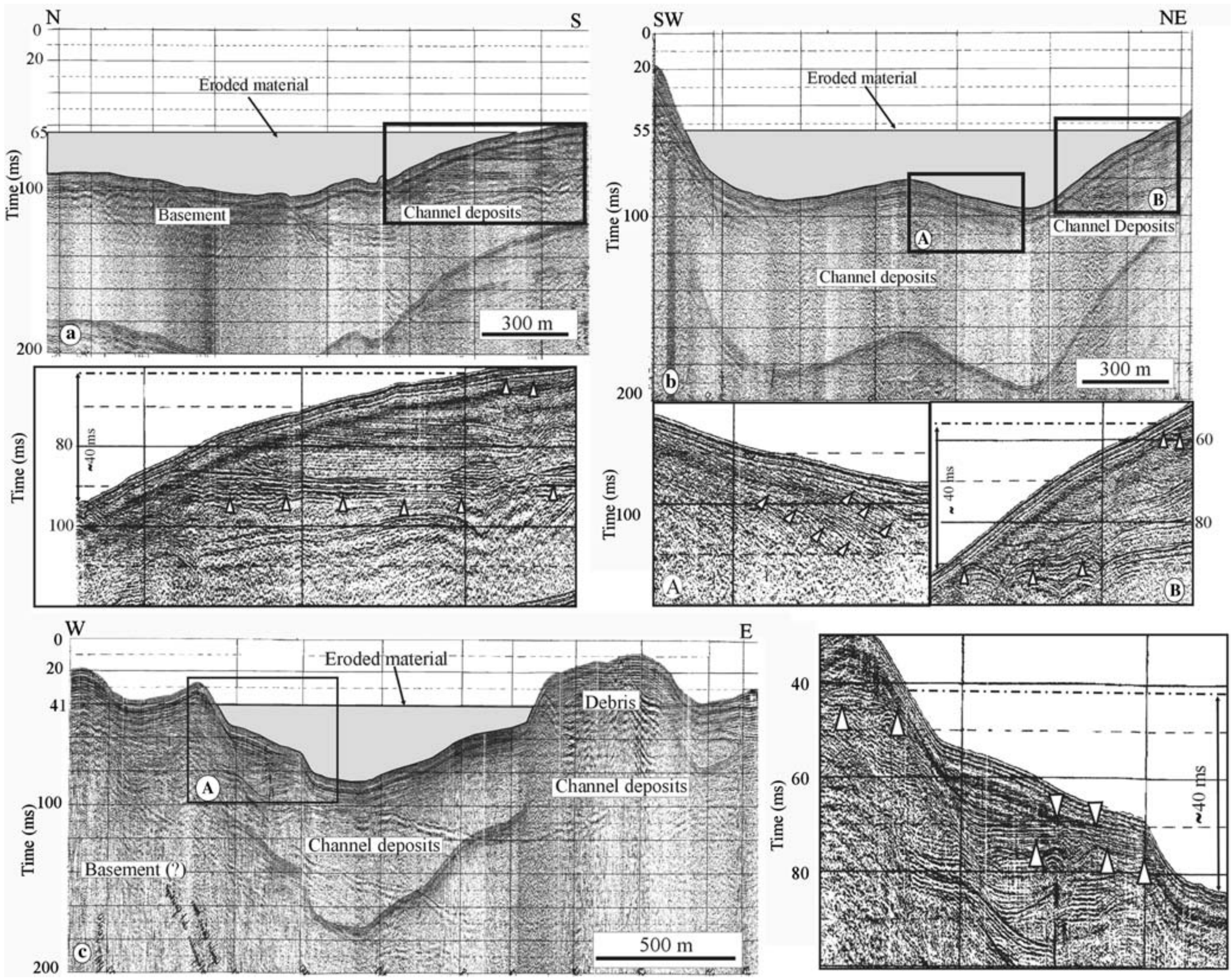



**Fig. 10 a–c** Seismic reflection profiles between Çubuklu (**a, b**) and Sarıyer (**c**). *Grey–shaded areas* show the possible volume of the eroded material. *Open arrows* in the insets indicate truncated layers. Incision values are shown in the insets (see Fig. 2a for locations)

The depth of incision increases from the south (9 m at the Marmara Sea entrance) to the north (34 m at the Black Sea entrance), to form an inner channel cut into the substrate of the Soİ. This inner channel is outlined by the 50-m depth contour in Fig. 2c. The morphology of this inner channel indicates that the flow was from south to north, i.e. from the Marmara Sea into the Black Sea.

The sedimentary sill and the basement high at the southern and northern entrances of the strait respectively must have played important roles in the evolution of the latest water connection, and the erosion associated with it. We contend that the sill controlled the flow by imposing a water divide during the initiation of erosion. On the other hand, the basement high at the northern entrance of the strait may have inhibited further incision by acting as a barrier, which protected the deposits along the strait from further erosion. Thus, most of the deposits in the strait would have survived erosion by the northerly flow.

## Possible reasons for the origin of the inner channel

Kerey et al. (2004) documented two coarse-grained sedimentary units separated by a clay horizon, which implies two erosional phases in the Holocene. The younger erosion phase may have been caused by the recent high-energy bottom currents. Velocity measurements of the two-layered currents along the strait showed that the dominant bottom current is on average faster than 20 cm/s (Ergin et al. 1991). Such velocities are certainly capable of eroding and removing finer materials. Highest velocities reach over 70 cm/s between Bebek and Kandilli (Ergin et al. 1991), coinciding with the deepest point of the strait (−108 m). North of

