Origin and distribution of surface sediments and human impacts on recent sedimentary processes. The case of the Amvrakikos Gulf (NE Ionian Sea)

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ABSTRACT

The sedimentology of the floor of the Amvrakikos Gulf, a river influenced, semi-enclosed relatively shallow-silled embayment, lying along the northeastern Hellenic coast of the Ionian Sea (eastern Mediterranean Sea), is investigated with respect to its origin (terrigenous and/or biogenic), the prevailing oceanographic conditions and human interference. Nearshore (water depths approximately <10 m) sediments, especially along the northern margin of the Gulf, consist mostly of biogenic sands, as the result of water exchange between the freshwater lagoonal waters and the surface waters of the Gulf. An exception to this is the mouth area of the Arachthos River, which is dominated by the terrigenous riverine sediment influx. The offshore (water depths >10 m) bottom surficial sediments are fine-grained (silty and clayey) of terrigenous origin (>70%); this is attributed to the inter-seasonal, strong two-layer stratification of the water column in the Gulf which restricts benthic productivity by inhibiting the downward flux of surface eutrophic waters and the development of nearbed disoxic conditions in water depths >40 m. River damming has reduced also the riverine terrigenous sediment supply; this is more profound in the case of the Arachthos River where not only the deltaic evolution has been affected, but also the textural character of the seabed sediments of the mouth area has been altered; this is expected to influence the benthic communities of prodeltaic surficial sediment.

1. Introduction

Coastal embayments comprise a broad category of ecosystem types, representing a spectrum of varying degrees of physical isolation from the open sea and undergoing specific hydrodynamic and sedimentological conditions. The morphological variability of these coastal systems, partially surrounded by land and acting as transitional zones, from terrestrial to marine conditions, is controlled mainly by riverine water/sediment fluxes and the interaction between land and sea processes (Valiela, 1991). Their hydrodynamics are related often to an estuarine-type circulation and/or vertical density gradients, wind and tidal mixing, without excluding processes associated with fronts, the presence of internal waves, geostrophic adjustment and the influence of the Earth’s rotation (the Coriolis effect). Usually, they are regions of high primary production and biodiversity, as they receive substantial amounts of suspended material derived from the land, dissolved and particulate matter, including nutrients, dissolved organics and metals from both natural and anthropogenic sources. Therefore, they form complicated coastal ecosystems with a large number of living and non-living resources; as such, they are considered to be areas of major socio-economic importance (Costanza et al., 1997). At the same time, these coastal ecosystems are particularly vulnerable to anthropogenic impact, i.e. changes in riverine water/sediment fluxes, alterations in the biological and chemical (e.g. agrochemicals) regime.

In the case of microtidal coastal environments, such as those of the Mediterranean Sea, the significance of the river input is enhanced, as their formation and evolution is related strongly to riverine (deltaic) processes. In terms of origin, sediments could be land-derived (terrigenous) and/or produced by marine organisms (biogenic), in conjunction with regional oceanographic setting.

Over the past decades, the construction of dams along river routes has not only affected deltaic evolution (e.g. Milliman, 2001 and McManus, 2002), but also the texture of prodelta sediment; this is more evident in the case of river influenced coastal embayments, such as that of the Gulf of California (Carriquiry and Sanchez, 1999), in Huanghe River estuary (Yu, 2002) and in the Inner Thermanikos Gulf (NW Aegean Sea) (Kapsimalis et al., 2005a).

Within this framework, the present investigation examines the sedimentological characteristics of the Amvrakikos Gulf (NE Ionian Sea, eastern Mediterranean), which is a rather shallow,
river influenced, silted (“fjord type”) embayment, highly stratified and characterised by relatively high productivity levels compared to the adjacent open Ionian Sea. In particular, this work focuses upon: (a) the origin (terrigenous vs. biogenic) and spatial distribution of the surficial sediments of the Gulf, in relation to river influxes, the existing bio-physico-chemical oceanographic conditions and (b) the impact of dam construction on recent sedimentation processes of the Gulf.

2. The study area

2.1. Geological setting

The Amvrakikos Gulf has a surface of some 405 km$^2$, a coastline length of 256 km and receives freshwater and sediment fluxes from its drainage basin of 3850 km$^2$; this includes the catchments of the rivers Arachthos (1894 km$^2$) and Louros (785 km$^2$), which cover 70% of the total area (Fig. 1). It is a relatively shallow (water depths <65 m), semi-enclosed marine embayment, communicating with the open Ionian Sea through a narrow (approximately 600 m wide), shallow (<5 m, water depth) channel of 5 km in length (Fig. 1); the latter includes an artificially dredged navigational channel, some 8.5 m in depth. The northern part of the Gulf is rather shallow and consists of a relatively wide subaqueous delta/prodelta platform (1–3 km wide), created by the deposition of sediments from the two main rivers Arachthos (primarily) and Louros. This deltaic platform is bounded offshore by a relatively steep prodelta slope, which lies in water depths of between 10 and 30 m. The greatest water depth (65 m) lies in the eastern part of the Gulf (Fig. 1).

