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RATES OF SOIL EROSION

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ABSTRACT

To exemplify and estimate the influence from human activities on soil erosion rates sediment cores from the Black Sea were studied. The geomorphological characteristics of drainage areas supplying the Black Sea are given as well as the background for calculations of the denudation rates. The present mean denudation rate for the entire Black Sea source is 0.063 mm yr^{-1}. High noise levels in sedimentation rates from A.D. 200 to present time was accounted for by agricultural activities and deforestation. This also indicated an acceleration of soil erosion by a factor of about 3 due to man's impact.

INTRODUCTION

During a recent workshop on the biogeochemical cycles of nitrogen, phosphorus, and sulphur, an attempt was made to assess man's impact on the global environment. Difficulties were encountered owing to lack of a proper reference state for these cycles in preindustrial and preagricultural times (Eriksson & Rosswall, 1976). In addition, there were serious gaps at critical points of the chemical cycles which made it hard to define global models even for the present situation. One particular unresolved question concerns the rate of weathering and soil erosion in the past and the present. We wish to direct our attention to this specific problem area.

Much areally isolated information is available on the extent of weathering and erosion under various climatic conditions. These locally restricted observations have been used previously as a basis for estimates on regional or global rates of denudation of continents (e.g. Lopatin, 1952; Kukal, 1964; Garrels *et al.*, 1975). In contrast, we will examine in detail a larger region, namely that part of Europe and Asia which drains into one single catch basin, the Black Sea. Since we also know annual rates of sedimentation in the Black Sea over the past 5 000 years (Degens *et al.*, 1976), man's possible impact on denudation processes should be reflected in higher sedimentation rates.

GEOMORPHOLOGICAL CHARACTERISTICS

The Black Sea source area can be subdivided into several orographic provinces which are distinguished by (i) areal extension, (ii) prevailing climate, and (iii) elevation. Regarding these factors the subdivision in Table 1 seems to be appropriate. The figures are accurate within a few per cent. It is of note that they only represent the planar projection of the individual terrain and not the actual surface area exposed to denudation.

Table 1. Rivers entering the Black Sea and their drainage areas.

River	Size of drainage area (km^2)
Danube	836,000
Dnestr	61,900
Y. Bug	34,000
Dnepr	558,000
Don	446,500
Kuban	63,500
Caucasian rivers	24,100
Rioni	15,800
Coruh	16,700
Turkish rivers	231,500
Bulgarian rivers	22,200
Total	2,290,200

The region under study is characterized by its diversity comprising all transitions between arid and humid climates or low lands and mountaineous areas. In Table 2, we made a few "cosmetic" corrections, because the (i) Pripjet swamps, (ii) the Panonic flatland and (iii) the low lands along the Black Sea coast are regions of sedimentation rather than denudation. The orographic relationships are depicted in Fig. 1.