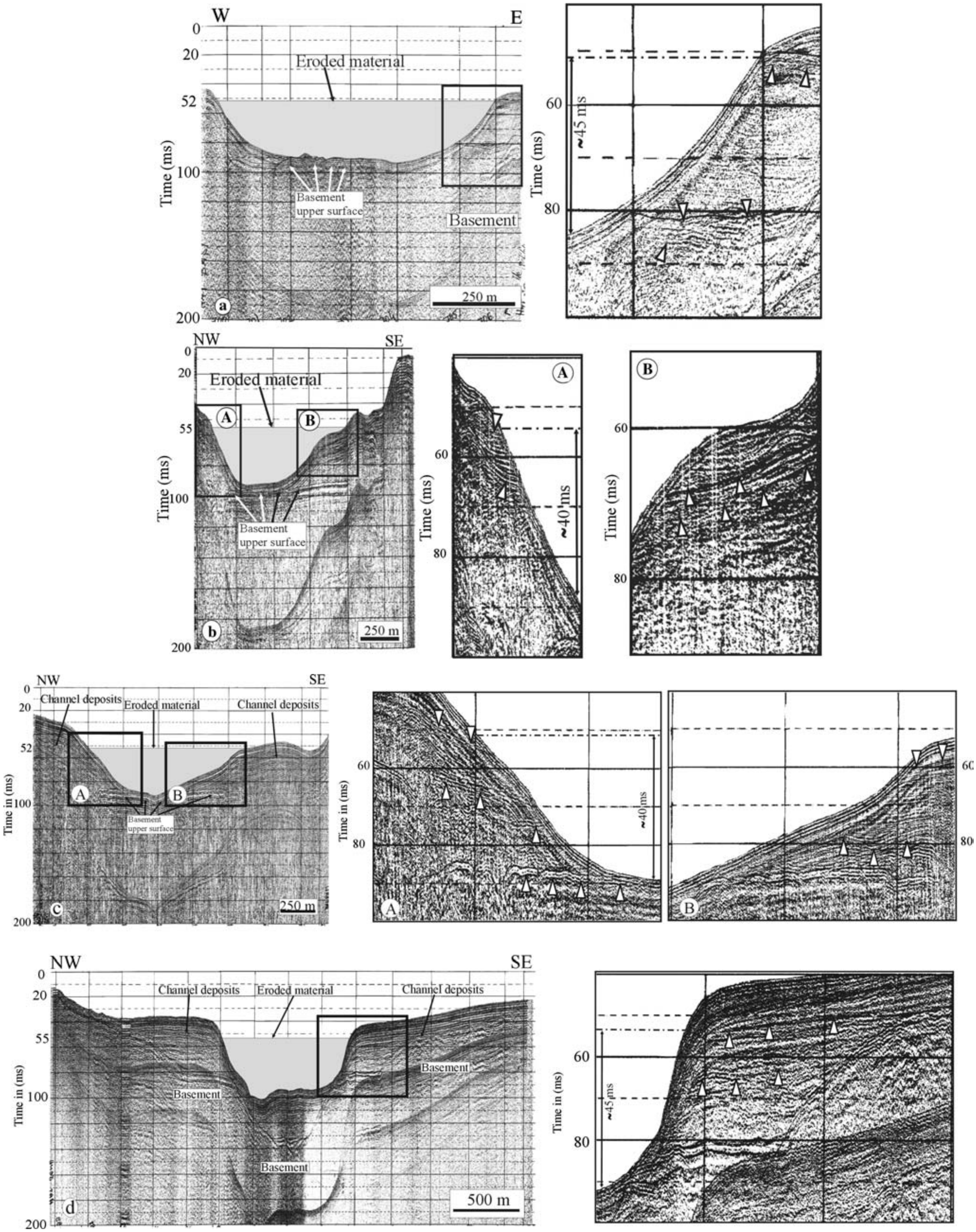



**Fig. 11 a–d** Seismic reflection profiles between Sarıyer and Black See entrance of the Sol (profile on **d** was modified partly after Gökaşan et al. 1997).*Capitals* indicate insets of the seismic profiles. *Grey-shaded areas* show the possible volume of the eroded material. *Open arrows* in the insets indicate truncated layers. Incision values are shown in the insets (see Fig. 2a for locations)

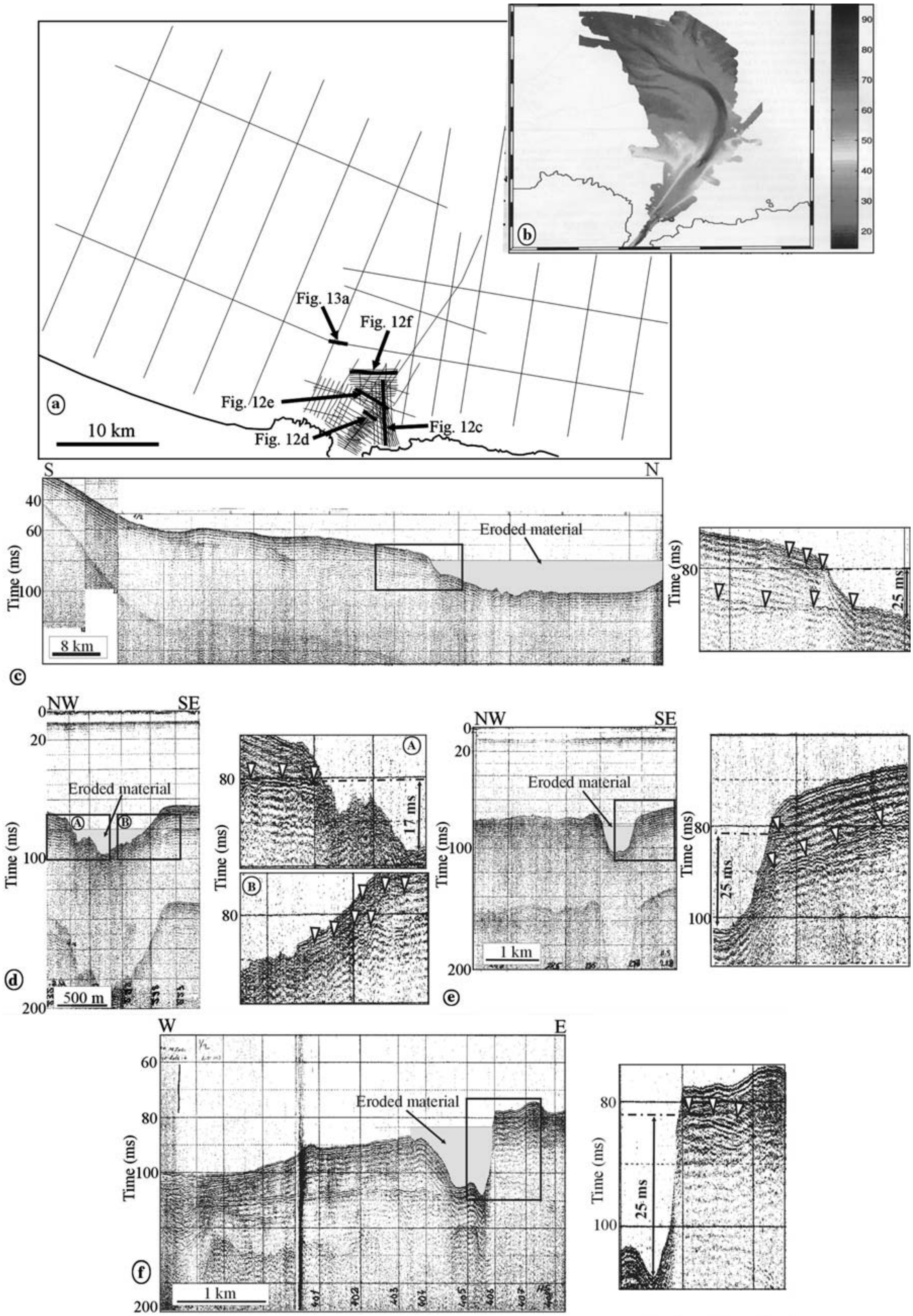



**Fig. 12 a** Locations of seismic reflection profiles obtained on the SW Black Sea shelf. *Bold lines* denote the sections shown in Fig. 12c–f and 13a. **b** Multi-beam bathymetry of the submarine canyon of the Strait of İstanbul on the SW Black Sea shelf (modified after DiIorio and Yüce1999). **c–f** Seismic reflection profiles. *Grey-shaded areas* show the possible volume of the eroded material. *Open arrows* in the insets indicate truncated layers. Incision values are shown in the insets (see **a** for locations)

