Northwestern Black Sea: Upper Quaternary water level and sedimentation

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THE DANUBE-DNIESTR FAN COMPLEX

Two overlapping deepsea fan complexes occur in the northwestern Black Sea: (1) the slightly inter-fingering Danube-Dniestr Fan complex fed by the River Danube, the Dniestr and possibly the Southern Bug, and (2) the Dniepr Fan built up by the River Dniepr (Fig. 1). The thickness and facies distribu-tions of eight seismic sequences were mapped in the former fan complex, of which four can be subdivided into parasequences. The two lower-most se-quences (sequences 1 and 2) consist mainly of unchannelized mass transport deposits (slumps, slides, debris flows), while the six upper sequences with their typical channel-levee systems as well as overbank and mass transport deposits make up the deepsea fan complex itself (Wong *et al.*, 1994, 1997; Winguth *et al.*, 2000).

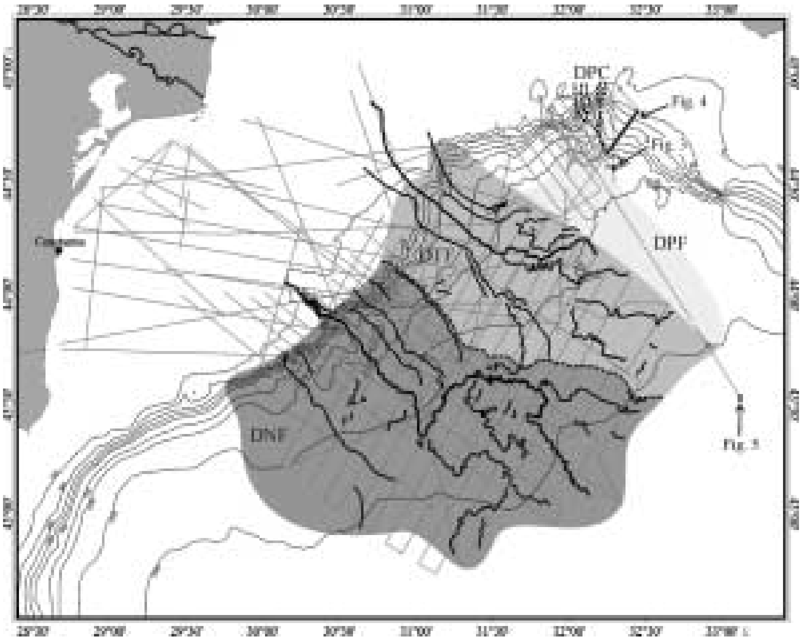

Fig. 1. Map of the northwestern Black Sea showing the locations of the main channels on the Danube-Dniestr Fan complex (**DNF** = Danube Fan and **DTF** = Dniestr Fan) and the upper Dniepr Fan (**DPF**). Dashed lines give the schematic boundaries between the fans. Grey lines show profile locations, with the profiles given in Figs. 3 and 4 marked in black. Thin black lines are the 100, 200, 300, 400, 500, 750, 1000, 1500 and 2000 m isobaths. **DPC** = Dniepr Canyon. Modified after Wong *et al.* (1994, 1997), Winguth *et al.* (2000) and Popescu *et al.* (2001).

In the Danube-Dniestr Fan, channel displacement occurs within a sequence as well as from sequence to sequence. This is probably due to activation and/or clogging of river arms or to channel breaching (Winguth *et al.*, 2000; Popescu *et al.*, 2001). Despite these dis-placements, the major channels did not migrate significantly, indicating that the sediment-contributing paleo-rivers flowed into the Black Sea approximately at their present mouths.

UPPER QUATERNARY WATER LEVEL CURVE FOR THE NORTHWESTERN BLACK SEA

Lowstands on a first regional water level curve for the northwestern Black Sea during the past 900 ky were reconstructed by identifying and mapping paleo-terraces and coastal onlaps on the shelf (Fig. 2). Corrections for sediment compaction, isostatic sub-sidence due to sediment load, thermal subsidence as well as vertical tectonic movements were applied. Ages for the water level cycles identified were assigned by correlating the water level curve with the global SPECMAP δ^{18}O curve (Imbrie *et al.*, 1984) as well as correlating the seismic sequences to commercial drill holes. Subsequent correlation of the fan sequences with the regional water level curve suggests that the Danube Fan was con-structed during the past 900 ky (sequences 3a to 8), and the Dniestr Fan during the past 800 ky (sequences 3b to 8).