The development of the Late Quaternary depositional phases of the Gulf have been studied by Poulos et al. (1995) and Kapsimalis et al. (2005b), and most recently by Anastasakis et al. (2007). According to these authors, sedimentation processes within the Gulf are the combined result of eustatic sea level changes, neotectonic activity and autocyclic switching of delta mouths; the latter applies mostly to the River Arachthos eastward mouth displacement, taking place after the completion of the phase of rapid sea level rise concluded ca. 6 ka BP.

2.2. Water and sediment fluxes-dam construction

The Gulf receives freshwater inputs from the two major rivers: Arachthos ($2200 \times 10^6$ m$^3$ a$^{-1}$) and Louros ($\sim 600 \times 10^6$ m$^3$ a$^{-1}$) (Therianos, 1974). In addition, the Gulf receives annually through precipitation (900–1100 mm yr$^{-1}$) a volume of freshwater of approximately $400 \times 10^6$ m$^3$.

The major terrestrial sediment fluxes are associated with the main rivers, with the River Arachthos being the most important sediment source, as it annually transports 7.31 million tonnes of suspended sediment (Poulos and Chronis, 1997); as such, it is among the Mediterranean rivers with the highest annual suspended sediment (Poulos and Chronis, 1997), since its drainage basin, consisting of calcareous sediments (~60%), supplies mostly material in solution (0.17 x 10$^6$ tonnes a$^{-1}$) of dissolved load; Skoulikidis, 1993, 1996). Finally, only limited terrestrial material is expected to be imported by the ephemeral streams along the eastern and southern margins of the Gulf. Similarly, the contribution of coastal erosion is expected to be very small, due to the rather weak wave activity in response to small wave fetches (<30 km) and the erosion resistant lithology (mostly metamorphic limestones), especially along the western and southern coasts of the Gulf.

Despite the construction of the Pantanassa Dam (in 1954) in the River Louros (up-dam area: 43%) the sediment load of the river has not changed significantly, due to its initially low sediment load. However, in the case of the Arachthos River, measurements undertaken in 1982, after the operation of the Pournari-I Dam (in 1981), located only 6 km from the river mouth, which blocked off the 98% of its total catchment area, revealed a reduction in 28% in the mean annual water discharge (Marinos et al., 1984). Likewise, most of its sediments do not currently reach the river mouth, as its total bedload and the majority of the suspended sediment load have been trapped within the reservoir. The situation has been intensified, following the operation of a second dam (Pournari-II, in 1997), a few kilometres downstream from the location of the Pournari-I Dam.

2.3. Oceanographic conditions

The Gulf has a general two-layer (fjord-like) type of stratification in the water column, governed by the sill depth (approximately 8.5 m), with the upper layer occupying the first 10 m (with the exception of summer when it is extended up to 20 m) and the lower layer being rather homogenous (Voutsinos-Taliadouri and Balopoulos, 1991). Furthermore, seasonal variations of temperature ($T$) and salinity ($S$) values of the Amvrakikos Gulf compared to those of the open Ionian Sea (Table 1) are attributed to the difference between freshwater input (river influx+precipitation) and evaporation, with the Gulf presenting the characteristics of a dilution basin ($S_{Gulf} < S_{Ionian}$) throughout the year, especially during the late autumn to early summer period.

The Gulf is microtidal, with tidal ranges being, in general, <20 cm (Tsimplis, 1994), characterized by a relatively calm wave regime due to the limited wave fetches (Poulos, 1989). Surface water circulation is also weak, presenting a clockwise trend (Marinos et al., 1984). Measured current speeds in the central part of the Gulf demonstrate mean values ranging from 0.3 up to 0.19 m s$^{-1}$ (in winter) (Voutsinos-Taliadouri and Balopoulos, 1991). The same authors have reported fast currents in the Strait of Preveza, ranging from 0.12 to 0.15 m s$^{-1}$ with some bursts reaching 1 m s$^{-1}$.

The upper water layer in the Gulf is well oxygenated, with DO levels being >7 ppm (Dassenakis, pers. comm.). In contrast, the lower layer had values >3 ppm during spring and <1 ppm in summer. Moreover, in a water depth of more than 40 m and closer to the bed, the DO was <0.3 ppm, indicating the development of disoxic conditions, at least during the summer period; this pattern is attributed to the strong stratification of the Gulf waters, which inhibits the renewal of deeper water masses.

Inter-seasonal measurements, undertaken in 1987, have revealed the eutrophic character of the Gulf, and in particular of the Preveza Bay, relative to the surface waters of the adjacent open Ionian Sea. (Friligos et al., 1977). The increased nutrient concentrations are also related to high values of chlorophyll-a, with the highest values (22.0–44.8 mg l$^{-1}$) measured in spring and the lowest during the summer and autumn periods (0.3–1.8 mg l$^{-1}$) (Gotsis-Skreta et al., 2000). For comparison, chlorophyll-a levels in the Ionian Sea are lower than 0.7 mg l$^{-1}$ throughout the year (Panayotidis et al., 1994).