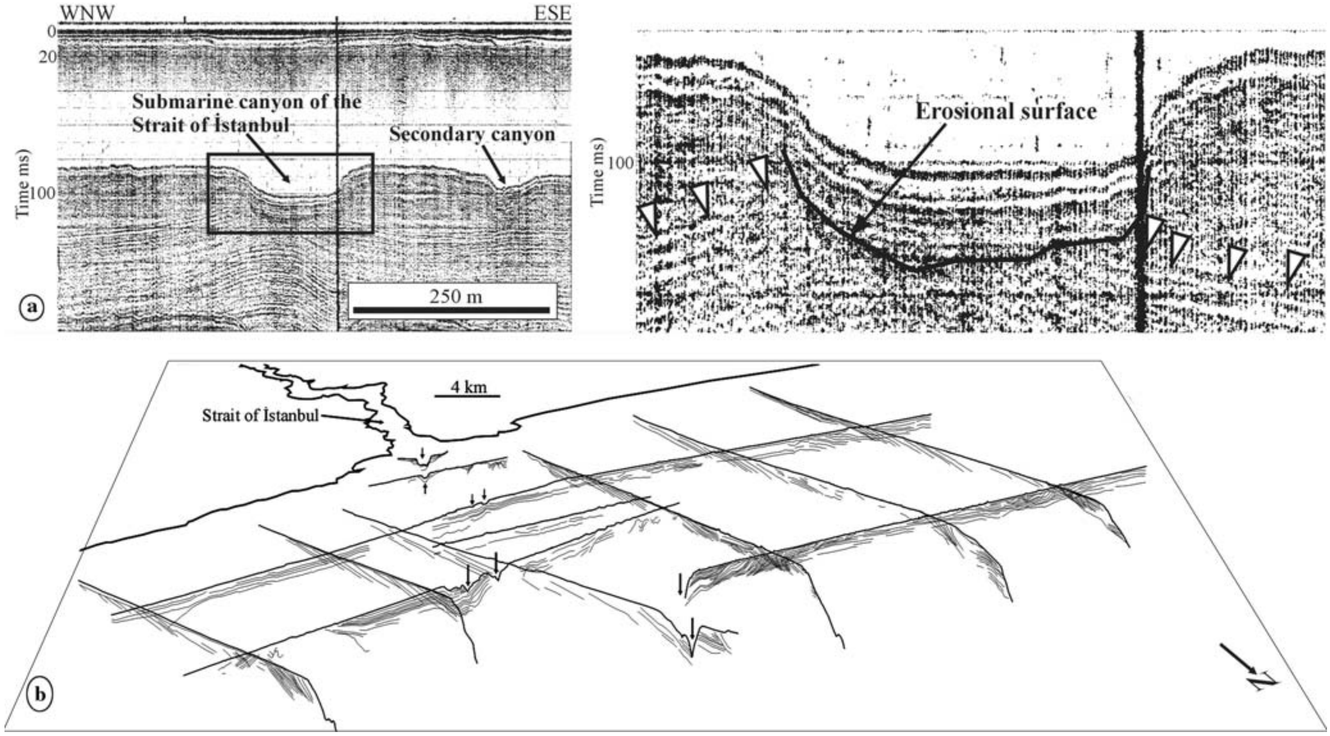



**Fig. 13** **a** A seismic reflection profile from the southernmost Black Sea. *Open arrows* in the inset indicate truncated layers (see Fig. 12a for location). **b** Latitudinal projections of seismic profiles on the SW Black Sea shelf (from north to south). *Short arrows* indicate the submarine canyon of the Strait of İstanbul and *long arrows* the canyons on the slope

Çubuklu, velocities decrease again as the strait abruptly widens. The sediment drifts observed on the bathymetric charts (Fig. 6) should thus be related to this diminishing bottom current. Although current velocity has been estimated to decrease from 50 to 20 cm/s towards the Black Sea entrance (Ergin et al. 1991), possibly due to thinning of the lower layer towards the Black Sea (Sholten 1974; Oğuz et al. 1990), more recent measurements have revealed that, due to meteorological conditions, the velocity of the bottom current increases at the Black Sea entrance of the strait (Özsoy et al. 1996; Sur et al. 2000). The existence of bottom currents along the valley of the SoI on the SW shelf of the Black Sea was documented by Di Iorio and Yüce (1999). This variation in velocity of the modern bottom current is consistent with local sediment erosion and deposition along the strait. Although the recent erosional effect of the bottom current was observed at some localities (i.e. between Bebek and Kandilli, where the maximum velocity occurs), observations in recent sediment depositional areas along the path of the inner channel (i.e. off Çubuklu, between Selviburnu and Tarabya in the SoI, and on the Black Sea shelf in the north; Figs. 5, 6, 13a) indicate that a previously higher erosion rate was necessary to form the inner channel of the SoI. Kerey et al. (2004) described a sharp boundary between the neo-euxinian sediments and the overlying deposits with Mediterranean fauna, indicating a significant time gap. This time gap with overlying coarse sediments would indicate strong erosion in the SoI with the Mediterranean invasion. Thus, erosion during the Mediterranean invasion would be the main reason for the origin of the inner channel of the SoI.

## An approach to the evolution of the inner channel

According to this model, the inner channel has mainly been formed by northerly flow of Mediterranean waters during the latest connection in the Early–Middle Holocene. Ryan et al. (1997) suggested that the last transgression in the Black Sea was fast and abrupt, being associated with invading Mediterranean waters flowing from the SoI onto the subaerially exposed shelf of the Black Sea. A rapid sea level rise in the Black Sea from −105 m to the present level was also documented by Demirbağ et al. (1999) and Algan et al. (2002). This rapid rise in sea level requires that a large volume of water entered the Black Sea via the SoI over a short period of time, as a result of which severe erosion occurred.

Previous studies suggested that the level of the Marmara Sea was 100 m below the present sea level (Smith et al. 1995), and that the Black Sea level was −105 m (Demirbağ et al. 1999; Algan et al. 2002) or deeper (Ryan et al. 1997) during the last glacial maximum. Stage A of Fig. 18a shows this situation. The level of the Marmara Sea started to rise some 12 ka b.p. after the initial Mediterranean Sea invasion (Çağatay et al. 2000), and thereby entered the southern entrance of the strait after the last glacial maximum. No throughflow took place