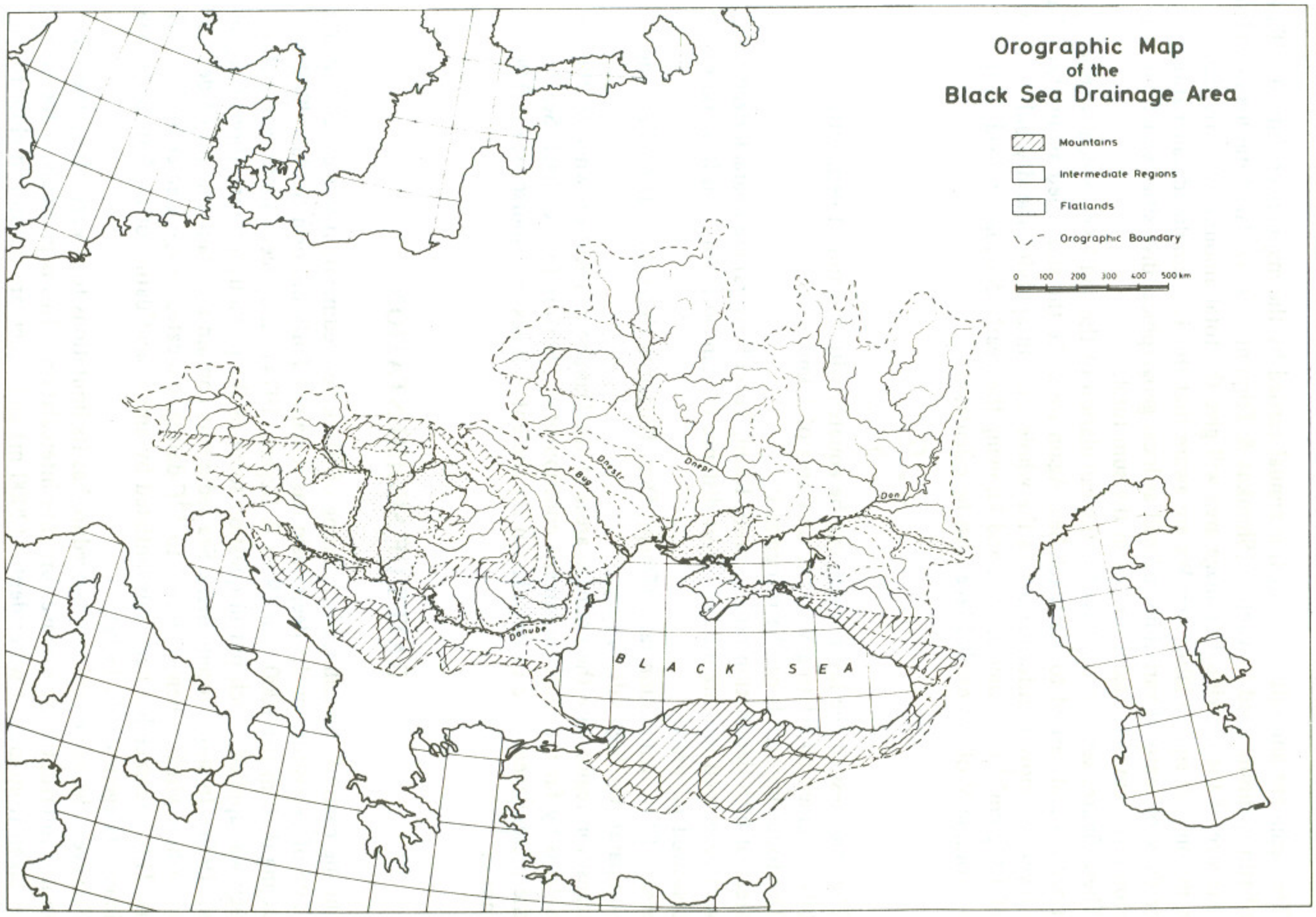

Figure 1. Orographic map of the Black Sea drainage area.

CALCULATION OF DENUDATION RATE

The sediment and salt load which is annual carried by the major rivers into the Black Sea basin is summarized in Table 2 (Shimkus & Trimonis, 1974). The total load divided by the size of the individual drainage area will give the total amount of yearly denudation in tons per square kilometer. We are aware that this is a simplified calculation, since daily or seasonal variations, as well as local geographical diversities which control erosion rates, are only taken care of in the sum total.

These figures serve as the base for the calculation of the soil layer which is annually stripped off and carried to the Black Sea. Again we make the simplified assumption that this layer is removed uniformly across the whole area. In applying the dry bulk density γt of 1.6 g cm^{-3} for a median soil, and knowing the yearly denudation load G, the mean volume V of the eroded layer can be calculated:

$$V = \frac{G}{\gamma t}$$

The thickness of the layer which can be equated with the annual denudation rate is readily obtained by relating V to the unit area of 1 km^2.

The following trends can be recognized:

- areas of high denudation rates (Coruh, Rioni, Turkish rivers) are characterized by a well developed mountain relief, short distance of transportation, and low content of dissolved minerals;
- areas of low denudation rates (Dnepr, Don, Bulgarian rivers) have flat reliefs and comparatively high salt contents;
- transition regions are the drainage areas of the Danube and Kuban, whereby the Danube is by far the most prominent contributor of detritus to the Black Sea basin;
- the present mean rate of denudation for the entire Black Sea sourse area is 0.063 mm yr^{-1}.

RATES OF SEDIMENTATION

On the basis of the radiocarbon dating of Black Sea sediments it was concluded that the rate of deposition in the deep basin has remained fairly uniform the last 7000 years, averaging 0.10 m per 1000 year (Ross & Degens, 1974). In a recent study, varve chronology was applied which put in question some of the previous interpretations (Degens *et al.*, 1976). In short, recent Black Sea sediments contain a certain amount of dead organic carbon which, when subjected to ^{14}C-dating, indicates an age greater by 2–3000 years. This inference has been substantiated by amino acid dating of modern Black Sea sediments (Degens *et al.*, 1976).

However, the varve-counting procedure has its limitations too. Very often, the varve pattern is interrupted by massive turbidite intercalations. This is particularly the case in cores taken from greater water depths (2000 m) and which are positioned close to the basin slope. Whereas normal rates are 0.1 m per 1000 years for the sapropel unit deposited in the time interval between 5000 and 1000 years B.P., and 0.3 m per 1000 years for the coccolith unit which formed over the past 1000 years, turbidity currents may

Table 2. Denudation in source area of Black Sea basin.

