Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. **11**, 2002, pp. 61-81. *Copyright ©TÜBİTAK*

Sonar and High Resolution Seismic Studies in the Eastern Black Sea

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Abstract: The Black Sea is one of the largest inland seas in the world. Off the shelf, the water depth quickly plunges to an average depth of 2 km. The Black Sea sediments are rich in calcite and organic carbon, the latter showing a high degree of preservation due to anoxia in the waters below 100-150 m. Slope failures and sediment instability related to immense gas and gas hydrate accumulations are serious problems that can lead to the failure of offshore installations. Marine geophysical surveys have been carried out in the Eastern Black Sea basin using state-of the-art technology to produce sonar and high-resolution maps. A number of prominent structures were detected in the area such as slumping, sliding, pockmarks, faults and dome-like structures. In the Turkish near shore and the abyssal plain, shallow gas accumulations have been detected and are continuous about 25-65 m beneath the seafloor. The gas-bearing strata appear as bright spots and cloudy spots, sometimes pockmarks and acoustic blanking. The sediments on the Turkish shelf contain certain concentrations of gas which can seep to the seabed surface and generate pockmarks. Gas-hydrate layers in the sediments often appears as dark and strong reflection pockets on sub-bottom profiler records.

Key Words: eastern Black Sea Basin, sonar records, high resolution seismics, gas accumulation in marine sediments, gas hydrates

Doğu Karadeniz Baseninde Sonar ve Yüksek Ayrımlı Sismik Çalışmalar

Özet: Karadeniz, Dünya'nın en büyük iç denizlerinden biridir. Şelften uzaklaştıkça, su derinliği hızla ortalama 2 km'ye iner. Karadeniz tortulları, kalsit ve organik karbon açısından oldukça zengin olup, bu durum, 100-150 m derinlikten itibaren başlayan oksijensiz ortam nedeniyle yüksek derecede korunum olduğunu göstermektedir. Yoğun gaz ve gaz hidrat oluşumu birikimi nedeniyle, denizel mühendislik yapılarının yıkılmasına neden olabilen yamaç kaymaları ve tortulların duraysızlaşması önemli bir sorun oluşturmaktadır. Sonar ve yüksek ayrımlı kesitlerin oluşturulması için, Doğu Karadeniz baseninde bir dizi deniz jeofiziği çalışması yapılmıştır. Bölgede, kütle düşmeleri, kaymalar, deniz tabanına gaz sızmaları, faylar ve dom benzeri yapılar gibi birkaç önemli oluşum gözlenmiştir. Türkiye yakınlarında ve abisal düzlemde, deniz tabanının 25-65 m altında devam eden sığ gaz birikimi gözlenmiştir. Gaz içeren ortamlar, parlak ve gölgeli noktalar, sızıntılar ve akustik boşluklar olarak kendini göstermektedir. Türkiye şelfi tortulları belirli yoğunluklarda gaz içermekte olup, bunlar yer yer deniz tabanına sızarak çöküntü alanları (pockmark) oluşturmaktadır. Tortullardaki gaz hidrat tabakaları, yüksek ayrımlı sismik kesitler üzerinde koyu renkli ve yüksek genlikte yansıma paketleri şeklinde gözlenmektedir.

Anahtar Sözcükler: Doğu Karadeniz baseni, sonar kayıtları, yüksek ayrımlı sismik, denizel tortullarda gaz birikimi, gaz hidratlar

Introduction

The Black Sea, one of the largest inland seas in the world and lying at the junction between Europe and Asia, is both oceanographically and geologically unique because of its anoxic layer below 100-150 m. Although there is an excessive supply of terrigenous sediment input into the Black Sea, pelagic sedimentation plays the major role in the deepest parts of the basin.

Since 1991, the group formed around the UNESCO/TREDMAR Training-Through-Research program has investigated the Black Sea in collaboration with other groups. During these surveys, SIMRAD EM 12S low-frequency multibeam and SEABAT echosounders were used to obtain bathymetric charts and reflectivity maps of the seafloor. In addition, a MAK-1 deep-tow side scan-sonar and sub-bottom profiler system was used to get acoustic images of the seafloor and shallow sediments.

The SIMRAD EM 12S multibeam echosounder operates at 13 kHz frequency and has an angular coverage of 1200 m. The main objectives of the echosounder system are to (a) obtain accurate water-depth information in the survey corridor in order to determine absolute bathymetric contours; (b) obtain bathymetric profiles along certain corridors; and (c) identify large geomorphological elements, such as continental slopes, submarine canyons and seafloor slopes.

The MAK-1 combined side-scan sonar and sub-bottom profiler system has a swath range of up to 500 m per side in long-range mode (30 kHz), and up to 200 m per side in high-resolution mode (100 kHz). The sub-bottom profiler system works at a frequency of 6 kHz and the objectives of the full system are to: (a) identify small geomorphological elements, such as creep, mud slides, pock marks and sand ripples; (b) identify areas with different seabed sediments in conjunction with gravity corer information; (c) locate and identify artificial seabed features, such as wrecks, obstacles, debris, exposed submarine cables or pipelines; (d) identify areas of offshore activities (dredging, dumping, etc.); (e) determine shallow geology, including the thickness of surficial sediments and transitions between different layers; and (f) detect the presence of shallow gas, mud diapirs, faults, slumps, etc.

In this study, the side scan sonar and the sub-bottom profiler data, obtained during these expeditions will be given together with general outlines of the major features. Figure 1 shows the sample locations for the data (solid circles) presented of this study in the eastern Black Sea region. The numbers indicate data numbers, appearing in the text as figure numbers. Data numbers 3 to 5 are from the Russian shelf, continental slope and apron areas; data number 6 is unique section from the abyssal plain of the basin region, whereas data numbers 7 to 14 indicate Turkish shelf, continental slope and apron areas.

General Tectonics and Structural Elements of the Black Sea

The Black Sea is located within complex folded chains of the Alpine system, represented by the Balkanides-Pontides to south, the Caucasus to the east, and the Yayla Range in the Crimea to the north (Figure 2). The Black Sea represents one of the deepest intra-continental basins in the world and yet is poorly understood in terms of the mechanism controlling its subsidence history. The Black Sea has a key role in the understanding of the Alpine orogeny in Turkey, and has recently drawn considerable attention because of its petroleum potential (Okay *et al.* 1994; Robinson *et al.* 1996; Görür 1997; Kazmin *et al.* 2000).

Continental mid-Black Sea Ridge (Finetti *et al.* 1988; Robinson *et al.* 1996): (1) the E-W–trending oceanic Western Black Sea Basin (WBSB), and (2) the NE-trending Eastern Black Sea Basin (EBSB) floored by oceanic or highly attenuated continental crust. According to most modern views and consistent with the geological/geophysical evidence, the deep Black Sea basins do not show a "*granitic*" layer, but a lower crust with about a 6.8 $km.s^{-1}$ seismic velocity, indicating oceanic-type crust (Ross 1977). The Black Sea comprises two extensional basins separated by a NW-SE–trending.

Mountain-building processes and subsequent erosion of the mountains around the basin edges have contributed to high sediment input. Seismic studies indicate a 15-km-thick blanket of Cretaceous to Recent sediments (Zonenshain & Le Pichon 1986; Finetti *et al.* 1988) with unusually low seismic velocities (3.0-4.5 km/s; Şengör & Yılmaz 1981). Several models have been proposed for the opening of the basins. The first model suggests that both the WBSB and EBSB commenced opening simultaneously in the Late Cretaceous or earlier due to the southward drift of the Pontide arc and clockwise rotation of the Andrusov Rise (Zonenshain & Le Pichon 1986; Finetti *et al.* 1988). According to the second model, the WBSB is a back-arc basin developed above the northward-subducting Neotethyan Ocean by the rifting of a juvenile continental-margin magmatic arc during the Early Cretaceous (Adamia *et al.* 1974; Hsü *et al.* 1977; Letouzey *et al.* 1977; Görür 1988, 1991; Manetti *et al.* 1988). Recently, Görür (1997) suggested that the break-out of continental crust and the start of spreading occurred during the Cenomanian-Campanian interval. Okay *et al.* (1994) claimed that the İstanbul zone rifted off of the northern passive margin of the Black Sea by back-arc extension during Albian-Cenomanian time, then drifted southward along the Western Crimea fault in the east and western Black Sea fault in the west resulting in the opening of the WBSB. Simultaneous separation of the Andrusov Rise and the Shatsky Rise by rifting and