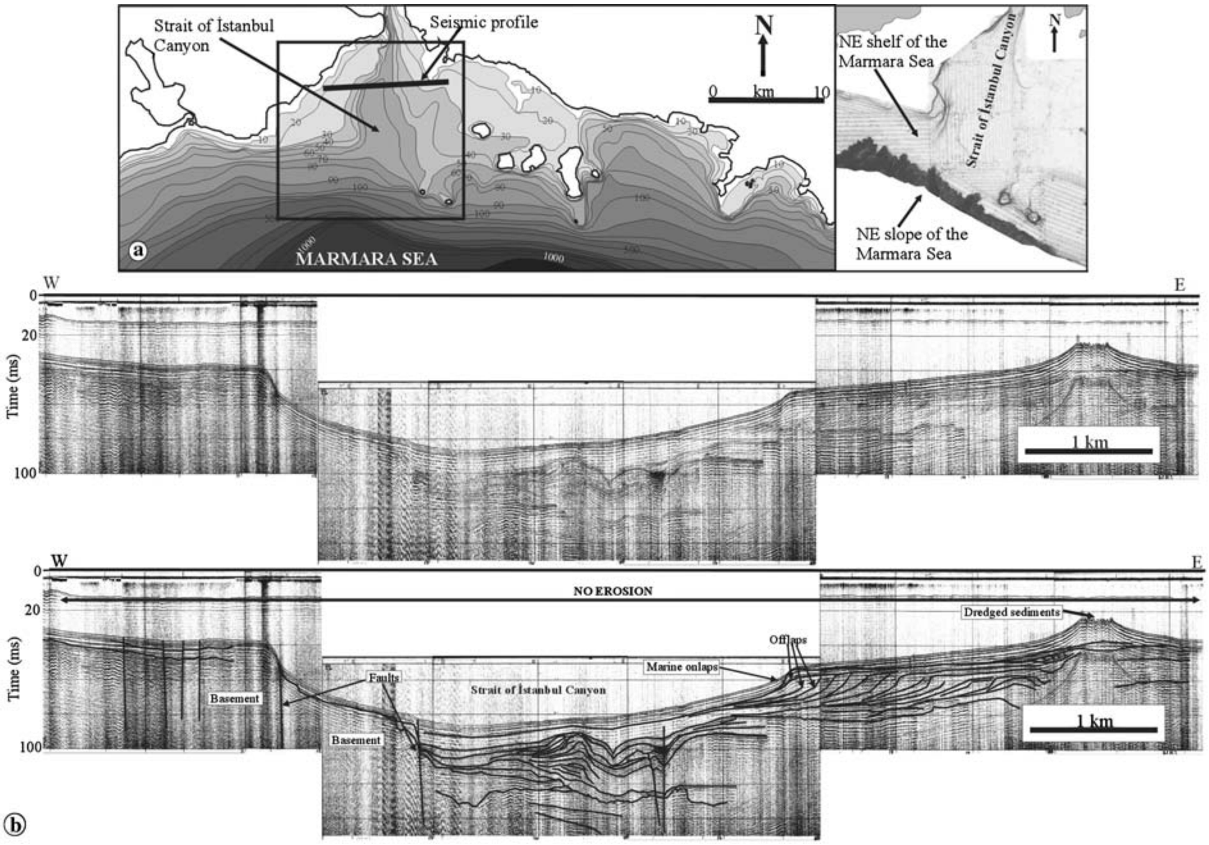



**Fig. 14** **a** Bathymetric map of the Marmara Sea exit of the study area (modified after Gunnerson and Özturgut 1974). *Inset map* shows the shaded relief image of the multi-beam bathymetry. **b** Interpreted and uninterpreted seismic profiles from the southern entrance of the Strait of İstanbul (see **a** for location)

until the water level reached and overtopped the sedimentary sill (level B in Fig. 18a). Demirbağ et al. (1999) suggested that the passing of a large volume of water over the sill in a short period of time may have been triggered by an earthquake in the course of which the upper part of the sill collapsed. Whichever the case may have been, the Mediterranean water masses flowing into the Black Sea eroded large volumes of sediment, as documented in this study (Fig. 18b). When the Black Sea level was raised by Mediterranean waters, the energy of the northerly Mediterranean flow reduced and locally sediment deposition commenced in some areas of the strait (i.e. in the widest part of the strait between Beykoz and Büyükdere (Kerey et al. 2004), and at the northern end of the SoI on the Black Sea shelf). With diminishing current velocities for Mediterranean waters, coarse sediments became finer upwards, and a low-energy condition was established in the strait for a short time, represented by clay deposition (Kerey et al. 2004). Subsequently, the two-layered current system along the SoI was established, and less vigorous high-energy conditions were re-established, represented by the upper upward-coarsening sedimentary unit (Kerey et al. 2004). Today, the channel floor along the narrow parts of the strait should be affected mostly by erosion, due to the high velocity of the bottom current (i.e. in the area between Bebek and Kandilli; Fig. 18c). On the other hand, sediment deposition is also continuing along the floor of the inner channel in the convex parts of the strait in the form of meandering deposits, for example, off Yeniköy, off Umuryeri where the strait widens in the form of drift sediments, for example, off Çubuklu, and along the slopes in the form of mass flows, such as north of Çengelköy and Umuryeri Bay. Therefore, depositional and erosional effects, together with some fault activity documented in previous studies (cf. above), account for the present-day, irregular seafloor morphology of the SoI.

The increasing depth of erosion towards the Black Sea entrance is considered as evidence favouring this model. However, since the Black Sea extension of the strait does not reach the canyon on the upper slope, this scenario is still partly unclear. The "fading out" of the strait on the shelf could be explained by (1) the Mediterranean outflow discharging into a lake located on the shelf, similar to Terkos Lake along the Black Sea coast of today (Fig. 1b; Demirbağ et al. 1999); (2) a fault having cut and displaced the Black Sea extension of the strait (cf. Demirbağ et al. 1999; Yılmaz 2005); (3) the Mediterranean outflow spreading across the shelf, thereby reducing its erosional force. These phenomena need further detailed studies in the region of the SoI canyon on the SW Black Sea shelf.

