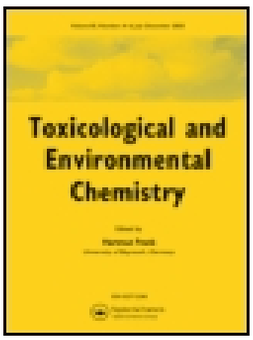

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GEOCHEMICAL AND PHYSICAL OCEANOGRAPHIC ASPECTS OF THE AMVRAKIKOS GULF (IONIAN SEA, GREECE)

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Surface sediment samples collected in Amvrakikos Gulf (Eastern Ionian Sea, Greece) during 1987 were analysed for grain composition, organic carbon content and Fe, Cr, Zn, Co, Ni, Cu, Mn and Pb concentrations. In addition, physical oceanographic data (temperature, salinity, current) obtained during the same period were used to study water mass characteristics and flow patterns. Analysis of the data reveals that metal concentrations are comparable with those seen in other unpolluted Greek areas. Maxima Mn concentrations, seeming to have a natural origin, are amongst the highest found in Greek sediments. Water property variations are great and highly depended on the variable flowrates of the rivers. Current speeds are very low (typically less than 3 cm/s) in Amvrakikos Gulf and remarkably higher (may exceed 100 cm/s) in the vicinity of the narrow (Preveza Channel) connecting the gulf with the Ionian Sea.

KEY WORDS: Ionian Sea, Amvrakikos Gulf, heavy metals, water characteristics, currents.

INTRODUCTION

The study area is located in the eastern Ionian Sea (northwestern Greece). It comprises a semi-enclosed embayment (Amvrakikos Gulf) and a lagoonal complex consisting of three systems (Rhodia, Logarou and Tsoukalio). The gulf is connected with Ionian Sea through Preveza Channel (sill depth 4 m; width 60 m; length 5 km). Water depths in Amvrakikos Gulf are less than 60 m, while in the adjacent lagoons they do not exceed 3 m. The Rivers Arachthos and Louros, with mean annual outflows[1] of 70 m^3/s and 19 m^3/s respectively, discharge into the bay (Figure 1). The rivers receive the main load of the domestic (around 100,000 inhabitants), agricultural (animal wastes, fertilizers, pesticides, eroded soil, etc.) and industrial (slaughterhouses, meat- and fishprocessing, soft drinks factories, etc.) wastes of the surrounding area.

Amvrakikos Gulf invites the attention of marine scientists because it consists of an important area for aquaculture and an excellent freshwater wild-life preserve. For the extensive culture of fish are also used the brackish water lagoons. The study area is of further interest in view of the proposed governmental plans to involve the whole northern part of it in intensive aquaculture projects.

Several oceanographic investigations have been carried out in the study area within the recent years.[2–5] This contribution is concerned with a presentation of the level concentrations and distribution of the heavy metals and organic carbon in Amvrakikos Gulf and the adjacent lagoons. In addition it is related with a general description of the seasonal physical oceanographic conditions in the area.