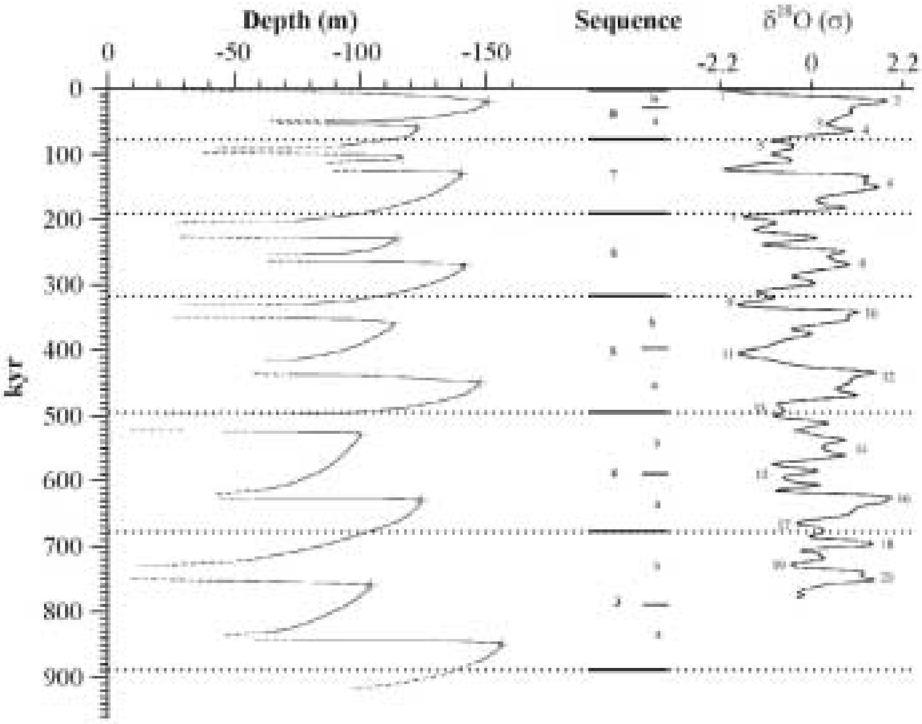

Fig. 2. (Left to right) Regional water level curve for the northwestern Black Sea; sequence correla-tions; SPECMAP δ^{18}O curve of Imbrie *et al.* (1984) (after Winguth *et al.*, 1997, 2000).

Deviations of our regional water level curve from the global sea level curve are due to isolation of the Black Sea from the global oceans during sea level lowstands, so that its water level could develop independently. Only during transgressions and highstands was the Black Sea reconnected to the Mediterranean via the Sea of Marmara, leading to freshwater outflow from and later saltwater inflow into the Black Sea. Timing of subsequent sapropel formation in the eastern Mediterranean Sea correlates well with the trans-gresssions presumed in our Black Sea water level curve. The water level lowstand during marine isotope stage 16 in the Black Sea is not as pronounced as in the world oceans, which may be a result of more humid conditions. The lowstand of -150 m during the LGM in the Black Sea is about 30 m lower than the eustatic lowstand of the world oceans. This hints at a dry regime in the Black Sea region during the last glaciation, when evaporation was presumably higher than precipitation and fluvial water influx.

The duration of the water level cycles identified in the northwestern Black Sea varies between 50 and 130 ky (except parasequence 8b which is still developing). Thus, they are 6th and 5th order cycles and are correlatable with the Milankovitch eccentricity and obliquity cycles.

EVOLUTION OF THE DANUBE-DNIESTR DEEP-SEA FAN COMPLEX

Development of the Danube-Dniestr Fan complex is controlled by the Black Sea water level (Weimer, 1990). During highstands, the deltaic regions are far removed from the shelf edge and function as depocenters for much of the fluvial sediment input. The slope and basin are sediment-starved. As the water level begins to fall, the river mouths advance towards the shelf edge and canyon formation begins. Mass transport processes lead to important deposits on the continental slope and rise. During a regression, when the retrograding canyons become connected with the fluvial valleys incised into the shelf, channel-levee systems start to form. At lowstands, the fan system becomes the main site of deposition. Coarse material is confined to the channels or it forms lobes at the channel terminations, whereas finer material is swept onto the levees and beyond to form overbank deposits. As the water level rises to a highstand, the deltaic system retreats towards the coast and the incised channels are filled. Thus, one cycle of water level fall and rise is responsible for the formation of a typical fan sequence.