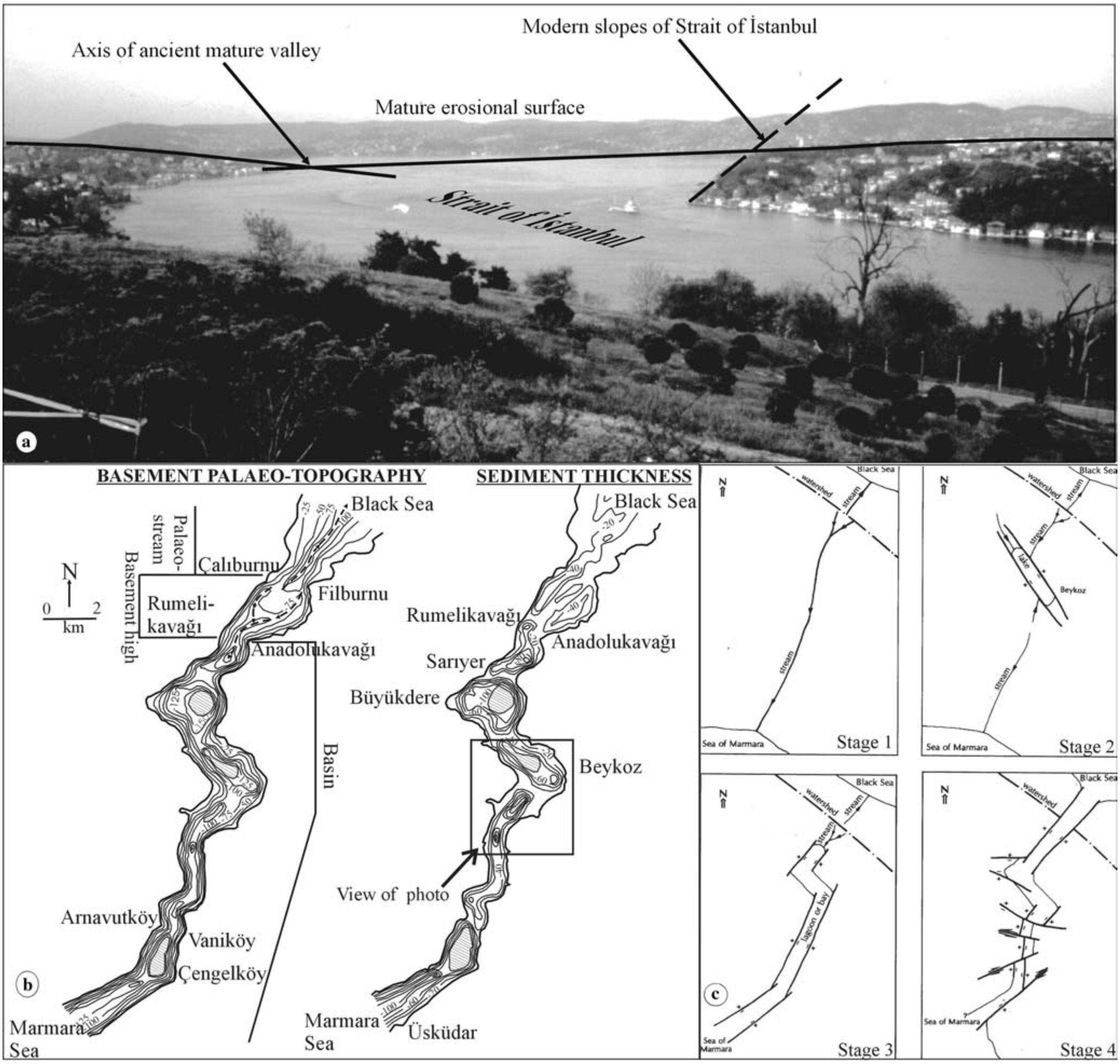



**Fig. 15** **a** A view from the Strait of İstanbul showing the relicts of a mature morphology of Upper Miocene–Pliocene-aged erosional events around the strait, and a correspondingly developed river valley along the Bosphorus axis (see sediment thickness map in **b** for view direction). **b** Maps of Palaeozoic–Upper Cretaceous basement palaeo-surface and thickness of overlying sediments (modified after Gökaşan et al. 1997). **c** Evolutionary stages of the Strait of İstanbul (modified after Gökaşan et al. 1997)

## Conclusions

Seismic and bathymetric data show that the floor of the SoI has been eroded. The erosion formed an inner channel by downcutting the sediment substrata of the SoI from the sill in the south to the end of the strait on the SW Black Sea shelf. The morphology of the channel and the estimated volume of eroded material indicate that the flow was from south to north. This inner channel was formed by the Mediterranean inflow to the Black Sea during the Holocene Mediterranean–Black Sea water connection; bottom currents of the two-layered current system in the SoI, which was established after the Mediterranean–Black Sea connection gave the final shape to the channel. On the basis of our present state of knowledge, this mechanism is a feasible alternative explanation, and further detailed investigations are required to resolve the issue.

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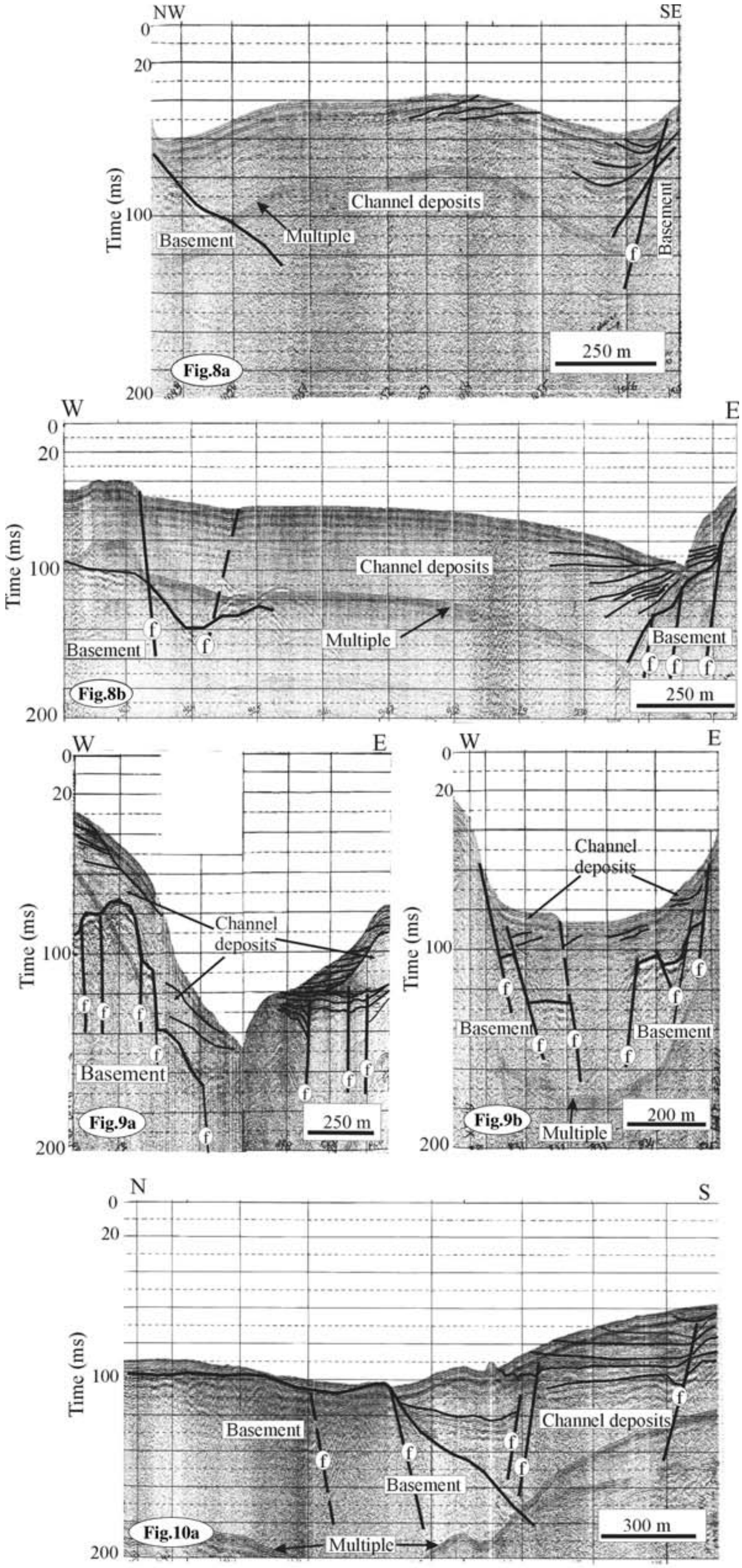


**Fig. 16** Interpreted seismic profiles illustrated in this study (*f* fault; each profile is labelled with its corresponding figure number)