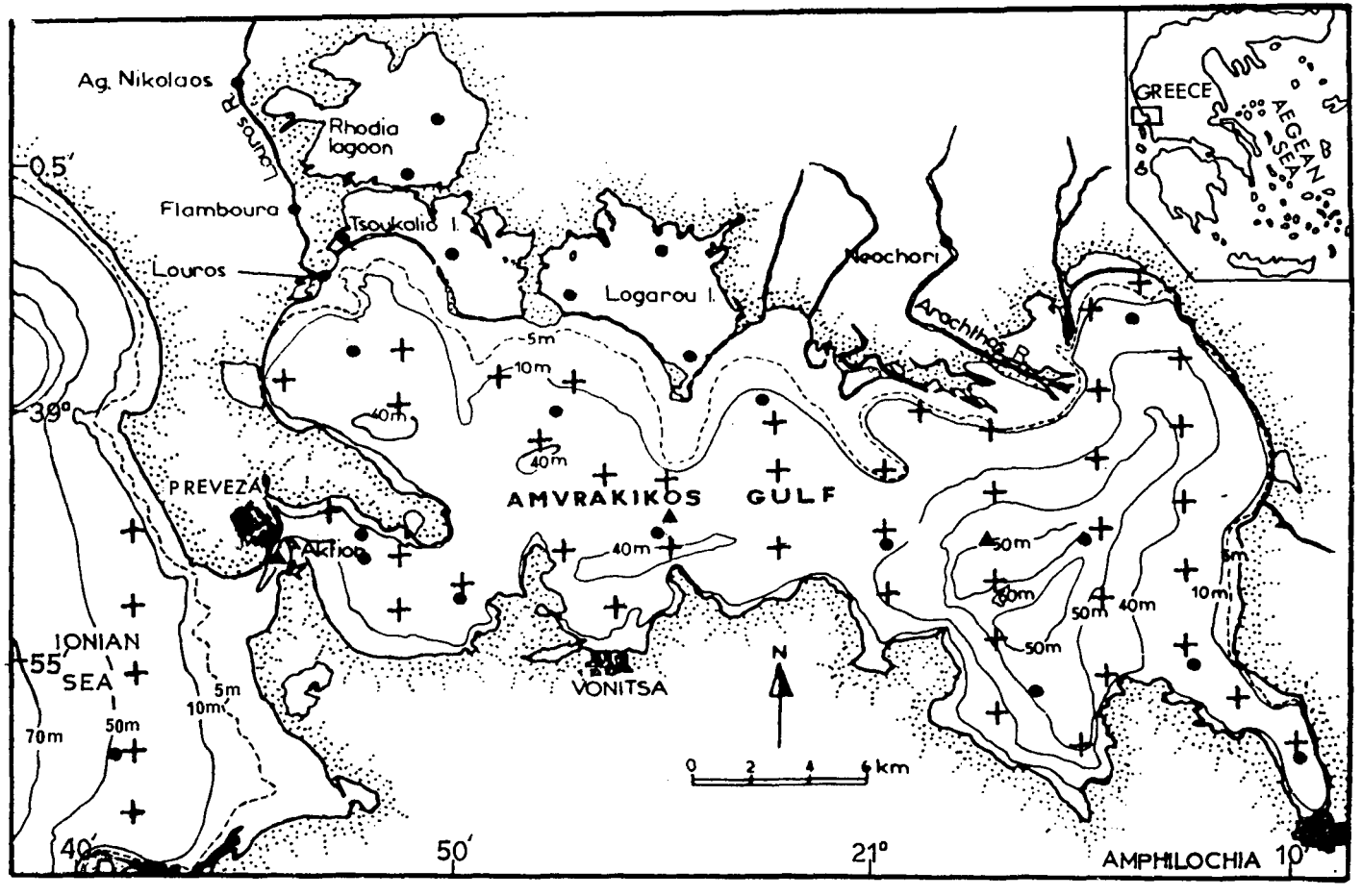

Figure 1 The study area showing its generalized bathymetry (depth contours in m), the locations of the surface sediment sampling stations (●), the oceanographic sampling stations (+), the current meter stations (▲), and places referred to in the text.

MATERIALS AND METHODS

Surface sediment samples were collected during four cruises in 1987 in a grid of 26 stations, using a 0.1 m^2 van Veen grab. The grain size measurement was performed by a technique modified[6] from that of Buchanan.[7] A portion of the sample was dried overnight at 105 °C in a ventilated oven, then crushed in a agate mortar to pass through a 0.063 mm sieve. Organic carbon was obtained according to Gaudette *et al.*[8]

To determine the levels of the metals, 5 g of the dry powder were shaken over 16 h at room temperature with 75 ml of 2N HCl.[9] The leachates were processed on a Perkin–Elmer 305B A.A.S., equipped with deuterium background corrector.[10] Analyses were performed in triplicate

Seasonal temperature and salinity data were also obtained in 1987 from a grid of forty five stations (Figure 1). Water temperatures, at individual depths, were measured by reversing thermometers (Kurt–Gohla type; −2 to 30 °C), attached to 1.35 litre N.I.O. water bottles; the water temperatures are considered accurate to ±0.2 °C. Post-cruise salinity analyses were carried out on a Tsurumi-Seiki salinometer; this was standardized against Copenhagen water. Salinity values are deemed accurate to ±0.01.