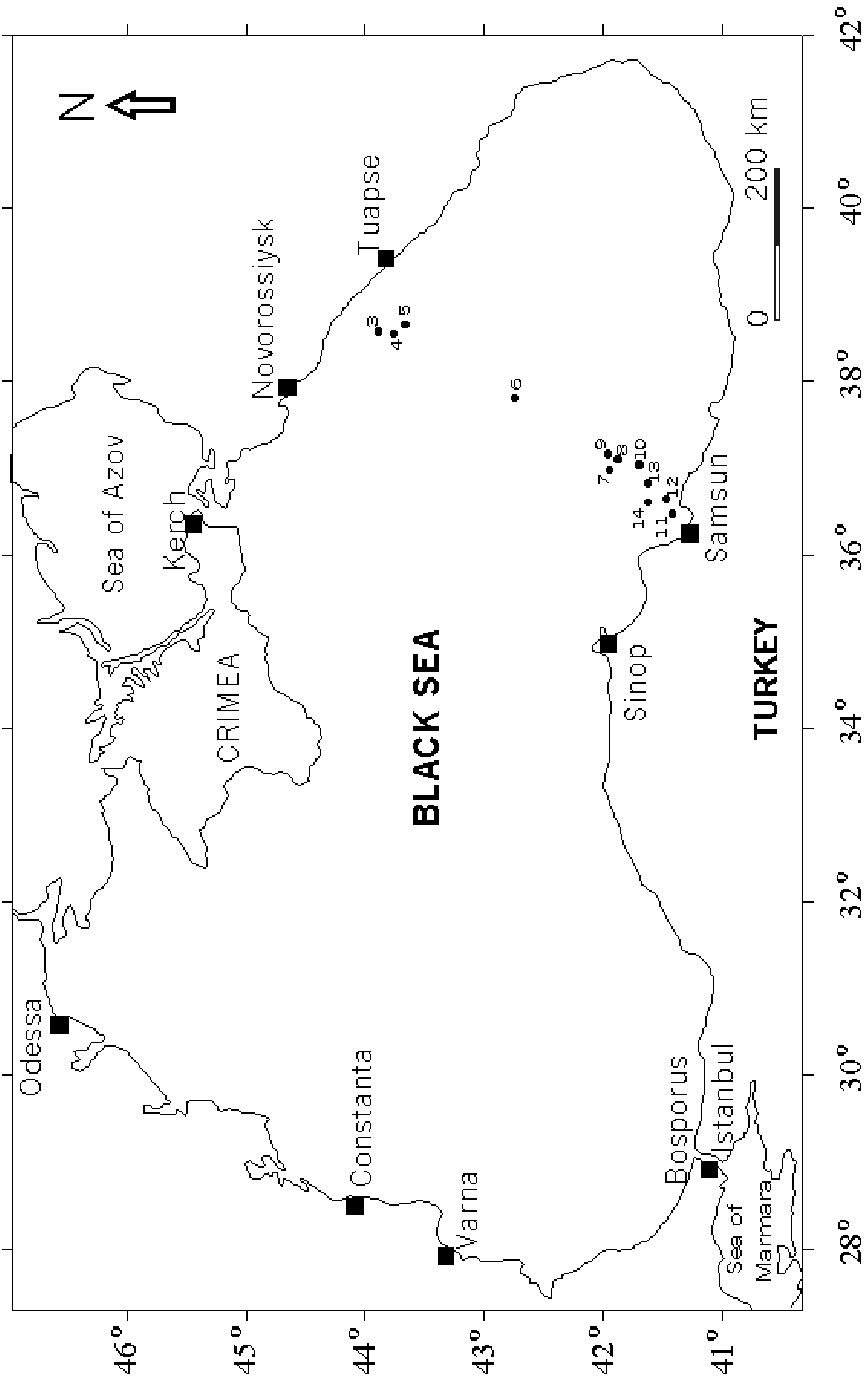

Figure 1. Sample locations for the data used in this study (solid circles). The numbers next to the circles correspond to the figure numbers. The profile directions are indicated in each figure.

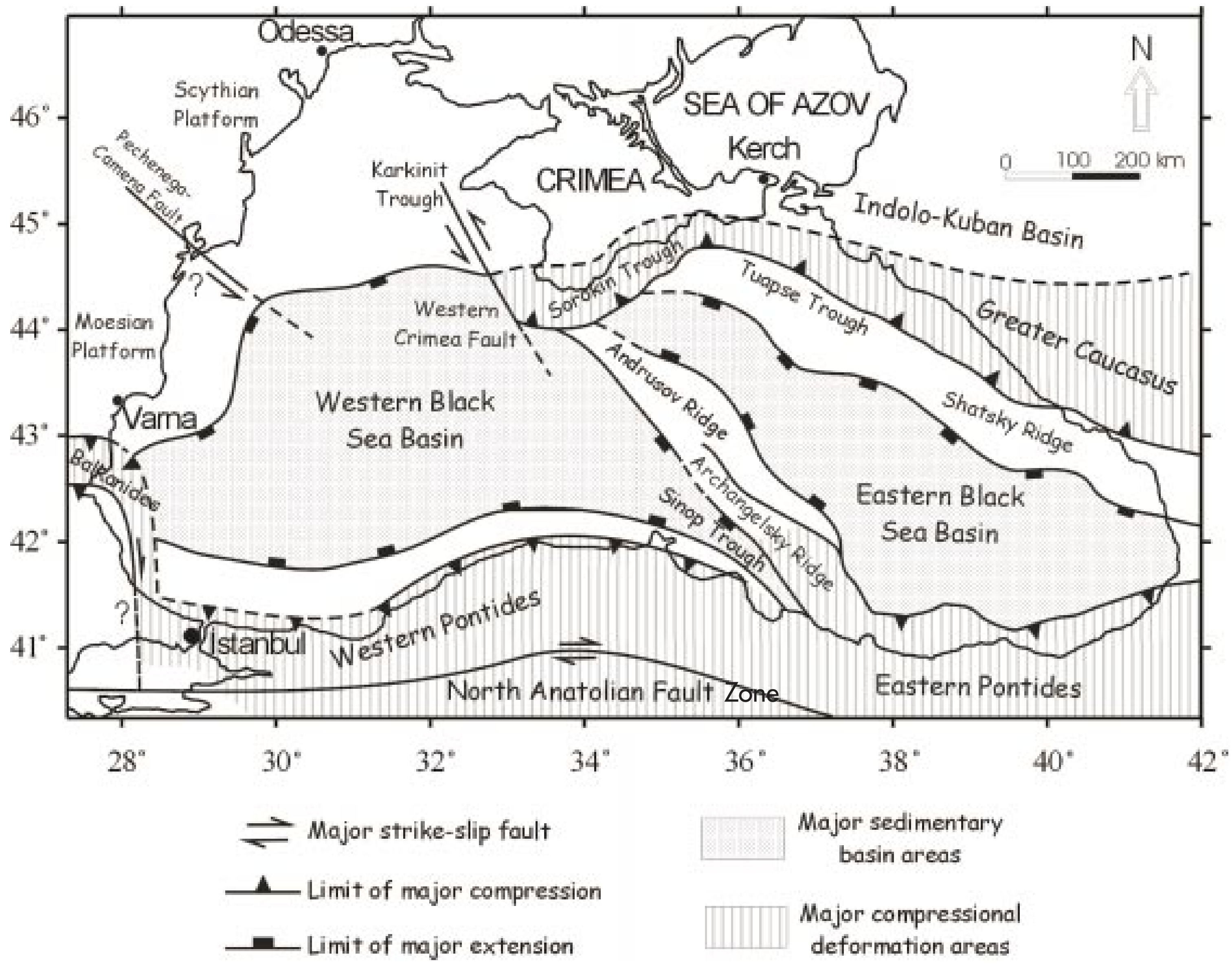

Figure 2. General tectonic framework of the Black Sea and surrounding region (after Finetti *et al.* 1988; Robinson *et al.* 1996; Kazmin *et al.* 2000).

anticlockwise rotation of the Shatsky Rise gave rise to the opening of the EBSB. According to the model of Robinson *et al.* (1995, 1996), the WBSB opened via back-arc rifting of the Pontides from the Black Sea margin in the Late Barremian-Albian time. EBSB is much younger and opened in Late Palaeocene and Early-Middle Eocene due to anticlockwise rotation of the Shatsky Rise, and Middle Palaeocene back-arc extension was superimposed upon the East Basin (Spadini *et al.* 1997). Okay & Şahintürk (1997) suggested a model that argues against anticlockwise rotation of the Shatsky Rise since there was no corresponding and/or shortening in the Greater Caucasus. They claimed that the WBSB opened in Barremian-Albian time as a back-arc basin behind the Pontide arc. The EBSB opened in Eocene time following the compressional phase in the eastern Pontides. According to this model, most of the western and eastern basins opened in the Eocene simultaneously, resulting from the southward drift of the Pontides and accompanying clockwise rotation of the Andrusov Rise (Kazmin *et al.* 2000).

The Shatsky Ridge is a buried regional feature, located between the overthrusts of the Greater Caucasus range and the deep Eastern Basin. It is a massive, uplifted crustal block with a highly asymmetrical shape. The consolidated crust of the Shatsky Ridge is 20- to 25- km-thick (Ergün & Çifçi 1999). The thickness of the overlying sediments increases from 1.5 to 9 km in the northeast. The southwestern slope of the Shatsky Ridge is very steep and forms a passive margin to the Eastern Basin as a system of listric faults. The Eastern Basin has a pre-Cenozoic basement measured to be at an average depth of 12 km. The basin has been filled with sediments of Mesozoic to Quaternary age. The Mesozoic sediments are intensely faulted and are overlain by a sequence of younger sediments (Finetti *et al.* 1988).

The transition from the eastern Black Sea Basin to the Turkish margin is marked by the Archangelsky Ridge, which is the southward continuation of the mid Black Sea Ridge. The Turkish continental slope developed toward the basin margin of the Archangelsky Ridge (Figure 2). On both sides, the Archangelsky Ridge is bounded by normal faults. These faults are of Palaeocene age and are overlain by more recent sediments (Ivanov *et al.* 1992). The Archangelsky Ridge is bound to the south by the eastern Pontide belt, a complex terrane formed by a sequence of orogenic events during the Mesozoic and Cenozoic.

The active North Anatolian dextral wrench fault divides the Pontides into northern and southern zones. The northern zone, forming the Turkish margin of the Black Sea, comprises by Upper Cretaceous and Eocene volcanics, asymmetric overturned folds and southward dipping thrusts (İzdar & Ergün 1989).

Interpretation of the Data from Eastern Black Sea Basin

The eastern Black Sea has all the geomorphological elements of a normal deep-water basin (i.e., shelf, continental slope, continental rise (apron) and abyssal plain; Çifçi *et al.* 1998). Several investigations have allowed us to determine the geomorphological elements of the shelf, continental slope, apron and abyssal plain. In this study, the data compiled from the eastern Black Sea are grouped into shelf, slope and abyssal plain regions. Therefore, each region and its major shallow geophysical and geological features will be discussed separately.