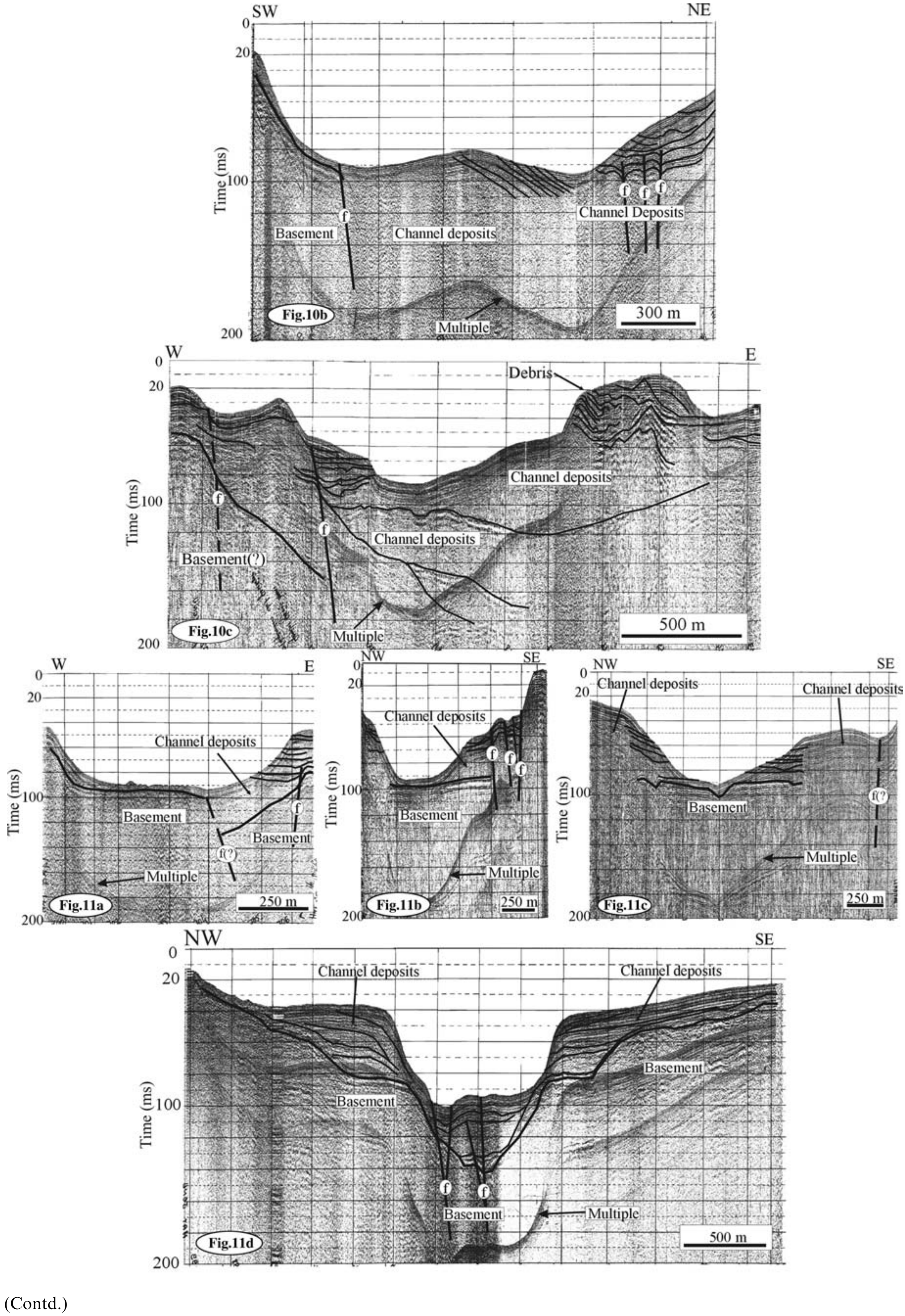
SW
NE
Time (ms)
0
20
100
200
Basement
Channel deposits
Channel Deposits
f
Multiple
Fig.10b
300 m
W
E
Debris
Channel deposits
Basement(?)
Fig.10c
500 m
Fig.11a
250 m
Basement
f(?)
NW
SE
Fig.11b
Fig.11c
Fig.11d

**Fig. 16** (Contd.)

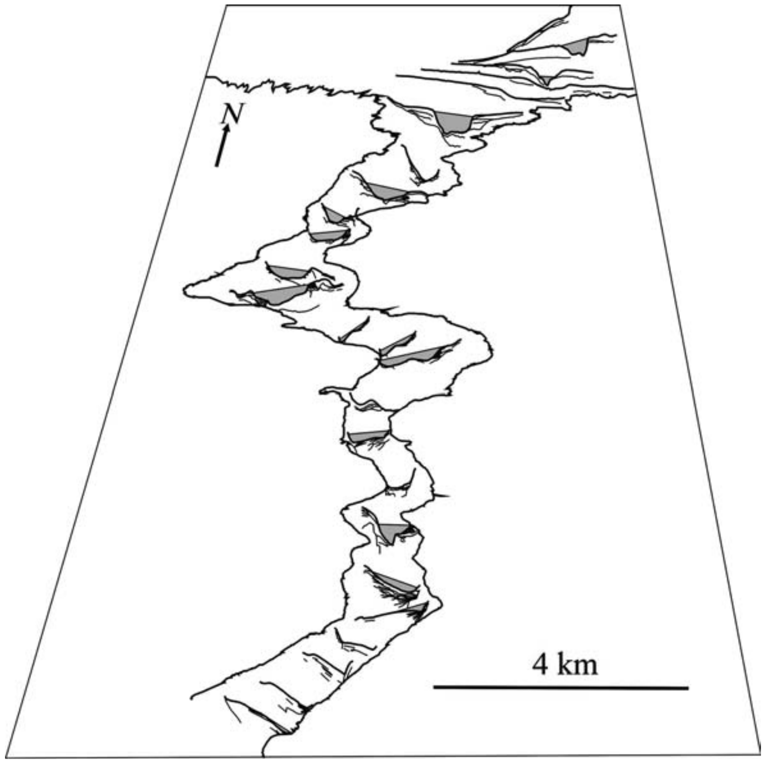


**Fig. 17** Latitudinal projections of seismic profiles of the Strait of İstanbul from south to north. *Grey– shaded areas*indicate eroded material

collection. We are also grateful to T. Ustaömer, F.Y. Oktay, O. Algan, and H.İ. Sur for their valuable contributions. Constructive comments by W.B. Ryan, G. Kelling and the editor of the journal B.W. Flemming were very helpful for the improvement of the paper.