Currents were measured at three locations with the aid of Aanderaa (RCM4 Model) self-recording current meters. These were deployed using a vertical mooring array with an anchor and subsurface buoyancy. The instruments recorded current speed, direction, temperature and conductivity at ten minutes intervals.

RESULTS AND DISCUSSION

Geochemical features

The sediment granulometric composition analysis indicated that four different sediment types are found in the study area. That is very fine sediment (mud; 2.25% sand, 43.85% clay), covering the central part of the gulf; fine sediment (silt; 3.31% sand, 72.21% silt), which covers the rest of the gulf; coarser sediment (sandy silt; 23.07% sand, 60.59% silt), which covers mainly the lagoons; and sediment containing more coarser fractions (silty sand; 78.32% sand, 16.36% silt) covering some parts of the lagoons, as well as the reference station area, in the Ionian Sea. In general Amvrakikos Gulf is covered by fine sediment (mud-silt), while the lagoons, the coastal zones between the lagoons and the gulf as well as, the reference station area are covered by coarser sediment (sandy silt–silty sand).[4,5]

Calcium carbonate values range from 27.7% to 57.9%. Lower values (30–40%) are found in the main part of Amvrakikos Gulf. Rhodia and Tsoukalio Lagoons display relatively higher (30–46%) $CaCO_3$ contents, while Logarou Lagoon, as well as, the reference station area, in the Ionian Sea, indicate even higher amounts (58%) of $CaCO_3$. The carbonate matrix with low Mg percentage[11] is of local origin and consists mainly of shells, or it is the result of chemical or biochemical processes.

The organic carbon values range from 0.19% (in the Ionian Sea) to 5.52% (near the city of Preveza). Excepting two enhanced values (5.52%, 2.41%) in the entrance of Amvrakikos Gulf, the remainder stations of the embayment display organic carbon concentrations ranging form 0.92% to 1.50%, which are indicative of a slight influence from organic matter. Such an influence could be expected for a semi-enclosed embayment like Amvrakikos Gulf where the renewal of its waters is very limited. The organic matter influence is greater in the western and southeastern areas of the gulf than in the northeastern sector of the embayment. Organic carbon values of the lagoons are relatively higher (4%–4.90% in Rhodia; 3.52%–4.10% in Tsoukalio; 2.23%–3.52% in Logarou) than those seen in Amvrakikos Gulf (Figure 2). These values are consistent with those found by Guelorget *et al.*[11] and are generally considered normal for lagoonal systems, particularly of the Mediterranean Sea.

Heavy metal concentrations are shown in Table 1. In general, concentrations for the various metals exhibited closely similar areal distribution patterns (Figure 3). That is, very low values at the reference station area (Ionian Sea); low concentrations in the lagoons; relatively higher values in Amvrakikos Gulf, with low fluctuations, showing a clear trend of maxima value in the central part of the gulf.

Generally, Zn and Cu concentration were low in Amvrakikos Gulf (70–80 ppm and 23–31 ppm for Zn and Cu, respectively), in the reference station area (12 ppm for Zn and 2 ppm for Cu) and in the lagoons. Slightly enriched Zn (81–85 ppm) and Cu (42–45 ppm) values were found in the Louros River sediments, which may be suggestive of a pollution due to anthropogenic reasons (fertilizers, domestic effluents, etc.).

Manganese concentrations exhibited great variations in Amvrakikos Gulf and ranged from 440 ppm to 3820 ppm, of the maxima values being found in the eastern (and deeper) part of the embayment (Figure 4). These maxima concentrations are probably caused by occasional inter-action between saline water and the suspended hydrate manganese oxide[12] supplied by Arachthos River.

