UPPER QUATERNARY SEA LEVEL CHANGES IN THE NORTHWESTERN BLACK SEA: PRELIMINARY RESULTS

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Abstract. Seismo-stratigraphic analysis of seismic profiles from the continental shelf of the northwestern Black Sea and correlation of the seismic sequences with shallow drill hole data and with a composite global oxygen isotope curve yielded a preliminary Upper Quaternary relative sea level curve for this area. This curve suggests three minor sea level cycles with a general sea level rise starting at about 480 ka BP, followed by a sharp sea level drop and another three minor cycles with a general sea level rise.

Key words: seismo-stratigraphic analysis, seismic sequence, continental shelf, oxygen isotope, Upper Quaternary, Black Sea.

INTRODUCTION

3,060 km of industrial multi-channel reflection seismic profiles obtained during the periods 1970-71 and 1981-1988 connecting the Danube fan to the Romanian shelf as well as data from 22 drill holes on the shelf were made available by the Romanian companies PETROMAR and PROSPECTIUNI (see Fig.1 for location of the profiles and of two drill holes). In this paper, we present a preliminary regional relative sea level curve for the past circa 480 ka deduced from these data.

SEISMIC SEQUENCES ON THE CONTINENTAL SLOPE AND SHELF

Seismic sequences are defined as genetically related successions of strata with no apparent internal unconformities, composed of parasequences and parasequence sets, arranged in systems tracts, and bounded by unconformities or their correlative conformities (Mitchum & Van Wagoner, 1991). The sequence boundaries are marked by the following reflector terminations: downlap, onlap or concordance at the lower boundary; toplap, truncation or concordance at the upper boundary. They are regarded as the equivalents of depositional sequences.

Eight seismic sequences have been identified in the Danube deepsea fan complex (numbered 1 to 8 from old to young; Wong et al., 1993, 1994), which has been shown to comprise two distinct but interfingering fans (the Danube and Dniepr fans; Wong et al., this vol.). The six upper sequences of these fans are of a typical fan facies. They can be followed onto the shelf in the industrial reflection seismic profiles available for analysis. Each of them can be subdivided into systems tracts which are defined according to their external shape and their position within the sequence and are interpreted as deposits typical of specific sea level phases (Posamentier et al., 1988). The lowstand systems tract (LST, with its basin-floor fan, slope fan and prograding wedge), the transgressive systems tract and the highstand systems tract comprise one sequence. Transgressive and highstand systems tracts are separated from each other by the maximum flooding surface which is characterized by basal downlap of the prograding highstand parasequences. In Fig.2 (profile 452B which runs subperpendicular to the coast), the sequences and depositional features are marked: a basin-floor fan with its typical bi-directional downlap, slope fans which contain channel-levee systems and mass transport deposits and are characterized by onlap terminations in the landward but downlap in the basinward direction over the initial depositional surface, prograding complexes beneath the shelfbreak with its typical clinoforms (at first largely progradational, later with increasing rate of sea level rise largely aggradational) and distal downlap as well as incised and subsequently filled valleys (ivf) on the shelf.

The observed depositional features suggest that all sequences are of the type I as defined by Posamentier et al. (1988). This implies that the relative sea level dropped below the shelfbreak when deposition of the sequence started. On the shelf, some of the sequence boundaries show a

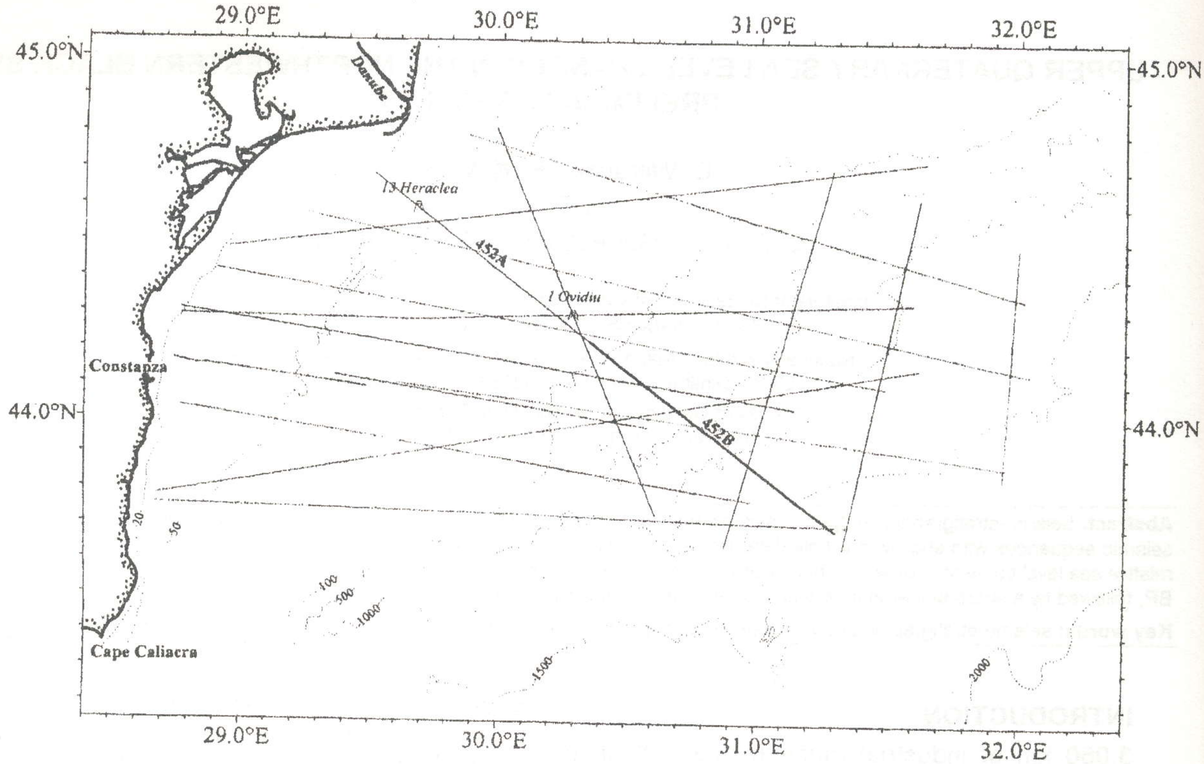

Fig.1 Location of the Romanian industrial profiles and of the two drill holes *1 Ovidiu* and *13 Heraclea*. Profile 452B is marked with a continuous line.