Our seismo-stratigraphic interpretation implies that the Danube reached the Black Sea for the first time about 900 ky ago. This is consistent with the assumption that the Danube and the Ukrainian rivers reached the Black Sea only in the Chaudian. In the Upper Quaternary, the Danube system drained probably into the Dacian Lake, which was separated from the Black Sea by a basement high except for an outlet (Spânoche and Panin, 1997). Breaching of this lake led to direct drainage into the Black Sea. In contrast, the Dniestr Fan started to form only about 800 ky ago. A higher subsidence rate on the northern shelf may have caused the water level here to recede beyond the shelfbreak later than in the Danube area. Alterna-tively, the Danube Fan may have formed earlier than the Dniestr Fan because of its higher water and with it higher sediment discharge compared to the Ukranian rivers.

Computed average sedimentation rates range between 1.19 and 2.19 m/ky for the Danube Fan and between 1.07 and 2.03 m/ky for the Dniestr Fan (Winguth *et al.*, 2000). The corresponding rates for sediment accumulation calculated by assuming a sediment density of 2.4 g/cm^3 are 68-141 t/yr and 41-82 t/yr respectively. Mean denudation rates in the drainage areas are computed to be 0.027-0.105 mm/yr for the Danube basin and 0.017-0.127 mm/yr for the Dniestr-Bug-Dniepr drainage basins.

THE DNIEPR CANYON AND UPPER FAN

The Dniepr Canyon (the Dniepr Fan valley in the sense of Normark and Piper, 1969) is incised into the shelf and especially into the upper slope west of the Crimean Peninsula. It is floored by coarse-grained lag deposits and flanked by finer-grained levee and overbank sediments laid down during overflow of the canyons. The Dniepr Fan starts at a water depth of about 300 m and extends to the abyssal plain, possibly overlapping the Dniestr Fan. It consists of a series of vertically-stacked, laterally displaced channel-levee systems. It was deposited during water-level lowstands when the shelf was exposed and sediments were transported to the deep sea via channelised flow along the canyon, thus bypassing the shelf. Meandering and channel avulsion led to stacking of channel-levee systems.

The area east of the Dniepr Canyon is characterized by drift sedimentation. The sediment drifts are aggradative and cyclic. They form stacked individual units separated by distinct uncomformities that are sometimes accompanied by a moat (Fig. 3). They are laid down possibly as the northward-directed near-bottom slope current becomes focused by the levee morphology. Flow intensification causes the sediment particles to deflect upslope by the Coriolis force. On settling out, they form deposits with a convex-upward cross-section and confer a gentle gradient to the upper slope. West of the Dniepr Canyon, mass wasting dominates the steep upper slope, while mass transport deposition is prominent on the gentler lower slope. The middle slope at an average depth of ca 700 m represents a break in the gradient and a site of slide and slump deposition. From 750 m water depth to about 1300 m, debris flow deposits dominate.