Lead shows different distribution pattern from those of the other metals. It exhibits slightly enriched values in the vicinity of Preveza city and Aktion airport, which are attributed to anthropogenic influence. This view is supported by the fact, that surface sediments from these particular regions show relatively high contents of $CaCO_3$, with trivial metal concentrations.[13]

Water mass characteristics

Water mass analysis indicated that in winter (February), removal of heat through the sea surface resulted in the presence of very low surface water temperatures (around 11.0 °C, though in a few cases were measured surface water temperatures up to 14.8 °C). Surface salinities and densities were also low and exhibited great variations at the various sea areas (ranges between 22.4–32.4 and 16.9–24.5 σ_t, respectively). Horizontal variations of the aforementioned water properties were

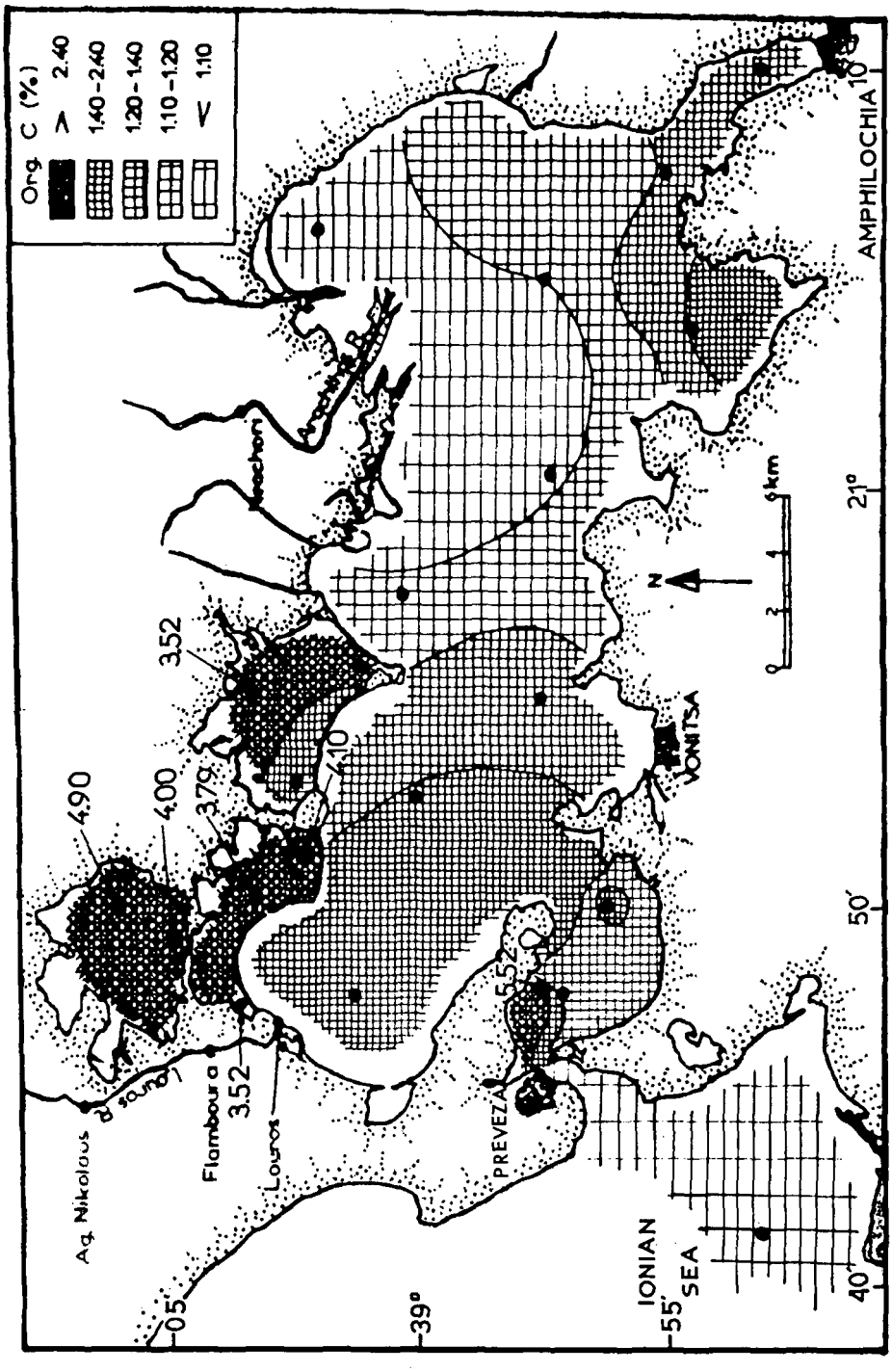

Figure 2 Areal distribution of organic carbon showing maxima values in the lagoons.