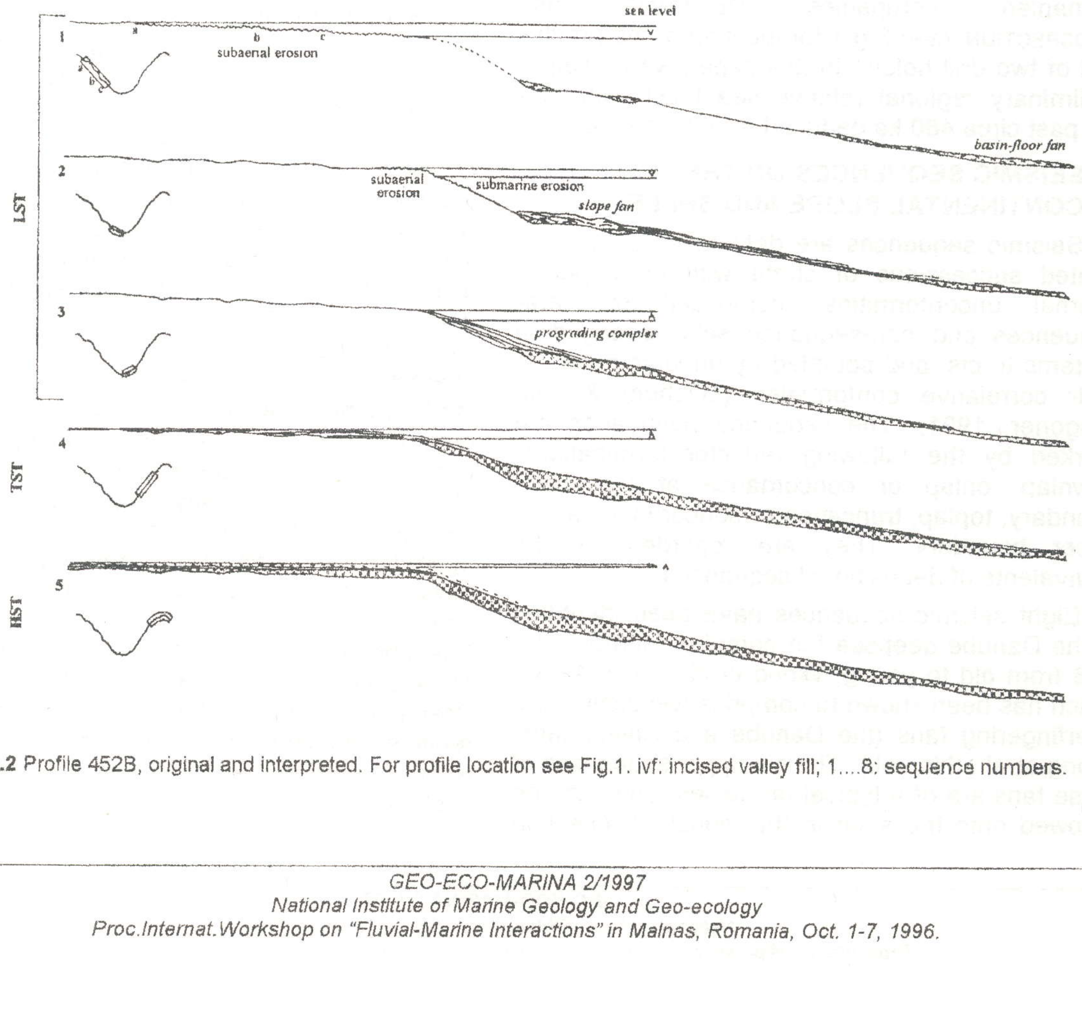

Fig.2 Profile 452B, original and interpreted. For profile location see Fig.1. ivf: incised valley fill; 1....8: sequence numbers.