## References

Aksu AE, Hiscott RN, Yaşar D (1999) Oscillating Quaternary water levels of the Marmara Sea and vigorous outflow into the Aegean Sea from the Marmara Sea-Black Sea drainage corridor. Mar Geol 153:275–302

Aksu AE, Hiscott RN, Yaşar D, Işler FI, Marsh S (2002) Seismic stratigraphy of Late Quaternary deposits from the southwestern Black Sea shelf: evidence for non-catastrophic variations in sea-level during the last 10,000 years. Mar Geol 190(1/2):61–94

Akten N (2004) Analysis of shipping casualties in the Bosphorus. J Navig 57:1–12

Alavi SN, Okyar M, Timur K (1989) Late Quaternary sedimentation in the Strait of Bosphorus: high resolution seismic profiling. Mar Geol 89:185–205

Algan O, Çağatay N, Tchepalyga A, Ongan D, Eastoe C, Gökaşan E (2001) Stratigraphy of the sediment infill in Bosphorus Strait: water exchange between the Black and Mediterranean Seas during the last glacial Holocene. Geo-Mar Lett 20(4):209–218

Algan O, Gökaşan E, Gazioğlu C, Yücel ZY, Alpar B, Güneysu C, Kırcı E, Demirel S, Sarı E, Ongan D (2002) A high-resolution seismic study in Sakarya Delta and submarine canyon, southern Black Sea shelf. Cont Shelf Res 22(10):1511–1527

Andrussow N (1900) Bosphorus und Dardanellen. Annu Gèol Minéral Russie 4:3–10

Çağatay MN, Görür N, Algan O, Eastoe C, Tchapalyga A, Ongan D, Kuhn T, Kuşçu İ (2000) Last glacial-Holocene paleoceanography of the Sea of Marmara: timing of the last connections with the Mediterranean and the Black Sea. Mar Geol 167:191–206

Cvijic J (1908) Grundlinien der Geographie und Geologie von Mazedonien und Altserbien. Gotha, Petermans Mitteil Erganzungsh I(162)

Darkot B (1938) Origin of the Turkish Straits (in Turkish). Geographical Research, Istanbul University, Lett Fak Geogr Inst Bull 4:1–14

Demirbağ E, Gökaşan E, Oktay FY, Şimşek M, Yüce H (1999) The last sea level changes in the Black Sea: evidence from the seismic data. Mar Geol 157:249–265

Di Iorio D, Yüce H (1999) Observations of Mediterranean flow into the Black Sea. J Geophys Res 104(C2):3091–3108

Ergin M, Bodur MN, Ediger V (1991) Distribution of surfical shelf sediiments in the northeastern and southwestern of the Sea of Marmara: strait and canyon regimes of the Dardanelles and Bosporus. Mar Geol 96:313–340

Erinç S (2000) In: Ertek A, Güneysu C (eds) Geomorphology I (in Turkish), 5th edn. Der Press, İstanbul

Eroskay O, Kale S (1986) Geotechnical results along the submarine passing line of the Strait of İstanbul (in Turkish). Eng Geol Bull 8:2–7

Gökaşan E (1998) The investinigation of the Quaternary evolution of the Bosporus by the seismic stratigraphic interpretation (in Turkish). PhD Thesis, Institute of Marine Science and Management, Istanbul University

Gökaşan E, Demirbağ E, Oktay FY, Ecevitoğlu B, Doğan E, Fettahoğlu MK, Şimşek M (1995) Discussion on the formation of the Strait of İstanbul using shallow seismic data (in Turkish). Geophysics 9(1/2):280–284

Gökaşan E, Demirbağ E, Oktay FY, Ecevitoğlu B, Şimşek M, Yüce H (1997) On the origin of the Bosphorous. Mar Geol 140:183–197

Gökaşan E, Gazioğlu C, Alpar B, Yüce ZY, Ersoy Ş, Gündoğdu O, Yaltırak C, Tok B (2002) Evidence of NW extension of the North Anatolian Fault Zone in the Marmara Sea; a new interpretation of the Marmara Sea (İzmit) earthquake on 17 August 1999. Geo-Mar Lett 21:183–199

Gökaşan E, Ustaömer T, Gazioğlu C, Yücel ZY, Öztürk K, Tur H, Ecevitoğlu B, Tok B (2003) Morpho-tectonic evolution of the

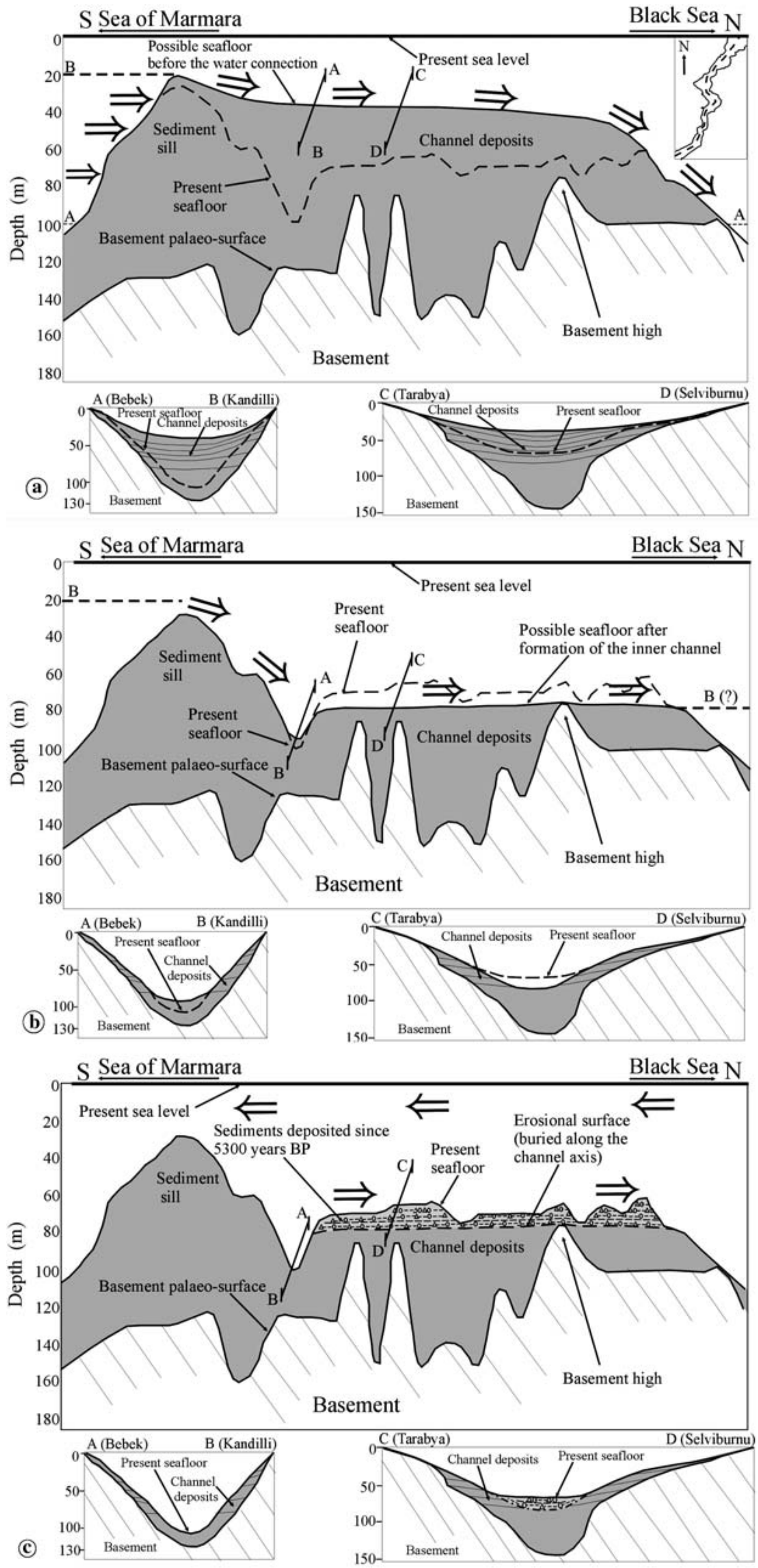


**Fig. 18 a–c** Longitudinal and latitudinal palaeo-geographic sections through the Strait of İstanbul (*dashed line* in inset map of **a** indicates the longitudinal section axis; modified after Algan et al. 2001). **a** Sections illustrating the environment prior to the Mediterranean–Black Sea connection. **b** Sections shows the environment after the formation of the inner channel. **c** Sections shows the present-day environment