Table 1 Concentrations of the constituents determined

Constituent	*Amvrakikos Gulf range*	*mean*	*Lagoons and Rivers range*	*mean*	*Reference station*
Org. Carb. (%)	0.92–5.52	1.67	1.08–4.90	2.78	0.90
Fe (%)	0.68–3.05	2.50	1.40–2.63	1.94	0.49
Mn (ppm)	440–3820	1170	310–750	590	320
Cr (ppm)	27–177	140	90–150	116	46
Ni (ppm)	80–188	152	90–163	116	33
Zn (ppm)	20–80	67	39–85	60	12
Cu (ppm)	12–31	24	11–45	24	2
Co (ppm)	9–30	21	10–19	15	4
Pb (ppm)	11–21	13	8–20	12	7

relatively small at a depth of around 20 m (13.3–15.8 °C, 33.7–34.9, 26.2–26.5 σ_t), and below this depth level. Vertical variations of temperature, salinity and density, exhibited closely similar characteristics throughout the Bay, and in general they increased greatly with increasing depth. The gradients were stronger in the upper 10 metre layer.

In spring (May), waters of very low salinity (16.8–26.8) and high temperature (18.7–21.4 °C) related to the river discharges could be detected in the upper layers, throughout the bay; these developed very strong vertical salinity and temperature gradients. The gradients resulted in strong stratification to around 10 m. Thus, water densities ranged from 11.0–18.8 σ_t at the surface, increasing to 25.3–26.1 σ_t at 10 m. Below this depth level, water properties (temperature, salinity, density) varied only slightly with increasing depth and in most cases the deeper portions of the water columns were almost homogeneous.

In summer (July), the upper portions of the water columns had been warmed substantially; this reflects the vigorous warming obtained at the height of summer. Surface water temperatures, compared to those of May, were found to be around 7.0–10.0 °C higher (28.8–29.9 °C). Due to extensive evaporation and decreased flow of the Rivers Arachthos and Louros, surface water salinities were also higher (26.4–28.8), than those seen in spring (May). Subsurface, water temperature decreased rapidly with increasing depth down to around 20 m, where horizontal variations of the aforementioned water property were usually small (14.8–16.2 °C). Conversely, water salinity and density increased greatly with depth to reach values of around 34.0–37.0 and 24.9–25.8 σ_t, respectively, at 10 m.

In autumn (November), the upper layer water down to around 10 m was, in most cases, characterized by small vertical variations of the water properties, suggesting that vertical convection was actively taking place. Surface water temperatures, salinities and densities ranged from 15.4–19.0 °C, 26.6–34.8 and 19.0–26.3 σ_t, respectively. The thermocline, halocline and pycnocline were stronger between 10 m and 20 m. Below the latter depth only small changes of salinity and density could be observed with increasing depth.

The study of current data revealed that mean current speeds in the vicinity of Preveza Channel ranged between 12.5 cm/s and 15.3 cm/s. Maximum current speed seen in this area was of the order of 97 cm/s. In the central part of Amvrakikos