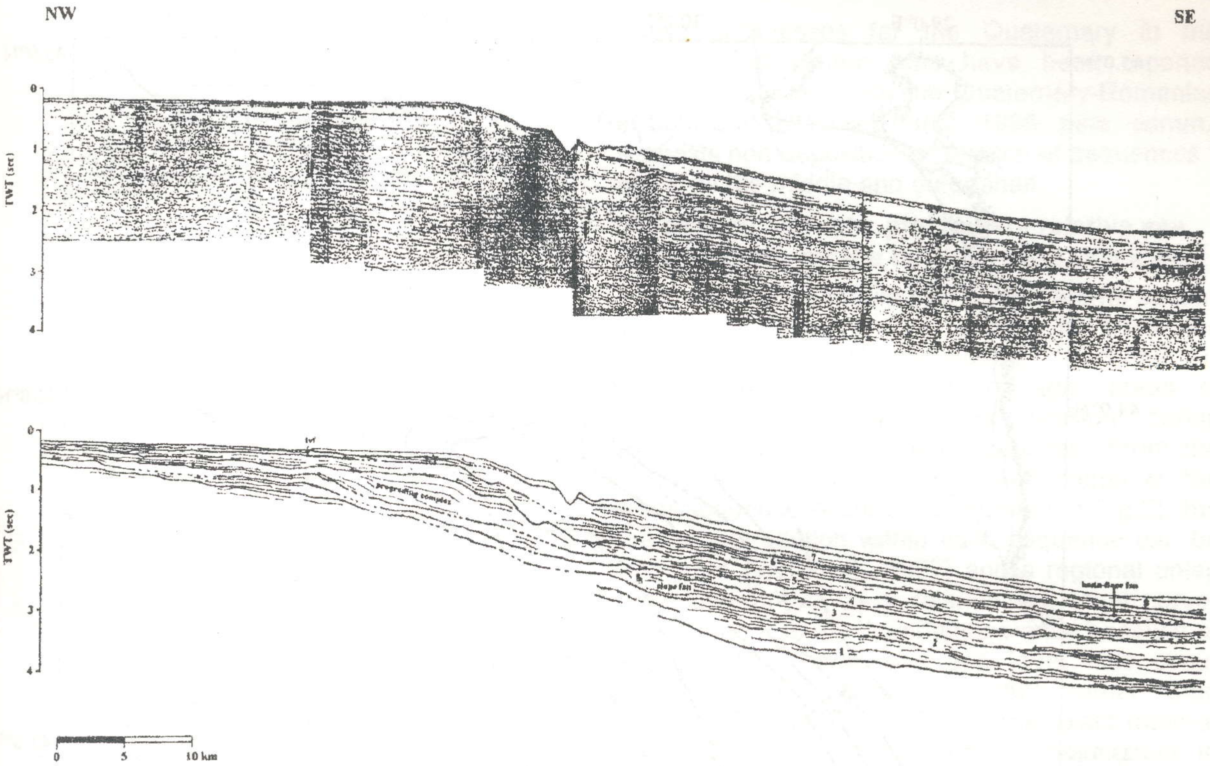

Fig.3 Schematic development of sequence 6 in profile 452B. Sections 1 to 5 depict the sequence at successive sea level phases (see text for details).

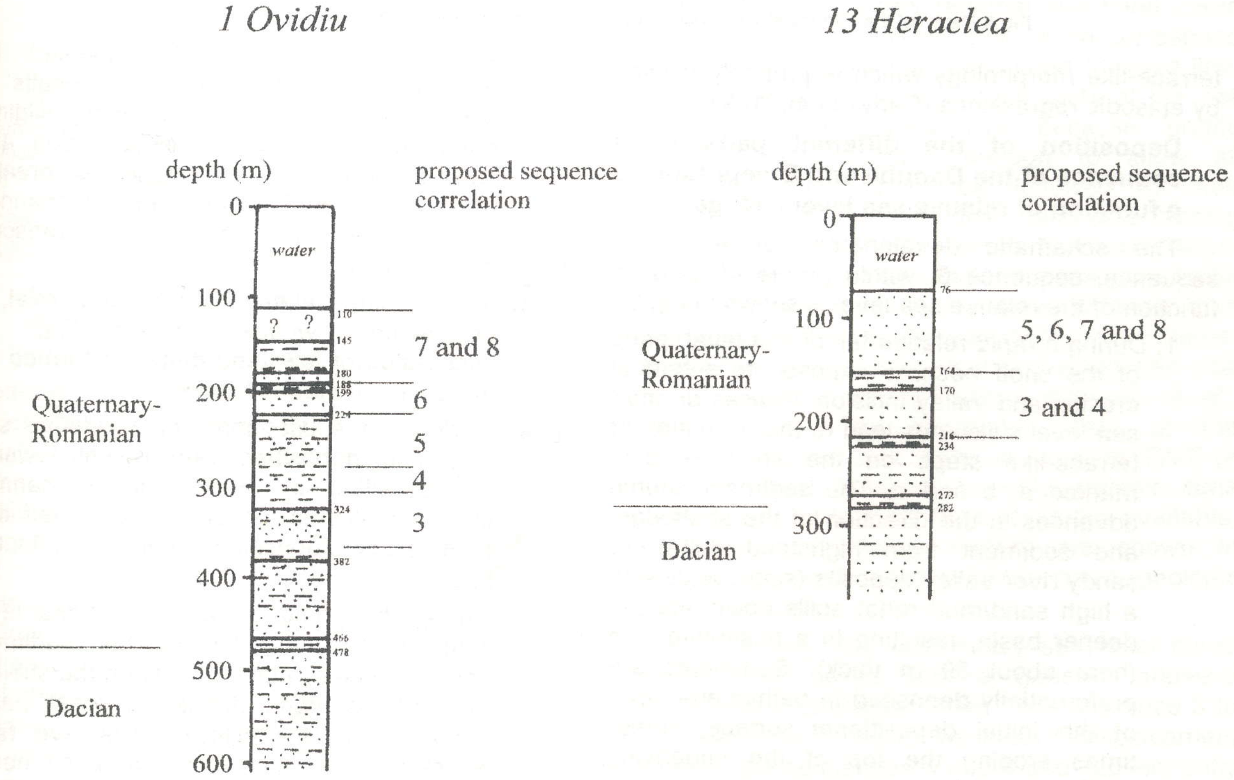

Fig.4 Lithology of the upper parts of drill holes *1 Ovidiu* and *13 Heraclea* with the proposed sequence correlations at lithological changes. See Fig.1 for hole locations.