Russian Shelf

The Russian shelf has a flat, smooth surface, with a general inclination of 0.4°. The coastal slope extends from the coastline to the 50-m-depth contour. The very distinct shelf edge marks the transition to the continental slope and coincides with the 100-m-contour. The seabed sediments consist of clayey silt and clay with shell fragments. The total thickness of the soft sediments varies mainly between 5 and 7 m. In the area of the 30-m-depth contour, the soft sediment cover has a thickness of 10 to 12 m. A clay layer with shell fragments occur below the clayey silt layer. This clay layer almost crops out at the seabed surface in the area between the 40- and 60-m-contours. Slumping of soft sediments is observed between the 80- and 90-m-depth contours, and is caused by the topography of the upper boundary rock.

Between the 10- and 105-m water-depth contours, the sediment cover overlies bedrock. This bedrock is a continuation of coastal structures represented by almost vertical layers of carbonate flysch, which were derived from the erosion of rising fold structures and which have been subsequently deformed by continuing orogenic movements. The surface of the bedrock has been detected at a depth of 10 m below the seabed. Undulations in the bedrock surface were caused by erosion and occur in the area of the 70- to 80-m-depth contour. The upper surface of the sediment cover follows the topography of the underlying bedrock.

Outcrops as 3- to 4-m-high blocks have been observed between the shoreline and the 10-m water-depth contour. These rock outcrops and blocks are associated structurally with the outcrops on shore. Anomalous acoustic contacts have been detected in the area around the 90-m-depth contour, and probably result from clay cropping out through the sediment cover.

General slope-gradient changes from place to place, with some hillocks up to 5-m-high. The nature of these hillocks is as yet unknown. It is possible to attribute them due to an underwater spring.

Russian Continental Slope

The Russian continental slope has concave morphological characteristics in which the gradient becomes progressively gentler as it is traced downward toward the foot of the slope. This gradient resulted from a cycle of erosion which cause of the parallel retreat of the slope and the development of a random network of dendritic valleys. The initial part of the continental slope is situated between the 100- and 200-m-depth contours. The bedrock surface crops out in this area at the 105-m-contour. Then the continental slope deepens to 1510 m and has a maximum slope angle of 18.7°. The slope is cut by minor and major canyons that become broad U-shaped valleys in the deeper parts of the slope. The canyons are divided by small crests. The U-shaped canyons comprise wide troughs with flat bottoms and steep slopes (up to 25°). The bottoms of canyons are defined by hard acoustic deformation which show strong backscattering on sonar records. The ridges show up as relatively high backscattering and acoustic shades in canyon areas, and low backscattering in slope areas. Rough relief exists in this area. The ridge slopes are made up of hard clay that is covered by thin layers of recent sediments. Slump processes are observed at the ends of these ridges. The slope sediments consist of very soft clay that is liable to creeping and slumping (Figure 3). The sub-bottom profiler records reveal chaotic and distorted bedding near the seabed.

Russian Apron

This apron area is defined by several ridges and submarine valleys that have E-W orientations that parallel the coastline. The ridges, remnants of an anticlinorium which fades out to the west may be regarded as a continuation of the structures of the western Caucasus structure. Quaternary sediments, with thicknesses ranging between 0 and several 100 m, lie unconformably upon older rocks.

In this area, sub-bottom profiler records in many cases show a series of parallel thin-bedded sediments cut by faulting due to the presence of shallow gas. Figure 4 shows the profiler record of an indistinct structure at the base of the slope, which may be a slump body or an outcrop of older consolidated rock. The sediments on the ridges consist of very soft to stiff clay. Figure 5 shows the sub-bottom profiler and side-scan sonar records of the top of a ridge.

Slump bodies are covered by very thin (1 m) layers of parallel-bedded sediments. Faulting cuts the sediments in the submarine valleys. This faulting is related to the presence of shallow gas, that has resulted in circular pockmarks with diameters of up to 100 m at the surface. Comparable features are found on deeper parts of the Turkish continental shelf. The transition to the horizontal flat, abyssal plain is abrupt.

Abyssal Plain

The abyssal plain of the eastern Black Sea basin is a horizontal, flat area with a fairly constant depth of 2130 m. The observed sequence comprises rather continuous well-bedded reflectors that are interrupted in places by the piercing of gas and associated disturbances in the sedimentary sequence. Side-scan records exhibit no apparent relief. The prominent type of bottom surface type is the smooth, horizontal seafloor (Figure 6). Therefore, the horizontal movement of sediments in this region is uncommon.

Turkish Apron

The Turkish apron defines the transition from the abyssal plain to the continental slope between 1800 and 2140 m. The slope apron is characterized by gentle gradients, the disappearance of channels, and gentle sub-horizontal,

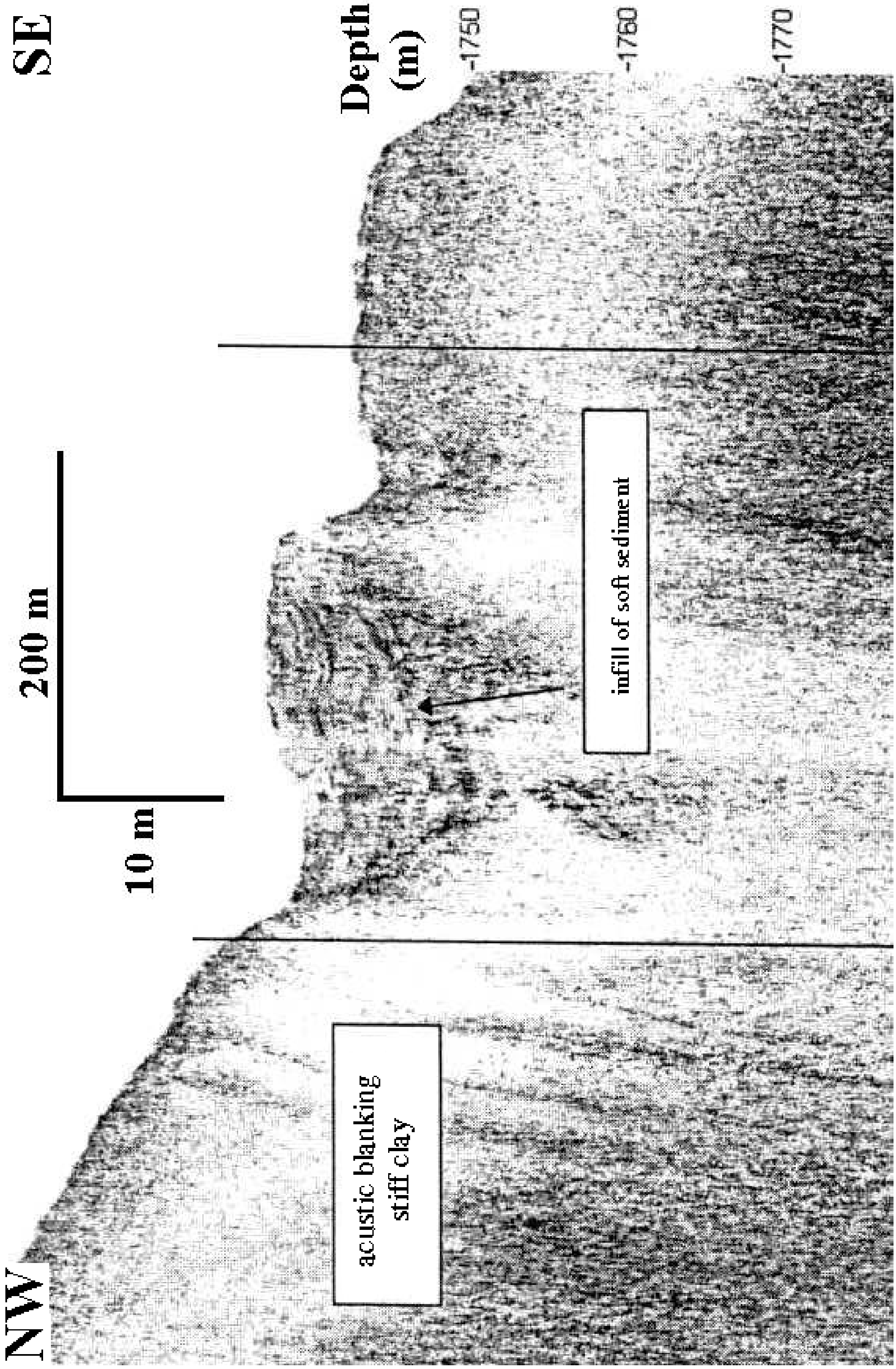

Figure 3. Sub-bottom profiler record showing infill of soft sediments at the Russian continental slope of the eastern Black Sea. Major clay accumulation results in an acoustic blanking zone.