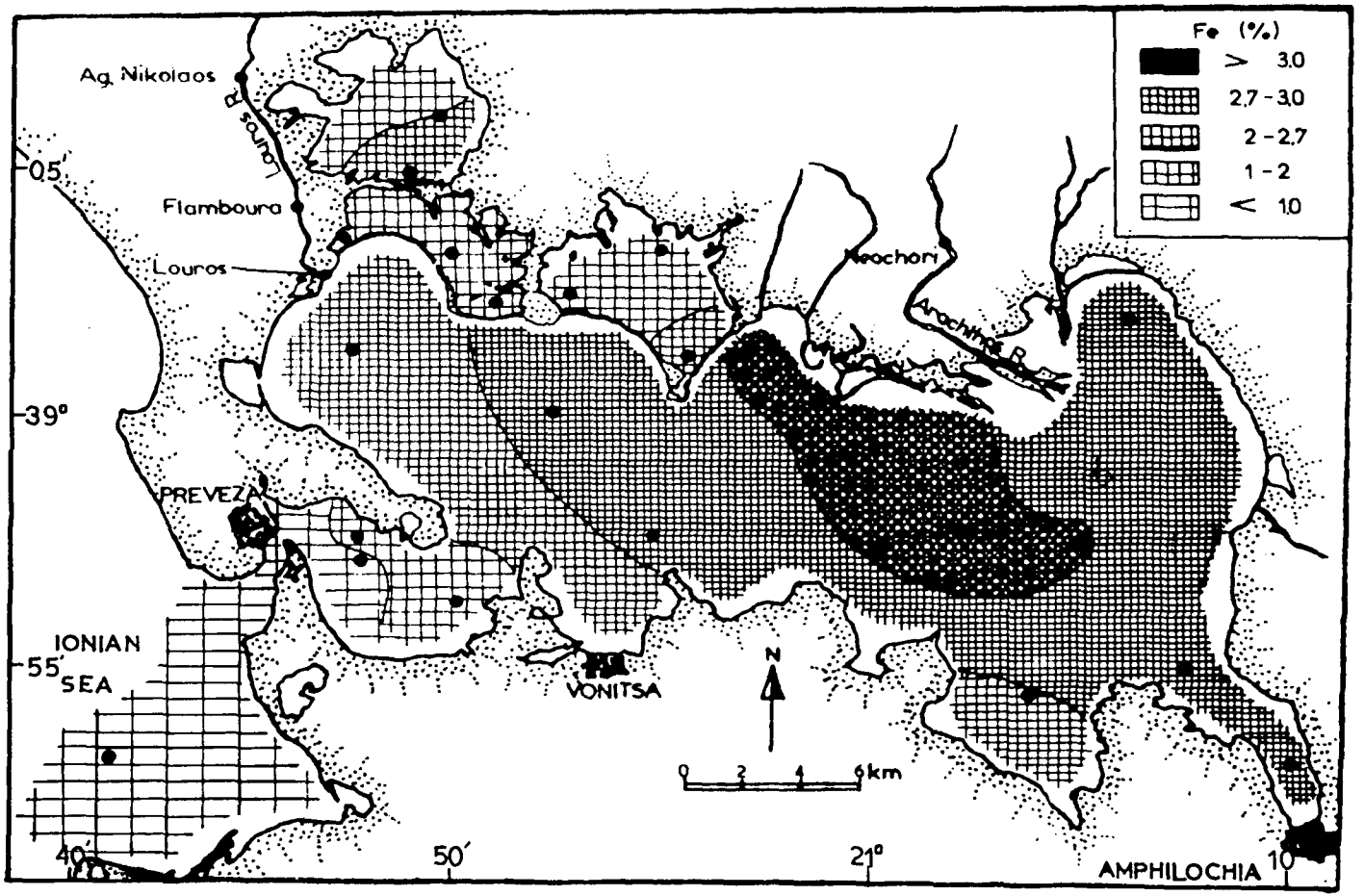

Figure 3 Iron areal distribution showing the general trend of all metals.