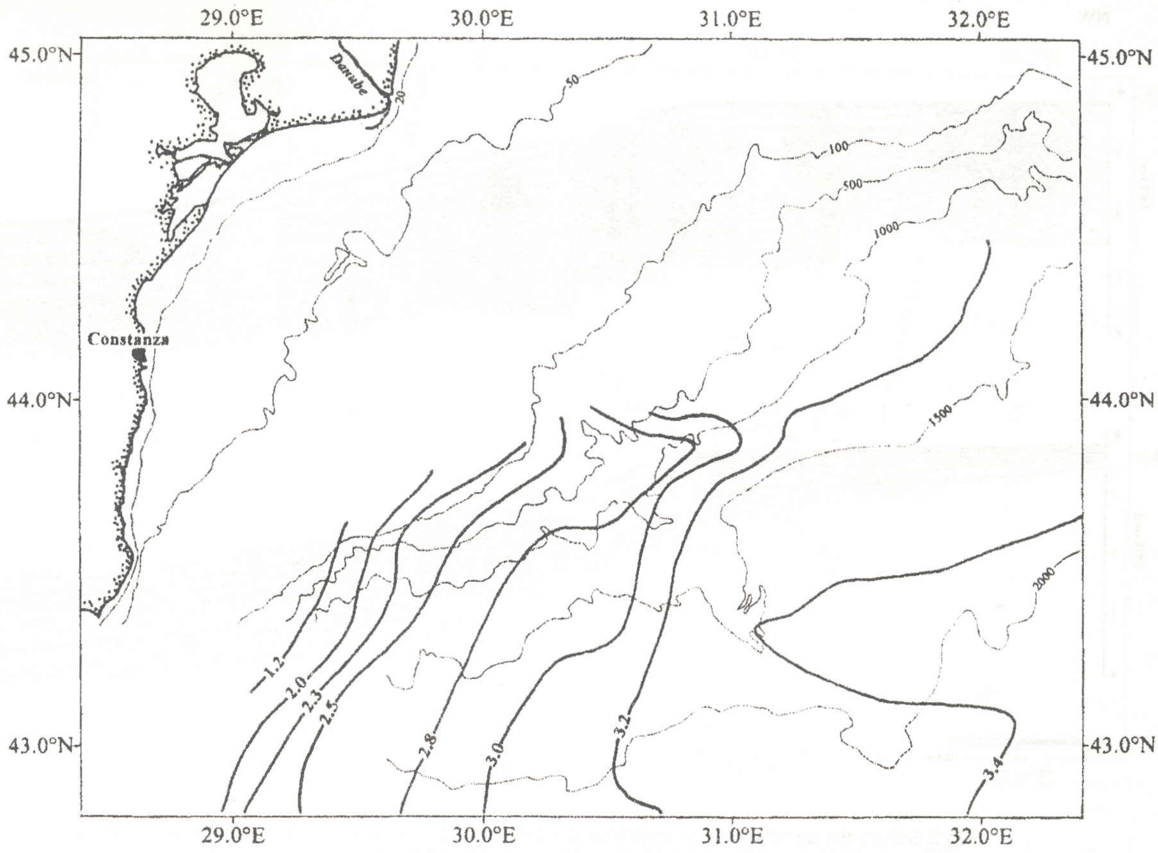

Fig.5 Depth of the Plio-Pleistocene boundary in km below sea level (after Gorshkov et al., 1989).

terrace-like morphology which is probably caused by episodic regressions (Carter et al., 1991).

Deposition of the different parts of a sequence of the Danube and Dniepr fans as a function of relative sea level change

The schematic development of a typical sequence, sequence 6, within profile 452B as a function of the relative sea level is shown in Fig.3:

1) During a rapid relative fall of sea level, parts of the shelf become exposed to subaerial erosion and valley incision. Phases of short sea level stillstands lead to the formation of terrace-like steps on the shelf surface, marked a, b and c. The sediment source advances in the direction of the shelfedge, and sediment from highstand deltas or sandy river valley deposits (supposedly with a high sand/mud ratio) spills down into the deeper basin, resulting in a basin-floor fan (here about 50 m thick). Sediments are preferentially deposited in bathymetric lows of the initial depositional surface, sometimes eroding the top of the underlying section.
2) Further sea level fall leads to progressive subaerial erosion, now reaching the shelfedge. Sediment instability caused by overpressure at the shelfedge results in submarine mass wasting (slumping, sliding, debris flow) and in scarp formation and canyon incision on the slope. At greater depths, a slope fan consisting of channel, levee, overbank and mass transport deposits builds up.
3) With a slow relative rise in sea level, a prograding wedge representing a succession of lowstand deltas is formed on the upper continental slope.
4) During the subsequent rapid relative sea level rise, deposition transgresses towards the coastline in an onlapping manner. Incised valley fill occurs on the shelf and hemipelagic deposition takes place in the basin.
5) During the phase of a relative sea level highstand (slow rise and slow fall), sediment deposition takes place mainly on the shelf in front of highstand deltas (at least partly eroded during the following sea level fall), whereas on the slope and in the basin hemipelagic sedimentation continues.