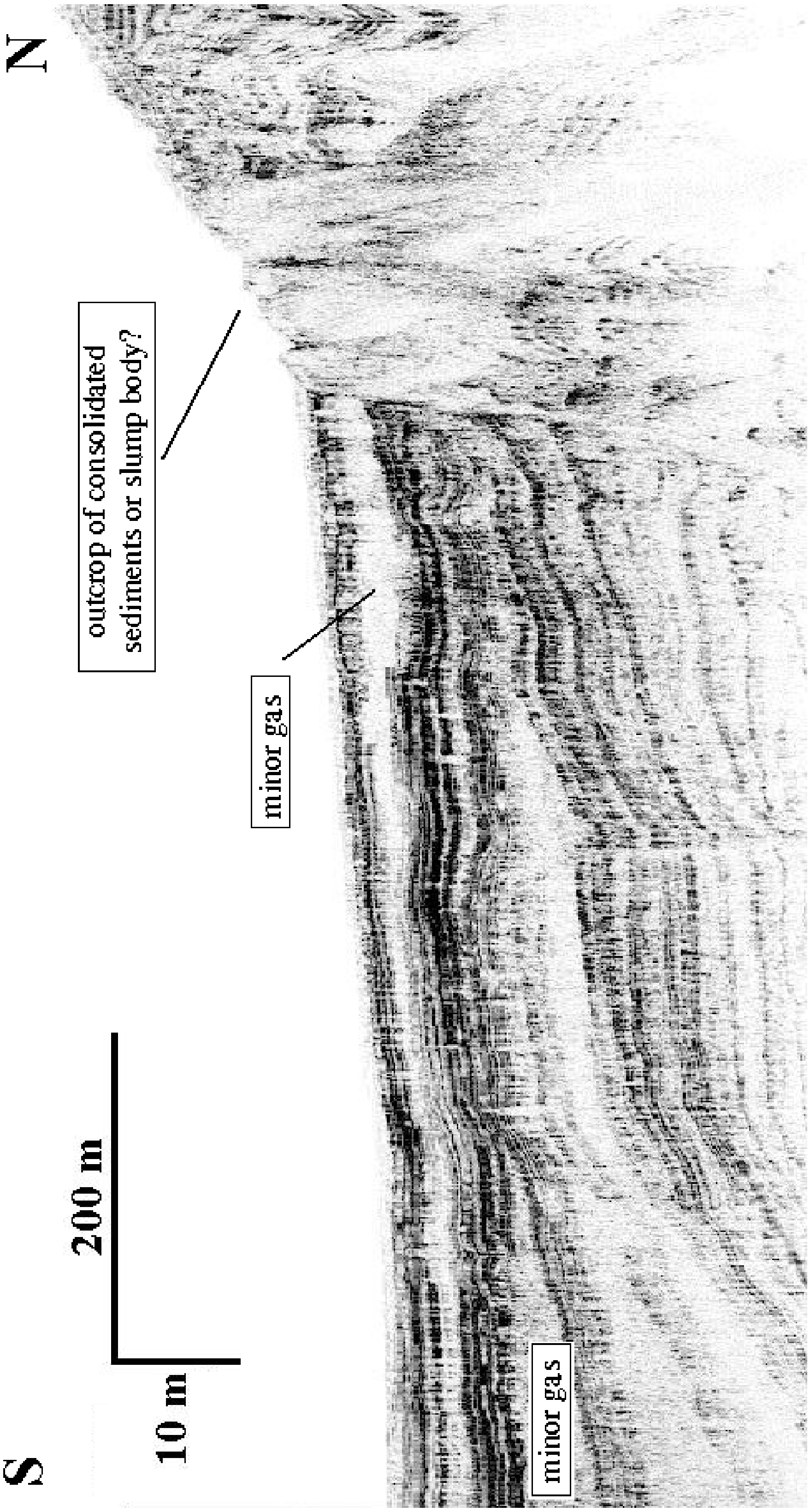

Figure 4. Sub-bottom profiler record from the Russian apron showing minor gas reservoirs and consolidated sediments at the base of a ridge slope.

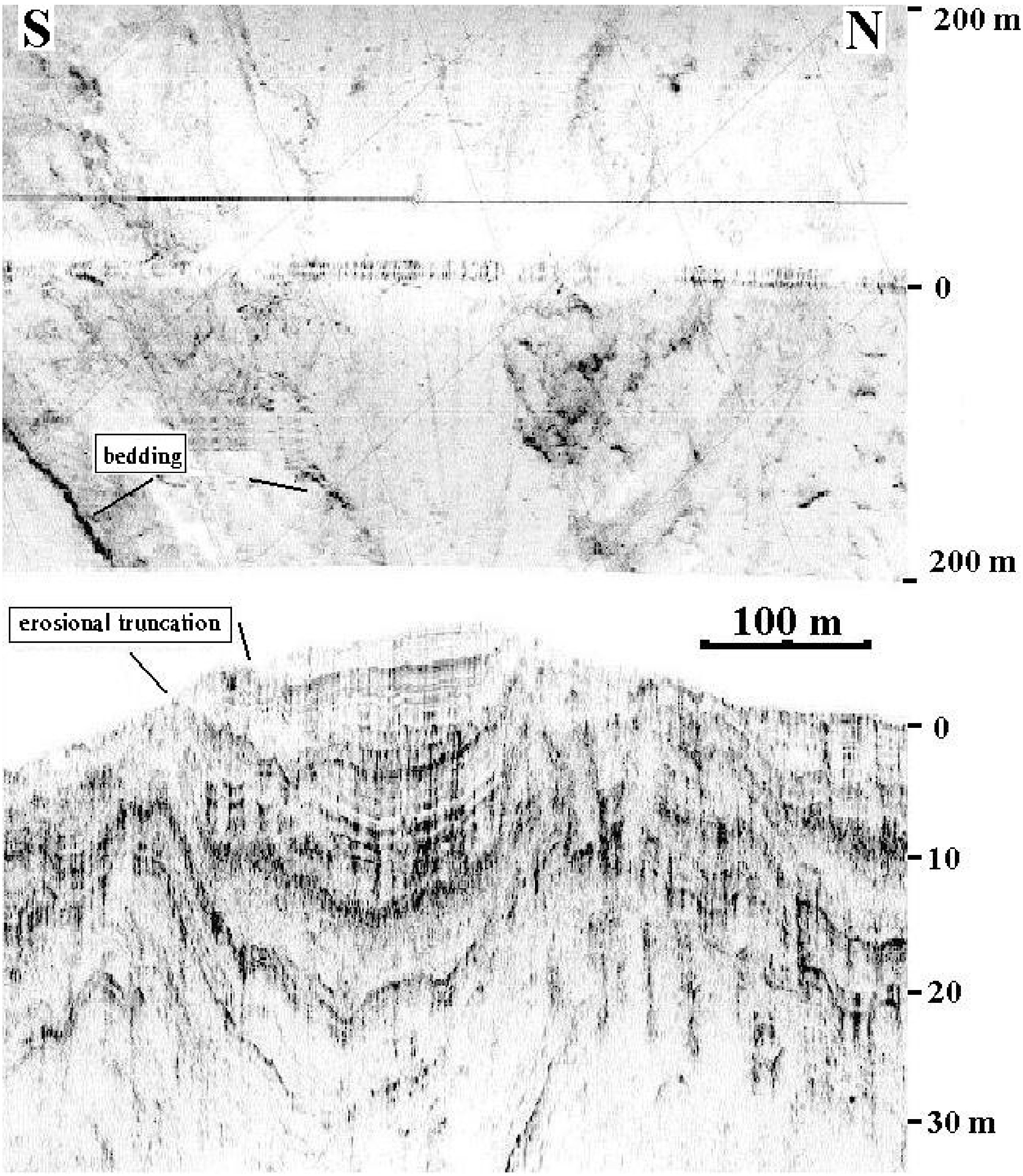

Figure 5. Record example of side-scan sonar (top) and sub-bottom profiler record (bottom) showing erosional truncation and bedding outcrop at the top of the ridge. The outcrop is defined as a high-backscattering line on the sonograph.

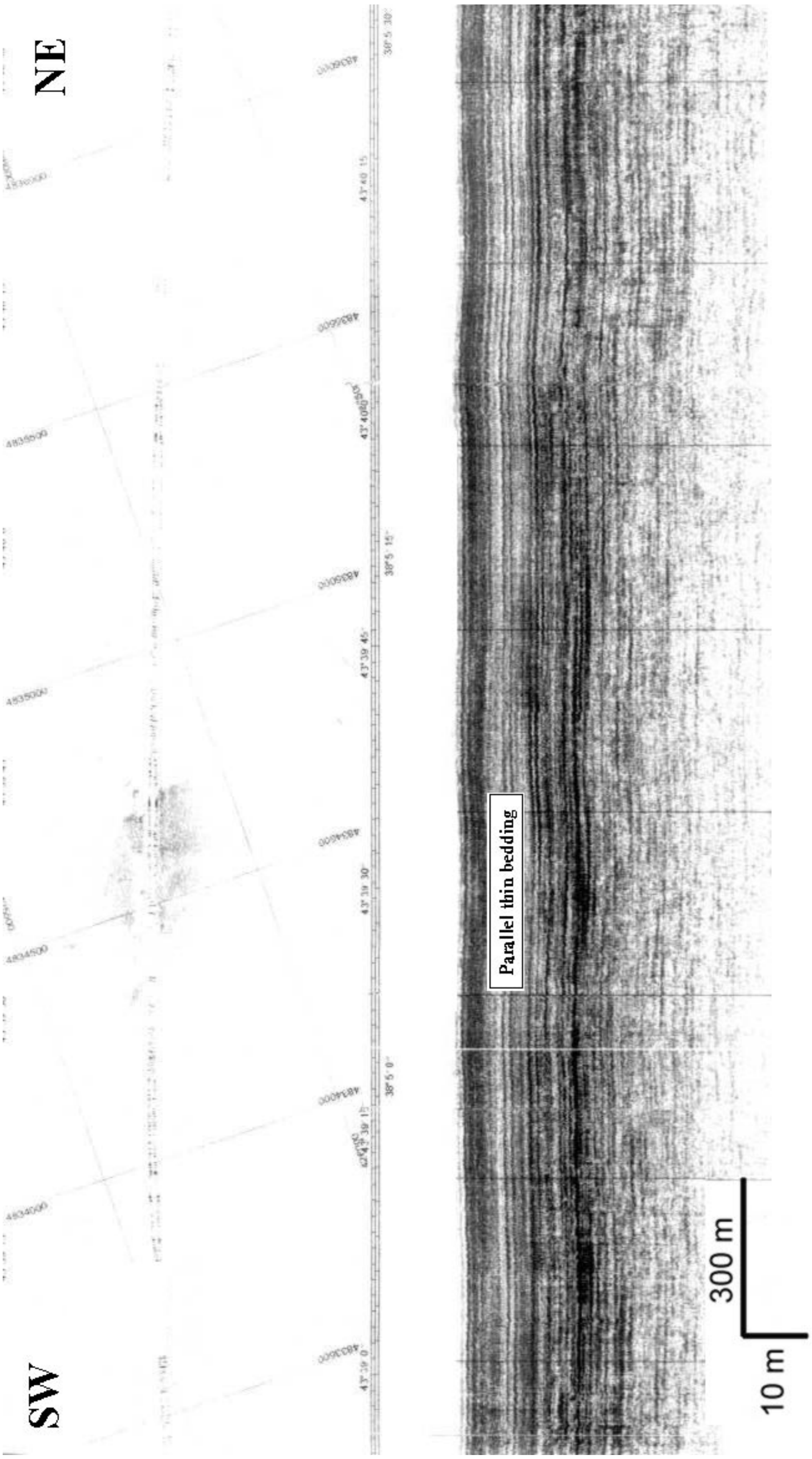

Figure 6. Side scan-sonar (top) and sub-bottom profiler record (bottom) showing parallel well-layered and undeformed sediments of the eastern Black Sea abyssal plain.

well-bedded formations of recent soft-unindurated sediments.