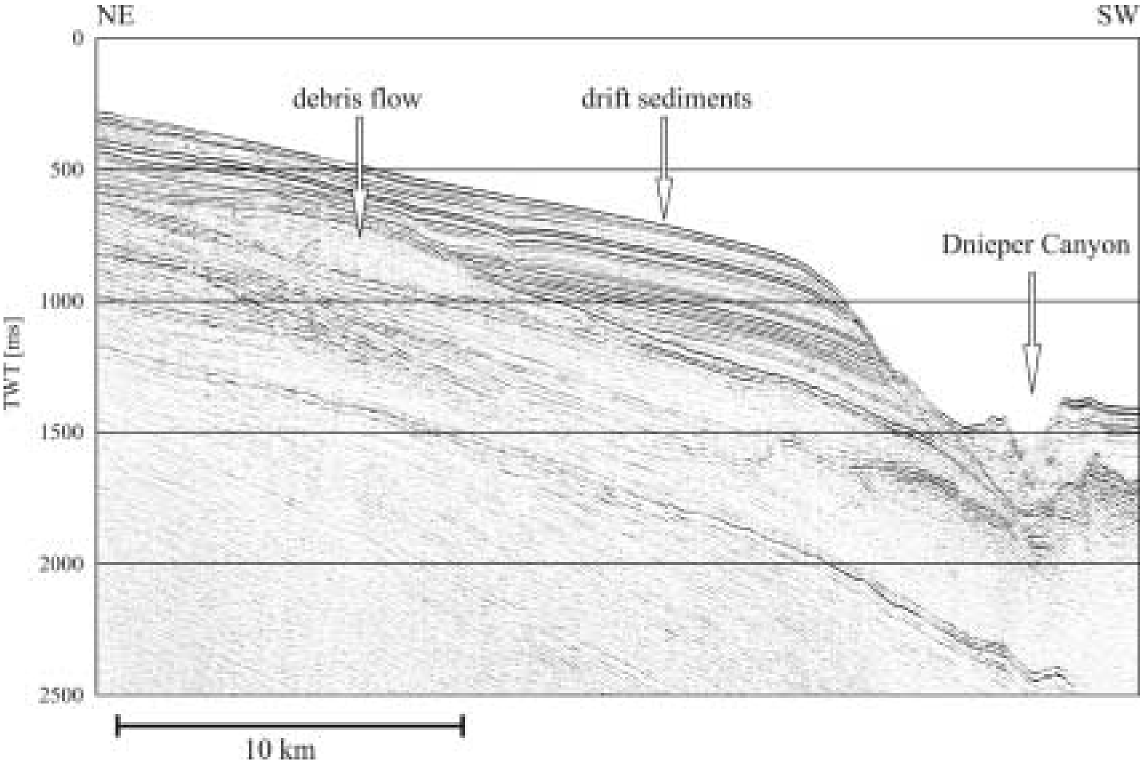

Fig. 3. Drift sediments and debris flows northeast of the Dniepr Canyon. See Fig. 1 for profile loca-tion.

A bottom simulating reflector (BSR), reported here for the first time in the Black Sea, occurs between water depths of 700-1500 m southwest of the Dniepr Canyon. It is a high-amplitude reflector that runs sub-parallel to the seafloor. Occasionally, it intersects the sediment stratifications but has always a polarity that is opposite to that of the seafloor reflection (Fig. 4). It marks the lower boundary of the thermobaric gas hydrate stability zone, in which gas hydrate can exist

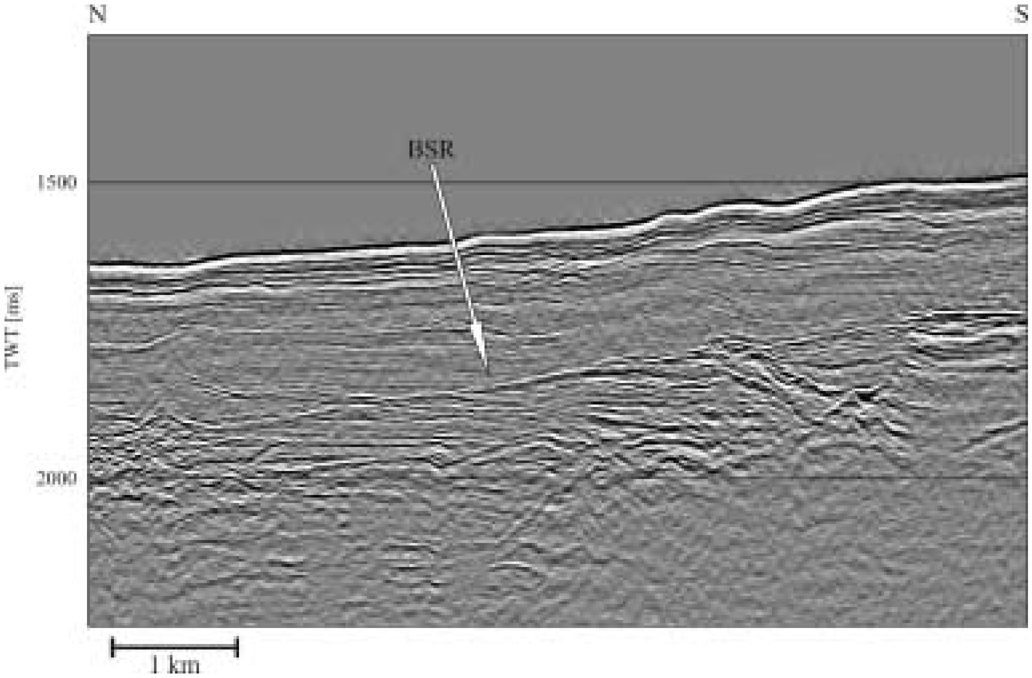

Fig. 4. Profile showing the occurrence of a bottom simulating reflector (BSR) characterized by a polarity that is opposite to that of the seafloor reflection and by intersections with the sediment strati-fication. See Fig. 1 for profile location.

as cement in the sediment. A BSR is absent where drift deposits occur, probably because these sediments are intrinsically gas-poor (low Corg content), or the gas generated in situ has already escaped during transport by bottom currents. A BSR is also absent in the distal fan. Here, gas concentrations below the gas hydrate zone (if one exists) is presumably so low that the impedance contrast is insufficient to produce a BSR. In addition, sediments in the lower Dniepr Canon have probably a permeability high enough to allow an upward migration of gas and fluids into the hydrate stability zone to allow the formation of gas hydrates. By assuming that the total pressure at the BSR depth is equal to the sum of the hydrostatic and lithostatic pressures, and that the methane hydrate stability conditions in seawater of Dickens and Quinby-Hunt (1994) applies, the heat flow distribution can be deduced by mapping the BSR depths. The resulting heat flow pattern is compatible with values from the Global Heat Flow Database of the International Heat Flow Commission.