Phases 1 to 3 lead to a lowstand systems tract,

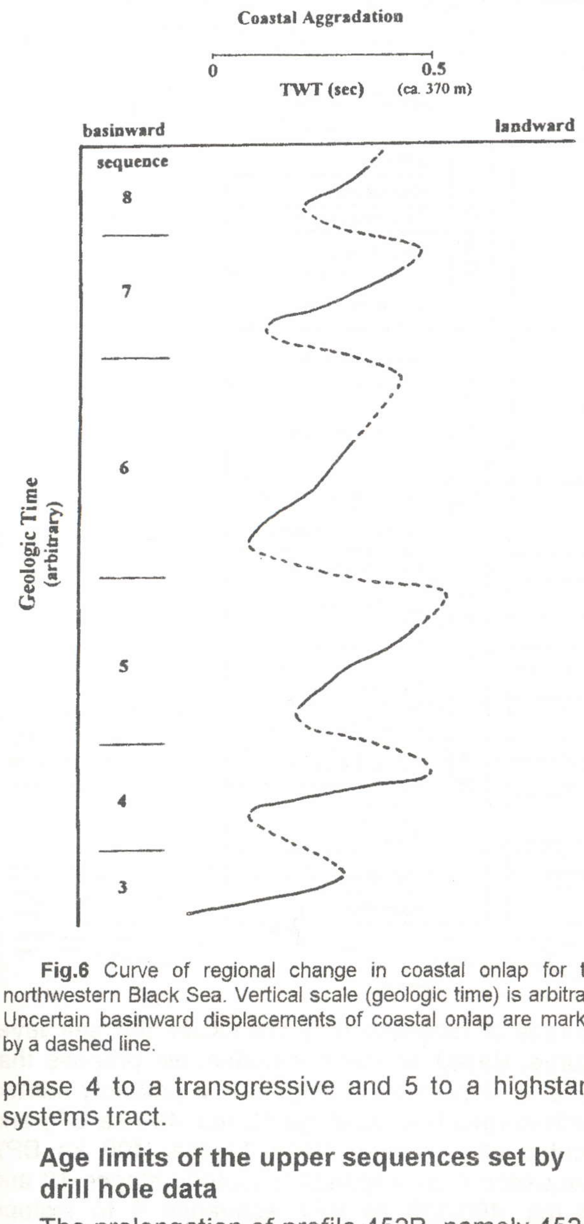

Fig.6 Curve of regional change in coastal onlap for the northwestern Black Sea. Vertical scale (geologic time) is arbitrary. Uncertain basinward displacements of coastal onlap are marked by a dashed line.

phase 4 to a transgressive and 5 to a highstand systems tract.

Age limits of the upper sequences set by drill hole data

The prolongation of profile 452B, namely 452A, passes near the drill holes 1 Ovidiu and 13 Heraclea (Fig.1). The lithostratigraphy of these drill holes as well as a proposed correlation with the six sequences identified is shown in Fig.4. The thickness of the Quaternary-Romanian (= uppermost Pleistocene) decreases from 368 m at 1 Ovidiu on the outer shelf to 206 m at 13 Heraclea on the middle shelf. Unfortunately, the Quaternary-Romanian has not been subdivided for these drill holes, but significant lithological changes suggestive of facies changes may be tentatively correlated with sequence boundaries. This yields a Pleistocene-Holocene age for all the sequences identified, a result which is also consistent with Russian studies in the deep basin where thicknesses for the Quaternary in the Danube and Dniepr fans have been reported (Fig.5). A hiatus within the Quaternary-Romanian in both drill holes (D. Lutac, 1996, pers. comm.) suggests non-deposition or erosion of sequences 1 and 2 on the middle and outer shelf.

Construction of a preliminary relative sea level curve for the northwestern Black Sea

By converting profile 452 B from a time section into a chronostratigraphic section in which the lateral extent of succeeding horizons is represented as a funciton of age, areas of deposition, non-deposition or erosion during specific time periods can be depicted. From the relative displacements of coastal onlaps at the lower sequence boundaries (marked in Fig.2), the coastal aggradation within each sequence can be measured (Vail et al., 1977) and a regional onlap curve (interpreted as a relative sea level curve) constructed (Fig.6). Uncertainties arise because at least for the Pleistocene sea level falls occur gradually (e.g., Williams, 1988) rather than suddenly (Vail et al., 1977), but the exact rates of fall are difficult if not impossible to reconstruct. In additon, sea level falls generally cause erosion, so that not only is there no sedimentary record of these events, but often part of the previous depositional record is also erased. Thus, those parts of the preliminary regional sea level curve for the northwestern Black Sea which correspond to sea level falls are only postulated (dashed line, Fig.6). In addition, the highstand parts of the sea level curve are speculative because profile resolution is not good enough to allow all onlapping reflectors to be followed to their proximal limits within the landward-thinning sedimentary covers of the shelf. Their reconstruction is based in part on coastal terraces cut during sea level highstands. Such marine terraces have been described in the Danube delta for the Paleo-Uzunlarian, the Uzunlarian, the Karangatian and the Neoeuxinian transgressions (Liteanu et al., 1961; Tab.1). The horizontal scale of the reconstructed curve is given in seconds TWT (= two-way travel time) since only seismic time sections but not true depth sections are available. Approximate depths in meters are shown in brackets. The vertical scale of the curve (geologic time) is arbitrary.

Qualitatively, our preliminary sea level curve shows three cycles with a general landward displacement of coastal onlap from sequence 3 to 5 followed by a sharp basinward displacement between the sequences 5 and 6 and subsequently a general but very small landward displacement of coastal onlap from sequence 6 to 7 to 8.

Table 1 Correlation of the regional subdivisions of the Quaternary with the northwestern European divisions (after Degens & Paluska, 1979).

Absolute age (ka)			NW Europe		Black Sea
0–10	Quaternary		Holocene	Black Sea	Recent
					Nymphean
					Thanagorean
					New Black Sea
					Old Black Sea
10–70		Pleistocene	Weichselian	Euxinian	New Euxinian
					Epi-Karangatian
70–100			Eemian	Karangatian	Late Karangatian
					Early Karangatian
100–250			Saalian	Uzunlarian	Epi-Uzunlarian
250–300			Holsteinian		Uzunlarian
300–500			Elsterian		Old Euxinian
500–750			Cromerian		
750–900			Menapian		Epi-Čaudian
900–1350			Waalian	Čaudian	Late Čaudian
1350–1600			Eburonian		Early Čaudian
1600–		Caenocene	Tiglian		Interval
					Gurian
–2500			Pretiglian		Akčagylian
>2500			Tertiary-Pliocene		Pliocene