A seamount, with a diameter of 2500 m and a relative height of 60 m, is observed on the Turkish apron. This mount may be the remnant of a mud volcano and slump-slides of the slopes on both sides (Figure 7). The depth of shallow gas within this area is less than 10 m. More slump features and normal faults are located in this area.

The sub-bottom profiler data show an acoustic migrating wave pattern in the upper 100 m of the sub-bottom (Figure 8). This pattern most likely represents sediment waves formed by density currents originating from the southeast. These density currents are believed to have been initiated by sediment outflow from the Turkish coast located to the southeast of this area.

The side-scan sonar records display numerous sinuous lines which may represent initial tension fractures in the uppermost sediments. These fractures are considered to be related to sediment instability which is due to the presence of shallow gas.

Discontinuous acoustic blanking by shallow gas is observed extensively within the sub-bottom sediments of the Turkish apron. High-amplitude reflectors are observed between the areas of acoustic blanking at depths of 15 to 40 m. These reflectors may represent gas hydrates.

Turkish Continental Slope

The continental slope deepens from 600 to 1800-2000 m (Figure 9) and comprises rectilinear gullies and V-like channels. In contrast to the concave Russian continental slope, the Turkish continental slope has a convex morphology. The slope gradient becomes progressively steeper as it is traced downward and this is a result of either mass movement or structural control. The continental slope is not cut by many canyons and valleys. The sediments on the continental slope show slump and creep structures. Seabed slumping and creep occur mainly in areas with slope gradients over 2°; this has been clearly identified both by slide faults on the sonar and especially by landslides on sub-bottom profile records. The channels can be identified clearly on sonar mosaics, bathymetric charts and sub-bottom profiler records, but are most visible on the cross-lines of sub-bottom profiles.

The velocity and direction of the sliding and flowing down of material is not constant along the slope. The sediment transportation direction is controlled by the general directions of the slopes and channels.

The seismic records show another interesting, acoustically anomalous reflector as a sequence of pockets. These anomalous reflectors are interpreted as gas-(mostly methane) transformed, solid-case gas hydrates, sometimes gas-hydrate crystals, and are typically represented by dark strong reflections (Figure 10).

Turkish Shelf

The shelf edge (slope) is located at a water depth of about 100. Strong reflections were determined beneath the seafloor at about 15-45 m (Figure 11). These strong reflection packets can be interpreted as gas-hydrate layers. Hydrates can form only at certain temperatures and certain pressures (Stoll & Bryan 1979; Sloan 1990). Stable-methane hydrates are found at temperature and pressure conditions that exist near and just beneath the seafloor on continental margins with high rates of sedimentation, and where water depths exceed 500 m (Xia *et al.* 2000). Gas hydrates are a type of natural formation that contains large amounts of methane, also known as natural gas, and water in the form of ice. They are a potential source - possibly a very important source - of energy for the future. However, little is currently known about cost-effective ways to make hydrates an energy resource.

Studying and understanding hydrates are important for a variety of reasons: (1) hydrates have potential as a future energy resource; (2) hydrates may be a source and also a sink for atmospheric methane. Better understanding of these natural deposits may increase our understanding of climate change, (3) Hydrates affect the strength of the sediments in which they are found, areas with hydrates appear to be less stable than other areas of the seafloor; (4) gas hydrates may be a hydrocarbon indicator where the seafloor is at greater depth; and (5) hydrates currently cause blocking in some underwater natural-gas pipelines. This problem had an increasingly negative impact as gas producers drill wells in deeper water.

Consequently, it is important to determine the presence of gas haydrates prior to the construction of

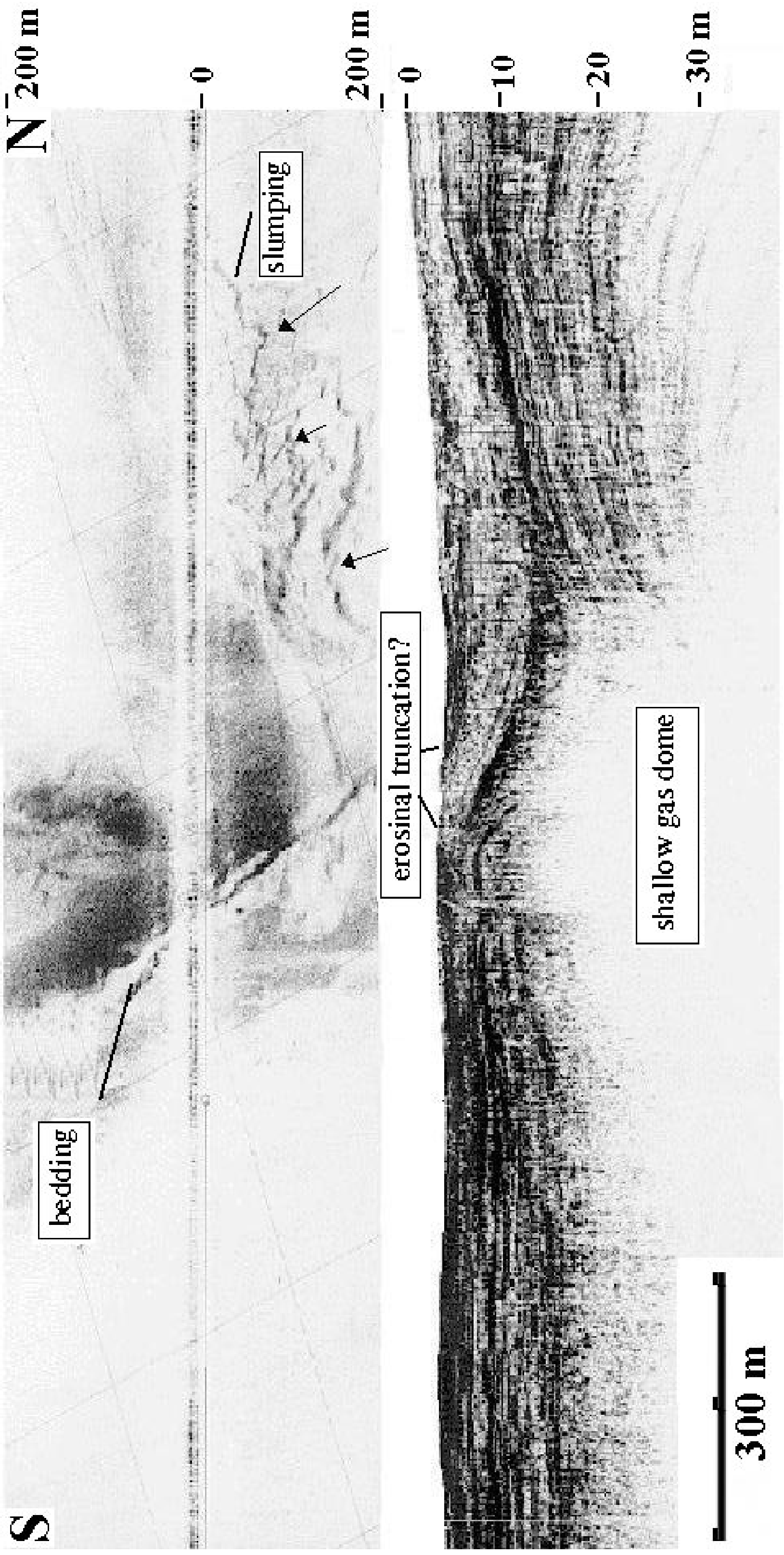

Figure 7. Example of side-scan sonar (top) and sub-bottom profiler (bottom) records showing slumping and creep off slope of a mount (possible mud volcano) with a shallow gas dome from the Turkish apron.