Marmara Sea inferred from multi-beam bathymetric and seismic data. Geo-Mar Lett 23(1):19–33

Gunnerson CG, Özturgut E (1974) The Bosporus. In: Degens ET, Ross DA (eds) The Black Sea—geology, chemistry and biology. AAPG Bull 20:99–114

Hiscott RN, Aksu AE, Yaşar D, Kaminski MA, Mudie PJ, Kostylev VE, MacDonald JC, Işler FI, Lord AR (2002) Deltas south of the Bosphorus Strait record persistent Black Sea outflow to the Marmara Sea since 10 ka. Mar Geol 190(1/2):95–118

Hochstätter F (1870) Die Geologischen Verhältnisse des Östlichen Teils der Europäischen Türkei. Jahrb Kk Geol Reichsanstalt 20(1):365–461

von Hoff KEA (1822) Geschichte der durch Überlieferung nachgewiesenen natürlichen Veränderungen der Erdoberfläche,vol 8. Perthes, Gotha, pp 105–144

Kerey E, Meriç E, Tunoğlu C, Kelling G, Brenner RL, Doğan AU (2004) Black Sea-Marmara Sea Quaternary connections: new data from the Bosphorus, İstanbul, Turkey. Paleo 204:277–295

Meriç E, Oktay FY, Sakınç M, Gülen D, İnal A (1991a) Sedimentary geology and palaeoecology of the Quaternary sequences of Ayamama (Bakırköy-İstanbul) (in Turkish). Çukurova Univ Eng Fac Earthsci Bull 8(1):93–100

Meriç E, Oktay FY, Sakınç M, Gülen D, Ediger VS, Meriç N, Özdoğan M (1991b) Sedimentary geology and palaeoecology of the Quaternary sequences of Kuşdili (Kadıköy-İstanbul) (in Turkish). Çukurova Univ Eng Fac Earthsci Bull 8(1):3–91

Meriç E, Kerey İE, Avşar N, Tunoğlu C, Taner G, Kapan-Yeşilyurt S, Ünsal İ, Rosso A (2000) New results about the Mediterranean-Black Sea connection during the Late Quaternary (Holocene) (in Turkish). Turk Geol Bull 43(1):73–118

Oktay FY, Sakınç M (1991) The Late Quaternary tectonics of the Istanbul graben and the origin of the Bosphorus. EUG 6 Strasb Terra Abstr 3(1):351

Oktay FY, Gökaşan E, Sakınç M, Yaltırak C, İmren C, Demirbağ E (2002) The effect of North Anatolian Fault Zone to the latest connection between Black Sea and Sea of Marmara. Mar Geol 190(1/2):367–382

Oğuz T, Özsoy E, Latif MA, Sur Hİ, Ünlüata Ü (1990) Modelling of hydraulically controlled exchange flow in the Bosphorus Strait. J Phys Oceanogr 20(7):945–965

Özsoy E, Latif MA, Sur Hİ, Goryachkin Y (1996) A review of the exchange flow regimes and mixing in the Bosphorus Straits. In: Briand F (ed) Dynamics of the Mediterranean Straits, spec, vol 17. Bulletin de l'Institut Océanographique, Monaco, CIESM Science Séries No. 1, pp187–204

Pamir HN (1938) On the problem about the formation of the Strait of İstanbul (in Turkish). MTA Bull 3/4:61–69

Penck W (1919) Grundzüge der geologie des bosporus. Veröffentl Inst Meereskund Berl NF Reihe A 4:72

Perinçek D (1991) Possible strand of the North Anatolian Fault Zone in the Thrace Basin, Turkey—an interpretation. AAPG Bull 75:241–257

Phillipson A (1898) Bosporus und Hellespont. Geogr Zeitschr 4:16–26

Ross DA, Uchupi E, Prada KE, McIlvaine JC (1974) Bathymetry and microtopography of Black Sea. In: Degens ET, Ross DA (eds) The Black Sea—geology, chemistry and biology. AAPG Bull 20:99–114

Ryan BFW, Pitman WC III, Major CO, Shimkus K, Moskalenko V, Jones GA, Dimitrov P, Görür N, Sakınç M, Yüce H (1997) An abrupt drowning of the Black Sea shelf. Mar Geol 138:119–126

Sholten R (1974) Role of the Bosporus in Black Sea chemistry and sedimentation. In: Degens ET, Ross DA (eds) The Black Sea—geology, chemistry and biology. AAPG Bull 20:115–127

Smith AD, Taymaz T, Oktay Y, Yüce H, Alpar B, Başaran H, Jackson JA, Kara S, Şimşek M (1995) High-resolution seismic profilling in the Sea of Marmara (northwest Turkey): Late Quaternary sedimentation and sea level changes. Geol Soc Am Bull 107:923–936

Sur Hİ, Doğan E, Güven KC, Sarıkaya HZ, Okuş E, Öztürk İ, Eroğlu V (2000) Monitoring of the marine outfall system of the City of İstanbul. In: Avanzini C (ed) Proceedings of the conference on marine waste water discharge 2000. University of Genova, Italy, pp 295–305

Uluğ A, Özel E, Çiftçi G (1987) Seismic studies in the Strait of İstanbul (in Turkish). Geophysics 1(2):130–144

Yalçınlar İ (1947) About valleys around the Strait of İstanbul (in Turkish). Istanbul University Press, Fac Lett Hist Geogr Bull VI(1):69–72

Yıldırım M, Özaydın K, Erguvanlı A (1992) Geological structures and geotechnical features of the southern part of the Strait of İstanbul and Golden Horn (in Turkish). Geol Eng 40:5–14

Yılmaz Y (2005) Morphotectonic evolution of the southern Black Sea region and the Bosphorus channel. In: Yanko-Hombach V (ed) The Black Sea flood question: changes in the coastline, climate, and human settlement. NATO Science Series IV, Earth and Environmental Sciences (in press)

Yılmaz Y, Sakınç M (1990) Approach about the geological evolution of the Strait of İstanbul (in Turkish). In: Meriç E (ed) Late Quaternary (Holocene) deposits of the southern part of the Strait of İstanbul and Golden Horn. ITü Foundation Publications, Istanbul, pp 99–105

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