Correlation of the regional sea level curve with a global isotopic curve

Measurements of $\delta^{18}O$ in foraminifers from sediment cores first carried out by Emiliani (1955) permit an indirect quantification of cold and warm periods. When ice shields are formed, ^{16}O is used preferentially so that the $^{18}O/^{16}O$ ratio rises in seawater and hence also in the foraminiferal shells. By correlating different $\delta^{18}O$-curves throughout the world, oxygen isotope stages have been defined. It is estimated that a change of 0.11 ‰ in $\delta^{18}O$ corresponds to a sea level change of 10 m (Williams, 1988). We have correlated our regional sea level curve for the northwestern Black Sea with the composite global isotope curve of Carter et al. (1991), refined in the upper part (the last 220 ka) by the more recent curve of Dwyer et al. (1995) who used Mg/Ca ratios for isolation of the influence of bottom water temperatures on $\delta^{18}O$. It should be noted that in this correlation, the shape of our sea level curve is only approximate since the y-axis (geologic time) is arbitrary. Only the peaks and troughs are correlated across the curves to establish time marks for the sea level curve. Based on this correlation, we propose that (Fig.7): deposition of sequence 3 probably started with oxygen isotope stage 12 (ca. 480 ka BP) and ended after isotope stage 11 (ca. 400 ka BP), sequence 4 corresponds to isotope stages 10 and 9 (ca. 400-320 ka BP), sequence 5 to isotope stages 8 and 7 (ca. 320-190 ka BP), sequence 6 to isotope stages 6 and 5 (ca. 190-75 ka BP), sequence 7 to isotope stages 4 and 3 (ca. 75-25 ka BP) and sequence 8 to isotope stages 2 and 1 (ca. from 25 ka BP to today; this sea level cycle is not yet complete). The low and high sea level stands within sequence 7 corresponding to isotope stages 4 and 3 are not clearly reflected in the global composite curve, but recent publications dealing in greater detail with the past 150 to 220 ka (e.g., Dansgaard et al., 1993; Dwyer et al., 1995; Linsley, 1996) show obvious $\delta^{18}O$ minima for isotope stages 2 and 4 and a maximum for the intervening isotope stage 3. Like-wise, the $\delta^{18}O$-curve for the eastern Mediterranean (Thunell et al., 1984) shows a similar pattern and is included

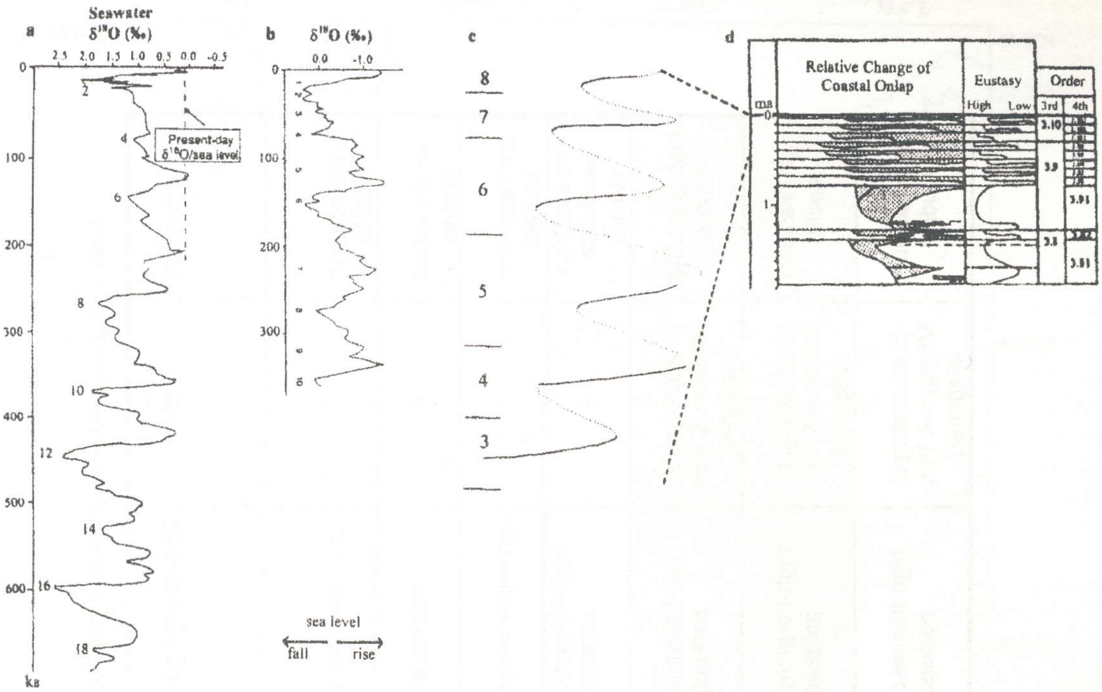

Fig.7 Correlation of the preliminary relative coastal onlap curve of the northwestern Black Sea (*c*; sequence numbers are indicated) with a composite global isotope curve (*a*; upper part from Dwyer et al., 1995, lower part after Carter et al., 1991; numbers represent isotope stages). An oxygen isotope curve from the eastern Mediterranean (*b*; Thunell et al., 1984) and the global eustatic sea level curve of Mitchum et al. (1994; after Wornardt & Vail, 1991; *d*) are also shown.