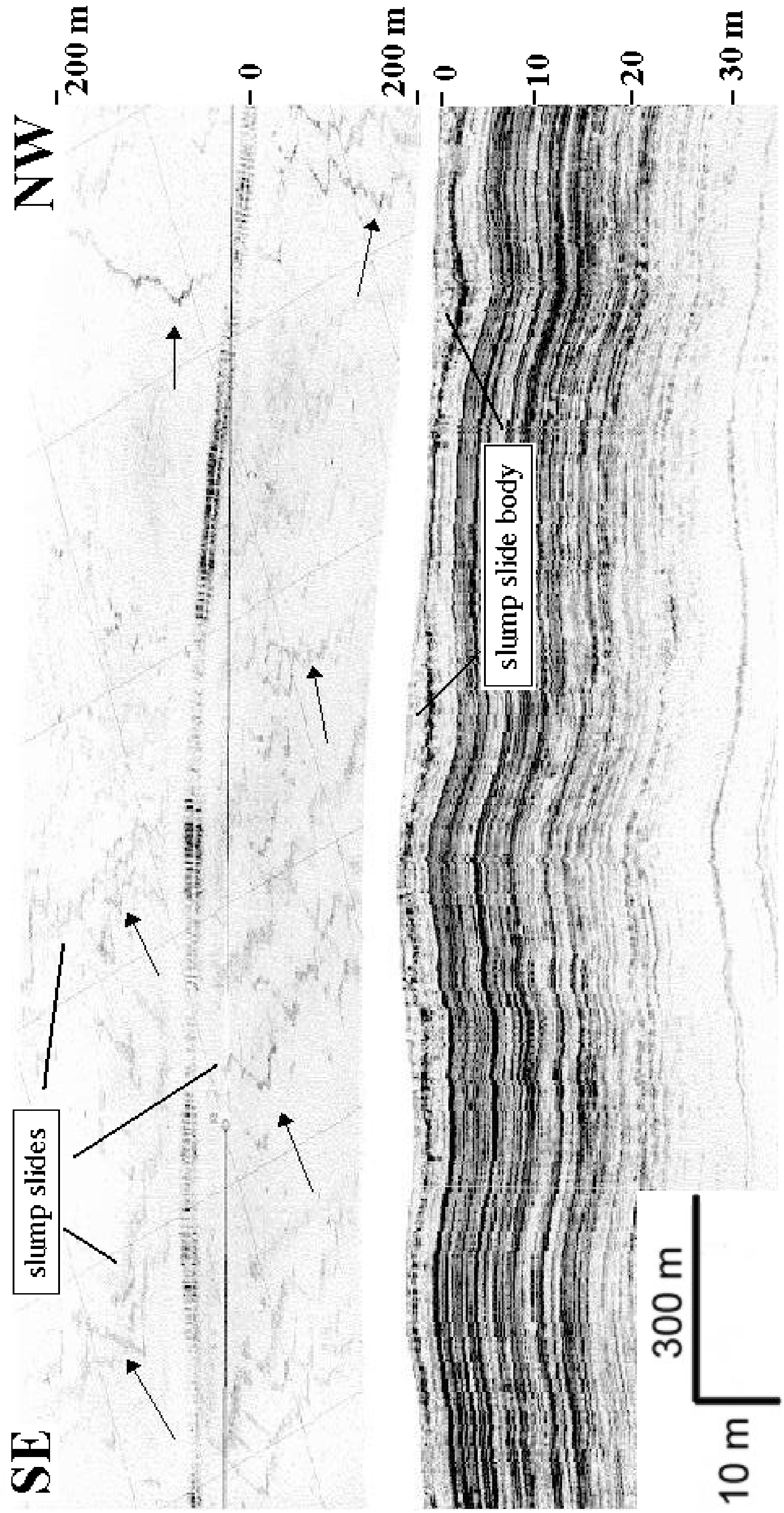

Figure 8. Side-scan sonar record (top) showing slumping and creeping. Slump slide bodies overlie the migrating wave-pattern sediments on sub-bottom profiler record (bottom) from the Turkish apron.

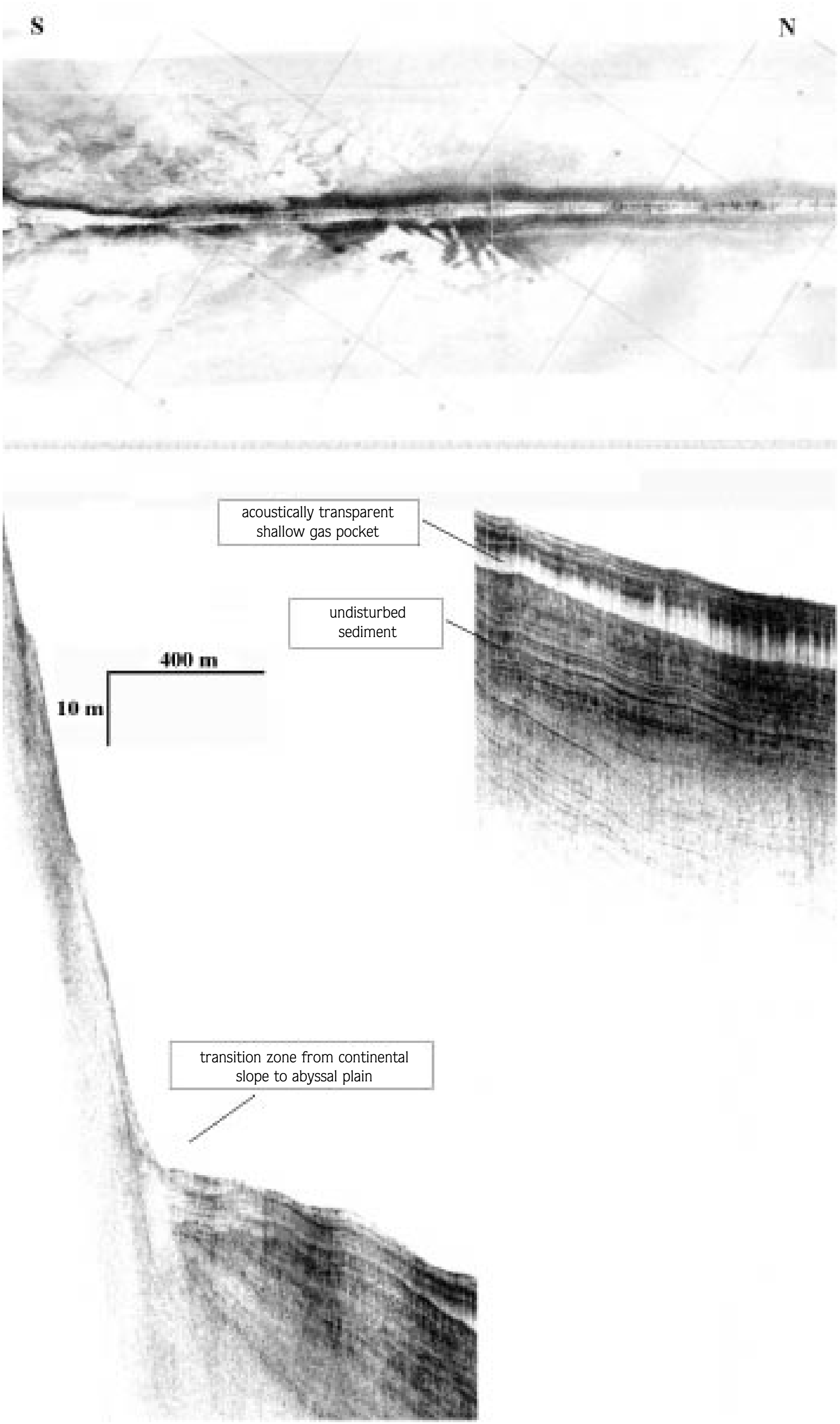

Figure 9. Side-scan sonar (top) and sub-bottom profiler record (bottom) from the Turkish continental slope to apron. The transition zone from the continental slope to the abyssal plain is clearly defined.

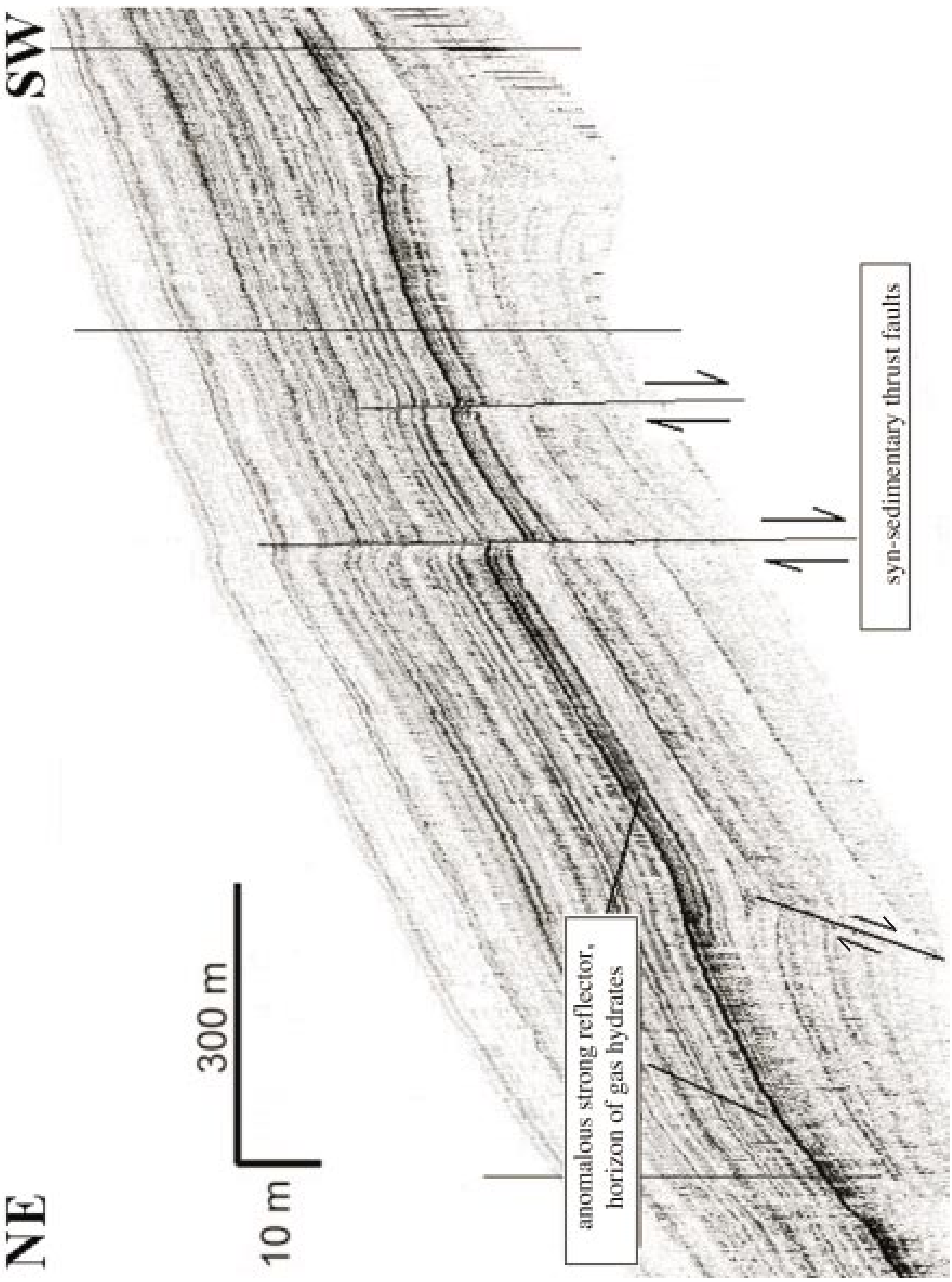

Figure 10. Sub-bottom profiler record showing syn-sedimentary thrust faults and a gas hydrate layer as a strong reflector in the upper part of the Turkish continental slope.