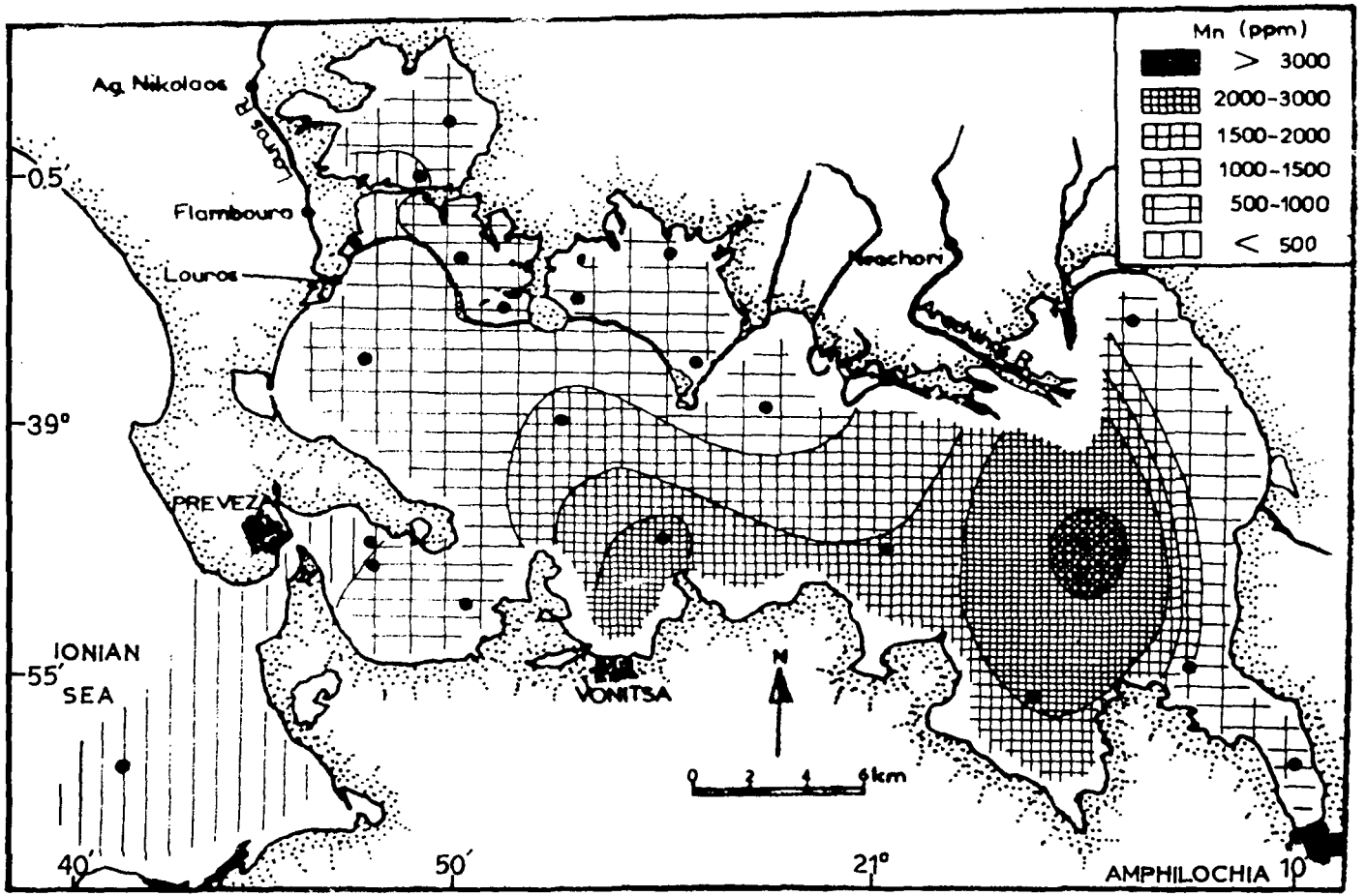

Figure 4 Areal distribution of Manganese, indicating great fluctuations in Amvrakikos Gulf with maximum value in the deepest zone of the eastern part.

Gulf current speeds were very low. The maximum current speed in this area was less than 6 cm/s during summer and did not exceed 19 cm/s in spring.

CONCLUSIONS

Surface sediments in Amvrakikos Gulf, the adjacent lagoons (Rhodia, Tsoukalio, Logarou) and in the Rivers Louros and Arachthos, show heavy metal concentrations similar to those reported in other non-polluted areas, although a slight anthropogenic enrichment of the concentrations of Zn, Cu and Pb can be suspected.

In Amvrakikos Gulf, surface salinity remains very low, resulting in strong stratification in the upper layers, throughout the year.

Horizontal and vertical variations of the water property in the bay are great, suggesting that the various areas are influenced to a varying degree from the freshwaters discharged by the rivers. The northeastern part of Amvrakikos Gulf is subjected to the greatest influence (owing to the freshwater discharge of the Arachthos River), whilst least freshwater influence is seen in the southeastern section of the embayment.

Current speeds in Amvrakikos Gulf are very small (typically less than 3 cm/s) and usually do not exceed 20 cm/s.

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