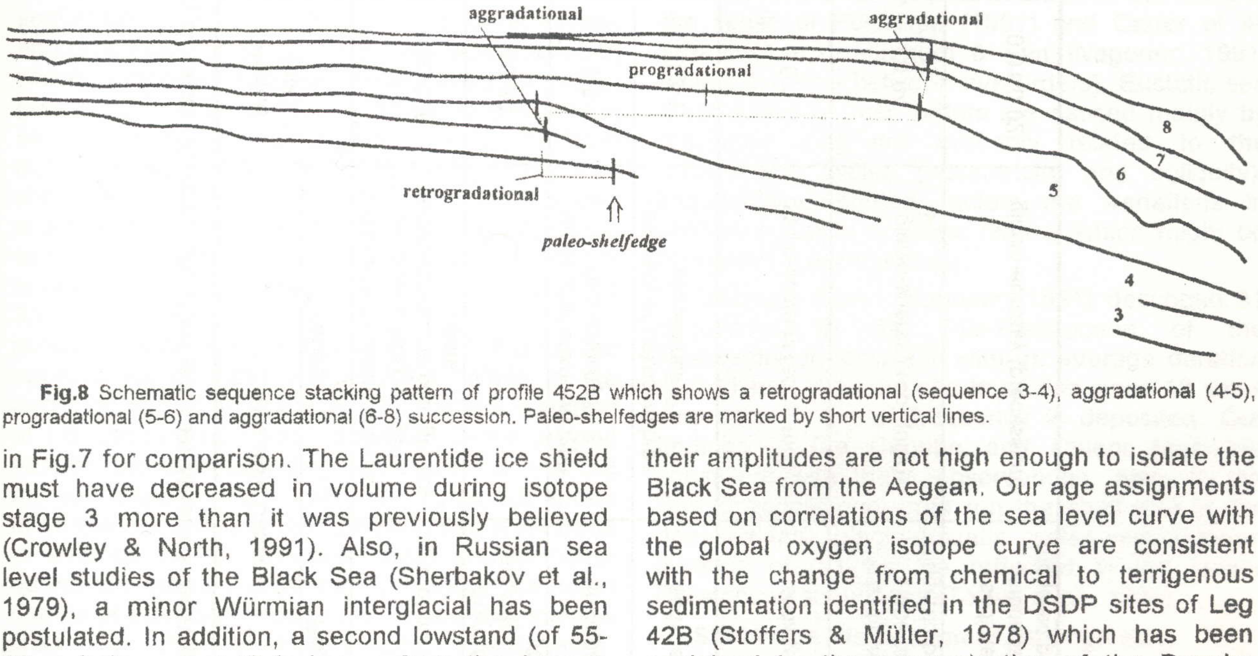

Fig.8 Schematic sequence stacking pattern of profile 452B which shows a retrogradational (sequence 3-4), aggradational (4-5), progradational (5-6) and aggradational (6-8) succession. Paleo-shelfedges are marked by short vertical lines.

in Fig.7 for comparison. The Laurentide ice shield must have decreased in volume during isotope stage 3 more than it was previously believed (Crowley & North, 1991). Also, in Russian sea level studies of the Black Sea (Sherbakov et al., 1979), a minor Würmian interglacial has been postulated. In addition, a second lowstand (of 55-60 m below present) is known from the Aegean within the Würmian (Lykousis, 1991). As the Black Sea is connected to the Sea of Marmara via the Bosphorus, which averages today 55 m in depth (max. 91 m), and from there to the Aegean Sea via the Dardanelles with a sill depth of 37-124 m, sea level falls in the Black and the Aegean seas are directly correlatable with each other as long as their amplitudes are not high enough to isolate the Black Sea from the Aegean. Our age assignments based on correlations of the sea level curve with the global oxygen isotope curve are consistent with the change from chemical to terrigenous sedimentation identified in the DSDP sites of Leg 42B (Stoffers & Müller, 1978) which has been explained by the reorganization of the Danube river drainage system sometime after 600 ka BP (isotope stage 15) as a result of climatic and tectonic changes (Hsü, 1978).

The sequences 3 to 8 as a whole fall into cycle 3.10 of the EXXON global sea level curve established by Haq et al. (1987, 1988) which,

Table 2 Frequency and origin of sea-level fluctuations and sedimentary cycles (after Fulthorpe 1991, Carter et al. 1991, Mitchum & Van Wagoner 1991).

Identification	Order	Sequence-stratigraphic Units	Period (ma)	Possible Causes	
				Eustatic	Regional
low resolution studies	1	composite stacked sequences	100-200	ocean-basin volume changes (plate tectonics), orogeny, sediment volume change, hot spots	thermal subsidence
low resolution studies	2	stacked sequences	10-30	?	thermo-tectonic subsidence, intraplate stress
low resolution studies	3	composite sequence, sequence	1-5	eustasy of unknown type (eccentricity?)	intraplate stress
low and high resolution studies	4	high-frequency sequence, parasequence	0.3-1	eustasy of unknown type (eccentricity?)	sediment supply
high resolution studies	5 (4 according to Mitchum & Van Wagoner)	high-frequency sequence, parasequence	0.1	glacio-eustasy (eccentricity)	sediment supply
high resolution studies	6 (5 according to Mitchum & Van Wagoner)	high-frequency sequence, parasequence	0.04	glacio-eustasy (obliquity)	sediment supply, slope failure (e. g. triggered by earthquake)
high resolution studies	7 (5 according to Mitchum & Van Wagoner)	high-frequency sequence, parasequence	0.01-0.02	glacio-eustasy (precession)	sediment supply, slope failure (e. g. triggered by earthquake)