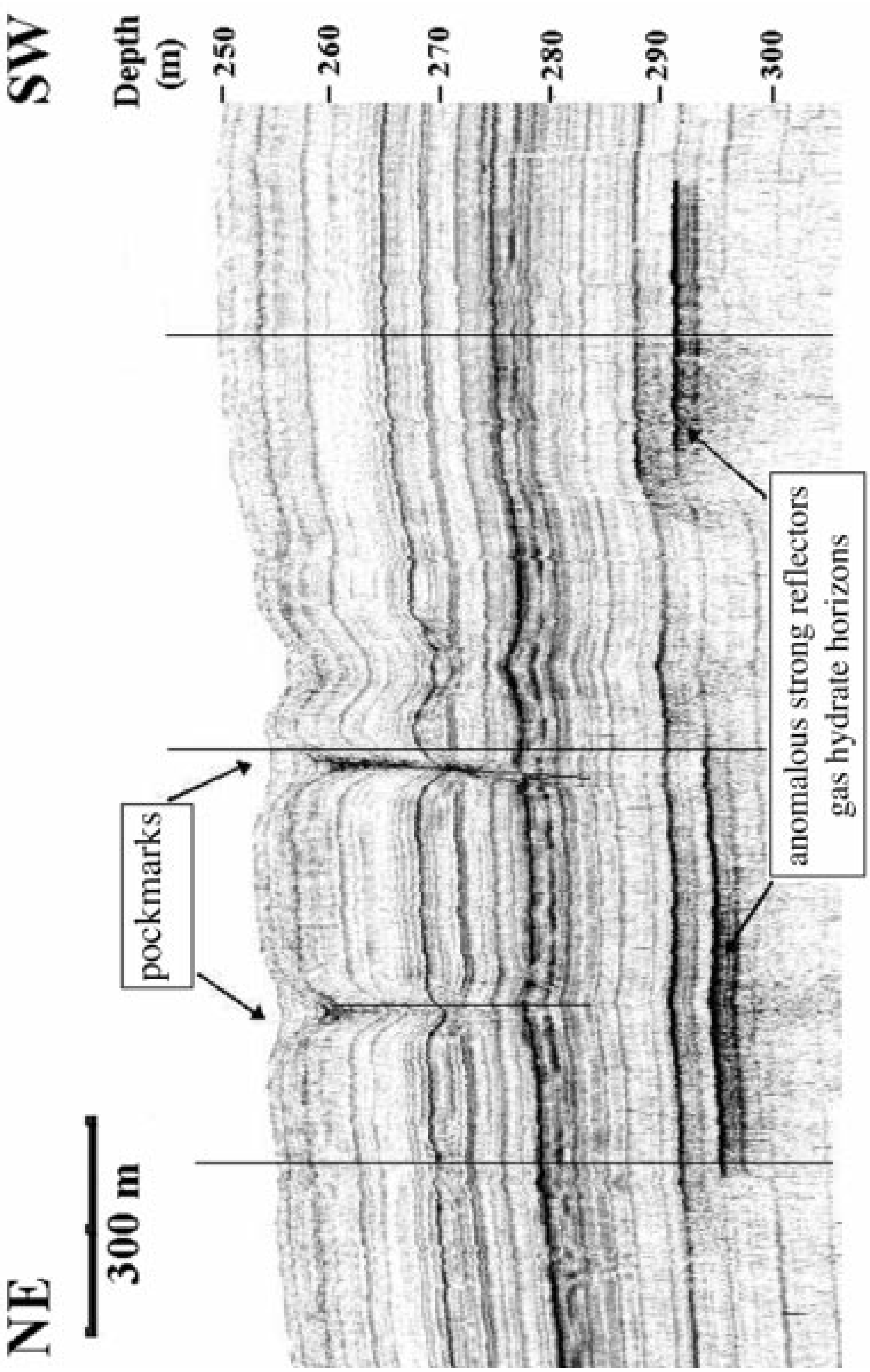

Figure 11. Sub-bottom profiler record from the Turkish shelf area showing two pockmarks as small depressions and strongly reflective gas hydrate layers.

underwater structures related to military defence, and to gas and oil exploration and production. Lack of stability might also be a factor in climate change.

The Turkish shelf area is divided into three different parts. The first is a sub-horizontal plateau and is characterized by pockmarks - circular depressions with diameters up to 50 m and relative depths of several meters (Figure 11). These features up as dark reflectors on side scan-sonar records (Figure 12). The origin of these pockmarks is probably related to local subsidence and faulting due to gas escape. Pockmarks are depressions in sediments caused by seepage of fluids through the seafloor. In the Black Sea, pockmarks are caused mainly by biogenetic gas escape and locally by hydrothermal gas escape. The second feature is the steep shelf slope, which exhibits minor and major northward-

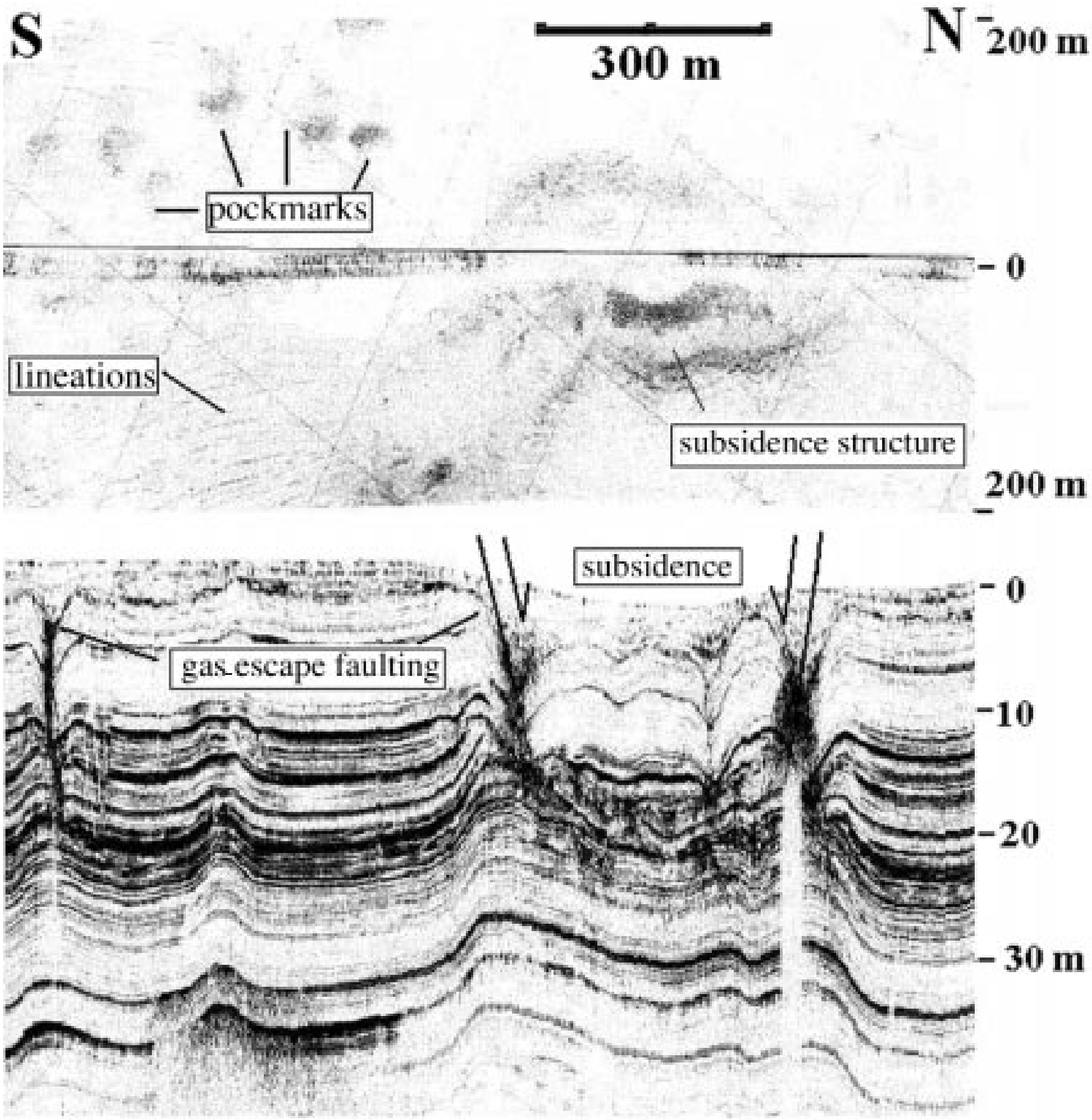

Figure 12. Side-scan sonar (top) and sub-bottom profiler record (bottom) from the Turkish shelf. Gas-escape features resulting in normal faulting, subsidence and pockmarks on the seabed. The pockmarks are identified as circular patches on the sonographs.