River	Detritus (10^6 t yr^{-1})	Salts (10^6 t yr^{-1})	Total load (10^6 t yr^{-1})	Size of area (km^2)	Amount of weight (t km^2 yr^{-1})	Denudation volume (m^3)	Denudation rate (mm yr^{-1})
Danube	83.00	52.51	135.51	681,000*	199.0	124.4	0.125
Dnestr	2.50	2.79	5.25	61,900	85.5	53.5	0.054
Y. Bug	0.53	1.35	1.88	34,000	55.4	34.6	0.035
Dnepr	2.12	10.79	12.91	383,500*	24.0	15.0	0.015
Don	6.40	8.43	14.83	446,500	33.2	20.8	0.021
Kuban	8.40	1.95	10.35	63,500	163.0	102.0	0.102
Caucasian rivers	6.79		7.3	24,100	303.0	189.5	0.190
Rioni	7.08	2.16	7.6	15,800	481.0	301.0	0.301
Coruh	15.13		16.2	16.700	971.0	607.0	0.607
Turkish coast	17.00	6.70	23.70	231,500	102.4	64.0	0.064
Bulgarian coast	0.50	0.80	1.30	22,200	58.5	36.6	0.037

* reduced area

contribute a substantial amount of detritus to the deep basin. As a result we may find in cores from the basin apron, a sediment layer of up to 2 m thick which at its base is just 1000 years old.

One core from the upper basin slope has been examined by varve techniques and was found to be essentially free of turbidites (Degens *et al.*, 1976). Some striking relationships come to light (Fig. 2). Sedimentation rates are uniform from 800 B.C. to about 200 A.D., after which they increase in a fluctuating fashion towards the present. The high noise level observed for the past 1500 years can best be accounted for by agricultural activities such as deforestation and the development of a "Kultursteppe". Episodic floods have carried vast amounts of detritus to the Black Sea and have produced the high peaks on our sedimentation curve.

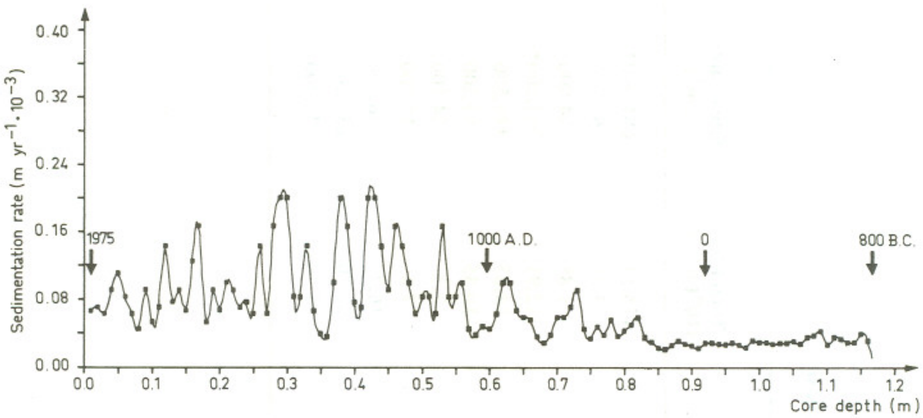

Figure 2. Rates of sedimentation in a sediment core from the Black Sea apron at a water depth of 470 m. The age assignment is based on varve counts (1 light and 1 dark layer = 1 year), and stratigraphic cross-correlations with 7 other Black Sea cores. Between 800 B.C. and 1000 A.D. repeated varve counts check within 1 %. An uncertainty of about 20 % exists for the upper 1000-year section. It is of note that varve dating of a nearby core which goes back to 4100 B.C. shows no apparent change in sedimentation rate below 800 B.C.

CONCLUSIONS

Man's impact on the soil environment is felt and registered in the form of increasing sedimentation rates in Black Sea sediments over the past 1500 years. It appears that agricultural activities have accelerated soil erosion by a factor of about 3.

We have stated that at present the average denudation rate for the area under study is 0.063 mm yr^{-1} or about 100 tons km^{-2}. In applying the appropriate mass physical properties of Black Sea sediments – size, shape, density and packing of mineral grains – we calculated the thickness of the sediment blanket one would annually yield, assuming that the entire Black Sea basin is covered uniformally with such a blanket. The sediment cover comes out to be 0.4 mm thick. Added to the detrital contributions are biogenic remains such as coccoliths which accumulate at a rate of about 0.1 mm per year. Thus the average annual sedimentation rate of the Black Sea taken as a unit is currently of the order of 0.5 mm. In the light of the actually measured sedimentations rates, this figure appears to be reasonable.

Details on calculation procedures and a full discussion on rates of erosion and sedimentation during Holocene and Pleistocene in the Black Sea region will be presented as a contribution to the "Initial Reports of the Deep Sea Drilling Project" Leg 42 B (Paluska & Degens, in preparation).

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