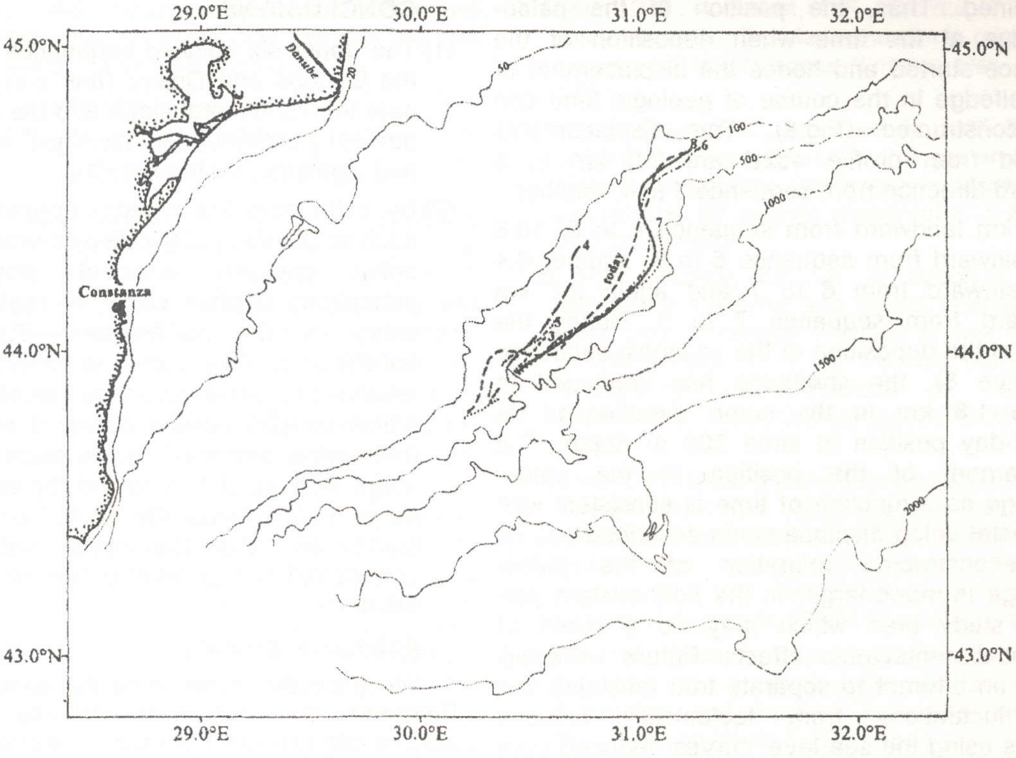

Fig.9 Position of paleo-shelfedge for sequences 3 to 8. Present-day shelfedge at a water depth of ca. 200 m is also marked.

however, does not have a resolution high enough to resolve the individual sequences. Our observed sequence stacking pattern (retrogradational, aggradational, progradational and aggradational) which suggests a higher order cycle of transgression and subsequent regression (Fig.8) cannot be directly correlated with the global sea level curve of Haq et al. because the global curve shows only a transgression and a subsequent stillstand for this cycle (3.10). However, Mitchum et al. (1994) used a revised version of the EXXON curve (after Wornardt & Vail, 1991), in which cycle 3.9 is divided into 6 and cycle 3.10 into 3 subcycles with a mean duration of 0.1 ma for the upper eight of these 9 subcycles. While in the curve of Haq et al. (1987, 1988), cycle 3.9 started at 1.6 and cycle 3.10 at 0.8 ma BP, in the revised version the corresponding ages are 1.3 and 0.3 ma BP respectively. In addition, cycle 3.9 shows largely a rising and 3.10 a lowering sea level trend in contrast to the previous curve and in better agreement with our data (Fig.7). It should be noted that local effects related to the narrow and shallow links to the world oceans (Dardanelles, Bosphorus), variations in sediment supply or tectonic influences may have further modified the sea level curve.

Order of the sea level cycles identified

The duration of one sea level cyle corresponding to one seismic or sedimentary sequence in the northwestern Black Sea lies between about 50 and 130 ka. This implies that they are sea level cycles of the 5th or 6th order in the sense of Fulthorpe (1991) and Carter et al. (1991) (Tab.2; Mitchum & van Wagoner, 1991, distinguish only between five orders). Eustatic sea level cycles of such orders are caused mainly by glaciation and are probably related to the Milankovich cycles (eccentricity and obliquity). Regionally important factors are variations in sediment supply or slope failure (which might be triggered by earthquakes).

Mitchum & van Wagoner (1991) described 31 sequences in the Plio-Pleistocene of the Mississippi deepsea fan with an average duration of 0.11 ma. With the sea level rise since 18 ka, a sequence of higher frequency is deposited. Our findings in the Danube and Dniepr fans are consistent with these observations. Also, in the Rhône depositional area (on the shelf and in the deepsea fan), glacio-eustatic cycles with a mean duration of 0.1 ka are reflected in the Upper Pleistocene sequences (Torres et al., 1995).

Shelfedge displacement through time

Seismic profiles transverse to the coast such as 452B show, from old to young, a retrogradational (sequences 3-4), aggradational (4-5), progradational (5-6) and aggradational stacking pattern (Fig.8). For a given profile, at the lower boundaries of each of the seismic sequences recognized, the position of the shelfedge with its distinct change in gradient can be readily determined. Thus, the position of the paleo-shelfedge at the time when deposition of the sequence started and hence the displacement of the shelfedge in the course of geologic time can be reconstructed (Fig.9). The displacements deduced from profile 452B are 3.0 km in a landward direction from sequence 3 to 4, another

0.3 km landward from sequence 4 to 5, 10.6 km basinward from sequence 5 to 6, another 0.4 km basinward from 6 to 7 and again 0.1 km basinward from sequence 7 to 8. During the course of the deposition of the youngest sequence (sequence 8), the shelfedge has continued to migrate 1.8 km in the same direction to its present-day position in circa 200 m depth. The displacement of the position of the paleo-shelfedge as a function of time is consistent with the coastal onlap displacements described above. The reconstructed migration of the paleo-shelfedge is much larger in the northeastern part of the study area which may be a result of differential neotectonic effects. Future work will include an attempt to separate true (eustatic) sea level fluctuations from tectonically induced changes using the sea level curves deduced from coastal onlap curves for different areas of the northwestern Black Sea continental margin and using the displacement pattern of the paleo-shelfedge through time.

CONCLUSIONS

(1) The upper six seismic sequences identified in the Danube and Dniepr fans can be followed onto the continental slope and the shelf, and in general subdivided into lowstand, transgressive and highstand systems tracts.

(2) By estimating the coastal aggradation within each sequence and the displacement of coastal onlap between adjacent sequences, a preliminary relative curve of regional coastal onlap for the northwestern Black Sea is constructed. This curve is converted into a relative sea level curve by correlation with a global oxygen isotope curve. It suggests that three minor sea level cycles existed starting at about 480 ka BP, followed by another three minor cycles generally at a lower sea level stand, and that the upper six sequences correspond to sea level cycles of the 5th and 6th order.

Acknowledgments

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