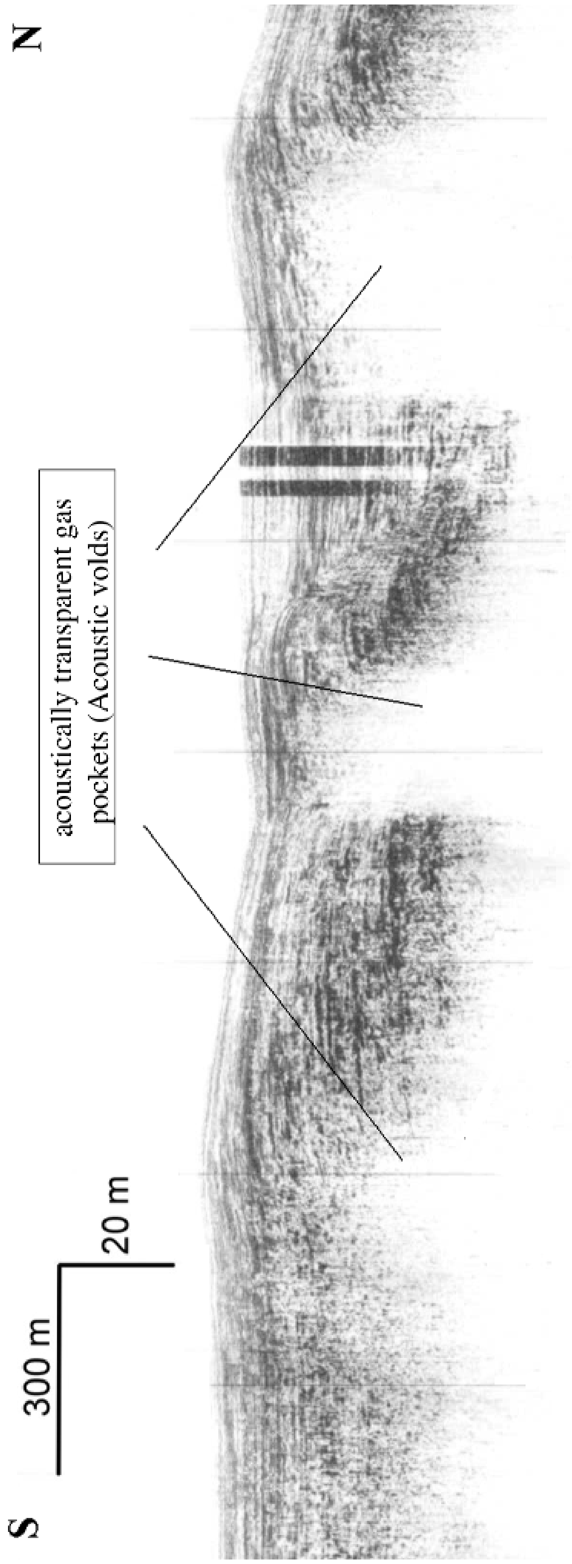

Figure 13. Sub-bottom profiler record from the Turkish shelf. In this area, shallow gas is nearly continues beneath the seafloor.

dipping listric faults as a result of slump and creep. The depth of the shallow gas remains constant at 20 m. Figure 13 shows a sub-bottom profiler record of three distinct gas accumulation zones. Gas uplift masks the continuation of the recent sediment bedding. The third feature is the gentle slope area. In this area, shallow gas penetrates the horizontal, fine-bedded sediments as a dome-like structure at a depth of 9 m below the seafloor, resulting in a northward-dipping normal fault at the surface (Figure 14).

Gas domes are observed in this area, less than 5 m beneath the seafloor, occasionally resulting in southward-dipping normal faults with offsets less than 1 m. The shallow gas coincides with gas seepage features (small pockmarks) at the surface, shown as circular reflector patterns (with diameters of 5 m) on sonar records. The top of the shallow gas remains constant at a depth of 15-20 m.

Conclusions

The bathymetry in the coastal area of the Russian shelf decreases gently (0.4°) landward. A 5- to 12-m-thick clayey and silty sediment cover overlies limestone, which crops out at the shore-line.

The water depth at the Russian continental slope increases from 100 to 1510 m over a distance of 11 km. The seabed has a maximum detected slope angle of 18.7° and is cut by dendritic valleys. Creep and slumping processes have occurred within the clay of this region.

The apron of the Russian continental slope extends over a distance of 38 km and is defined by five ridges which are remnants of an anticlinorium. The ridges have heights of 12 to 400 m and maximum slope angles of 8.7°. Slump bodies are detected in the silty-clay on some ridges.

Well-bedded and undisturbed sediment layers characterize the east Black Sea abyssal plain. The surface is composed of small hillocks and hummocks. The abyssal plain extends over a distance of 180 km and has an average water depth of 2135 m. Areas with pockmarks and normal faults are observed.

The water depth at the apron of the Turkish continental slope shallows gently (2°) from 2130 to 1800 m. Slump features and normal faults are preserved

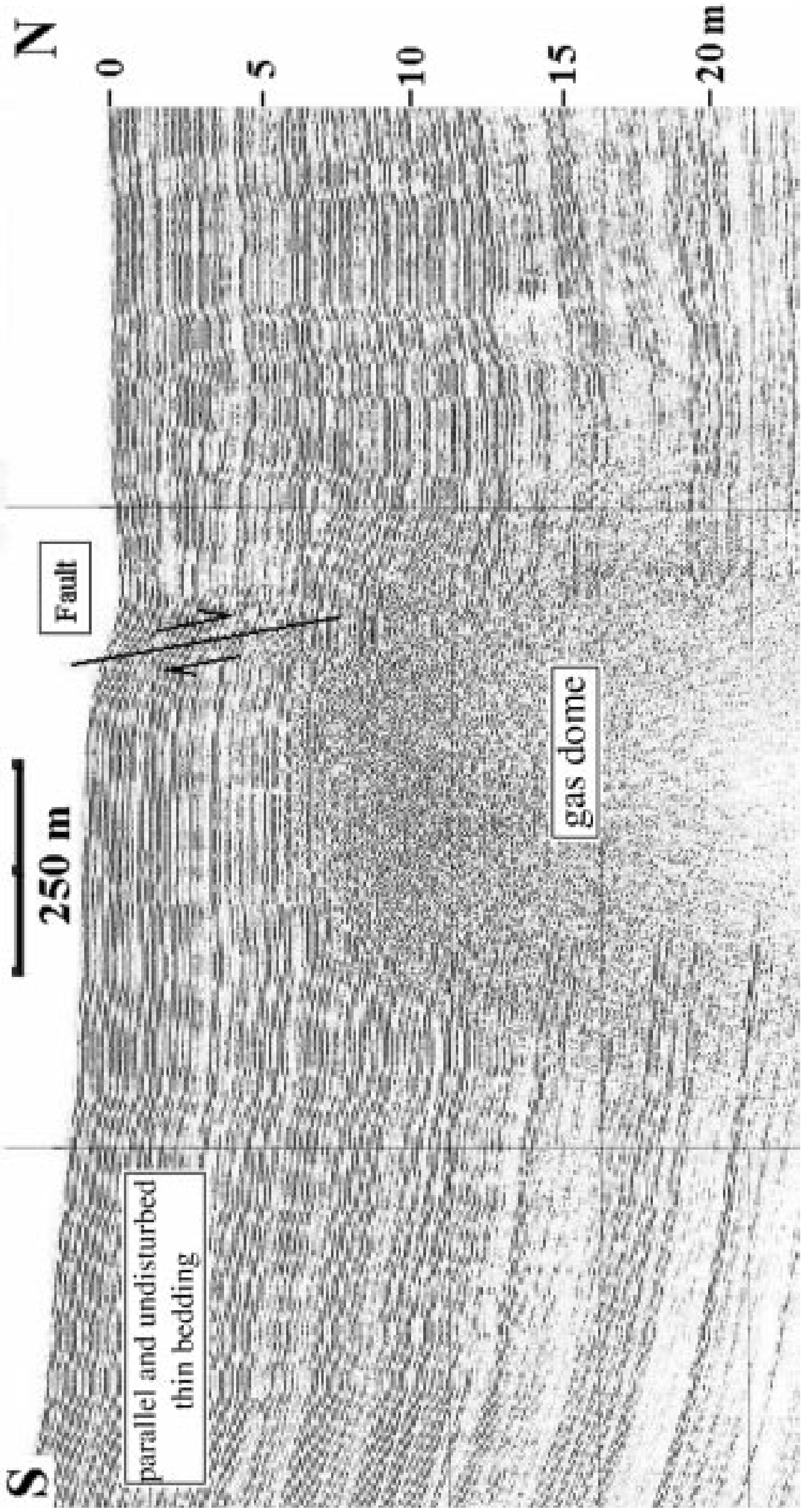

Figure 14. Sub-bottom profiler record showing a gas dome, penetrating into the sediment sequence resulting in a normal faulting in the overlying sediments in the Turkish shelf area.

in this area. The Turkish continental slope extends over a distance of 15 km and the water depth shallows from 1800 to 300 m. The seabed has a maximum detected slope angle of 12.6°. At the Turkish continental slope, creep and slumping processes occur in the soft silt.

The Turkish shelf is divided into three areas, namely a sub-horizontal plateau, a steep shelf slope and a gentle shelf slope. Throughout the Turkish shelf, shallow gas has been detected in sub-bottom profiler records. Pockmarks occur within the sub-horizontal plateau and gentle shelf slope. Slump and creep features are detected on the steep shelf slope. Shallow gas is nearly continuous beneath the seafloor at water depths of 25-65 m. Gas hydrates are observed in the shelf and slope areas as strong reflections on sub-bottom profiler sections.

Acknowledgements

The authors would like to thank anonymous reviewers for their incisive reviews and suggestions that improved the paper significantly. We particularly thank Erdin Bozkurt for his background information on the geological setting of Black Sea. Steven K. Mittwede helped with the English.

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Received 26 February 2001; revised typescript accepted 19 October 2001