The estimated total volume of gas associated with gas hydrates in the study area is of the order of $3x10^{11}$ m^3. This value is 5 orders of magnitude lower than the global reservoir of methane from gas hydrates layers, which is $2\text{-}4x10^{16}$ m^3 (Kvenvolden, 1998). Seismic refraction measurements made by GEOMAR show a velocity inversion at the BSR, with velocities of 1850 m/s for the gas hydrate layer, and 1400 m/s for the underlying gas-bearing sediments (Dr. Matthias Zillmer, per. comm., 2002).

Upward mud and fluid migration in the central Black Sea southeast of the fan area is documented in mud volcanic activity such as that at the MSU Mud Volcano (Fig. 5).

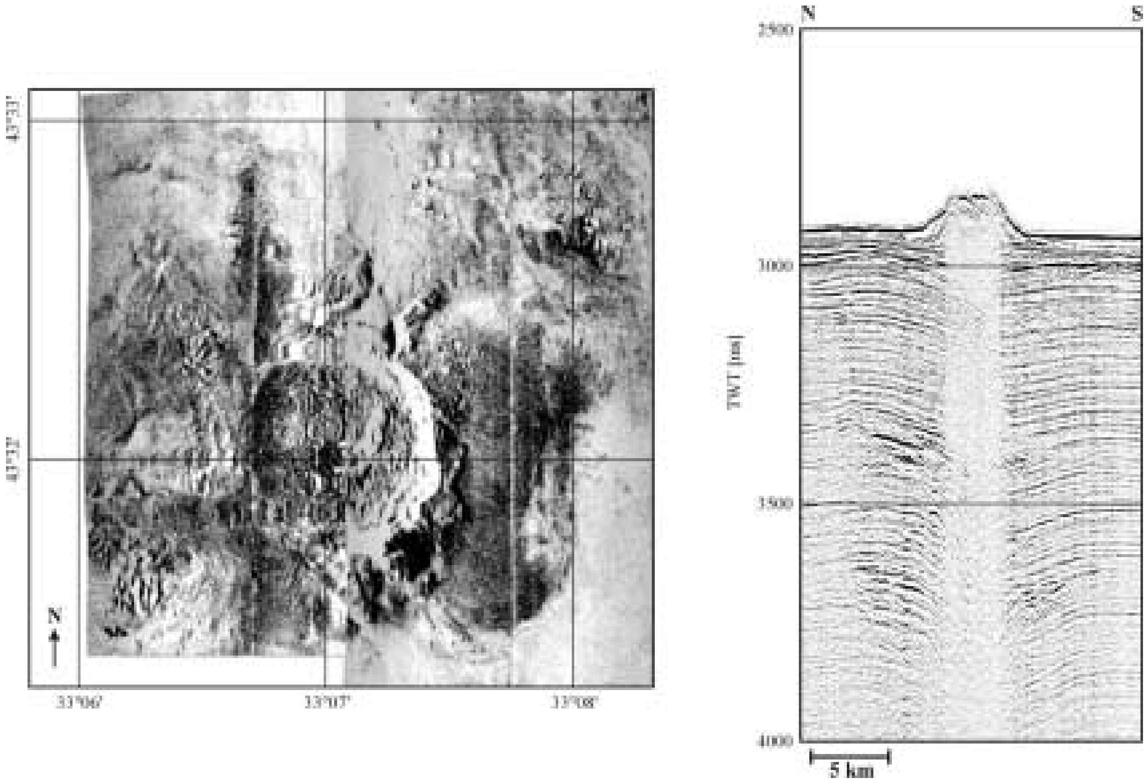

Fig. 5. (a) Sidescan mosaic of the MSU Mud Volcano, showing a round crater with rim, eruption centres within the crater, and mud flows down the flanks. (b) Seismic reflection profile through the MSU Mud Volcano. See Fig. 1 for profile location.

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