2.4. Sedimentological characteristics

The first description of the granulometry of the surficial sediments of the Amvrakikos Gulf was presented by Piper et al. (1982). In Fig. 2, the results concerning the spatial distribution of sand, silt and clay percentages are given schematically. In
Fig. 1. Geographical location of Amvrakikos Gulf. (a) Drainage basin, (b) lithology and (c) bathymetry. (Key: black vector indicates the eastward displacement of the mouth of Arachthos River during upper Holocene; Pan: Pantanassa Dam; Pr-I: Pournari-I Dam and Pr-II: Pournari-II Dam).
addition, it has to be pointed out that this work is based upon the collection of surficial bottom samples, which took place in the summer of 1979, prior to the operation of the Pournari-I Dam, in the Arachthos River. Besides, a clay mineral identification applied to the clay fraction of the subaqueous deltaic prisms of the rivers Louros and Arachthos (Poulos et al., 1996a) has revealed that the most abundant clay mineral is illite (50–70%) followed by chlorite+kaolinite (15–35%) and smectite (5–20%). Finally, information for the offshore benthic microfauna assemblages (foraminifera and ostracodes) have been presented earlier by Tziavos and Vouloumanos (1994).

3. Data collection and methodology

The present investigation is based upon a data set of 99 surficial sediment samples, collected from the seabed of the Amvrakikos Gulf in 1986, almost 5 years after the operation of Pournari-I Dam, in the Arachthos River. Besides, a clay mineral identification applied to the clay fraction of the subaqueous deltaic prisms of the rivers Louros and Arachthos (Poulos et al., 1996a) has revealed that the most abundant clay mineral is illite (50–70%) followed by chlorite+kaolinite (15–35%) and smectite (5–20%). Finally, information for the offshore benthic microfauna assemblages (foraminifera and ostracodes) have been presented earlier by Tziavos and Vouloumanos (1994).

Grain size analyses were undertaken on these samples in order to identify the sand (>63 μm), silt (2–63 μm) and clay (<2 μm) contents using the standard pipette method, while textural classification has been conducted according to Folk (1974). All the surficial sediment samples were analysed in order to define the carbonate content. The total carbonate content was calculated by determining the pressure of the CO2 released, after applying HCl 10% on ground-to-dust samples, using the carbonate bomb method (Müller and Gastner, 1971).

Microscopic examination was applied in order to be identified as the mineralogical synthesis of the seabed sediments and to be distinguished into their inorganic and organic phases.

A further investigation of the synthesis of the biogenic material was carried out on bottom sediments focusing upon the qualitative determination of the species (or taxa) of the macro and microfauna present in the offshore and nearshore samples. Thus, the determination of macrofauna has been carried out on a sub-sample of the bulk sediment. For the microfauna analysis, a grab-sample was wet sieved, using a mesh size of 125 μm, and dried. Subsequently, small quantities were extracted from this sand fraction and all the foraminifera and ostracod shells were put in Chapman-type containers and microscopically examined (identified).

In relation to the terrigenous and biogenic carbonate material ratios, the bed of the Gulf has been characterised on the basis of the six sedimentary types proposed by Emelyanov et al. (1996) for the surficial unconsolidated sediment of the Mediterranean seafloor (Table 2).

Finally, the consequences of river damming (Pournari-I Dam) concerning primarily the northeastern part of the Amvrakikos Gulf.
Gulf where the Arachthos River discharges is investigated. For this reason, the silt/clay ratios used are extracted from two different data sets: the first one collected in 1979 (Piper et al., 1982), prior to the operation of the dam (in 1981) and the second one (present study) collected in 1986, i.e. approximately 5 years after the operation of the dam; this latter data set includes data abstracted from Poulos (1989), collected also in March 1986 (Fig. 3).

4. Results and discussion

4.1. Spatial distribution of grain-size assemblages

The seabed of the Amvrakikos Gulf presents sand concentrations mostly below 3% (Fig. 4a), with the exception of its northern nearshore zone (water depths <10 m) and the Preveza Bay, where sand percentages are up to 67%. These high sand percentages are associated with high concentrations of coarse-grained biogenic material (shell fragments) (as discussed below), whilst in the case of the Preveza Bay the absence of muddy sediment is related also to the strong currents (up to 1 m s\(^{-1}\)) that either inhibit settling and/or remove fine-grained material. Thus, the nearshore zone sands of the Salaora Bay (especially in front of the Tsoukalio and Logarou Lagoons) are mainly due to the abundance of biogenic material (mostly ostracod shell fragments), the insignificant supply of fine-grained terrigenous (muddy) material and the washover resulting from the wave activity (although it is rather weak). The relatively high sand percentages in the case of the Kopraina Bay are attributed to sediment inputs from Arachthos and the nearby small Vouvos River (see Fig. 1a).

The silt content (Fig. 4b) of the surficial bottom sediments of the Gulf varies between 30% and 40%, with higher values observed in the region of the Arachthos delta front (up to 60%); this is considered to be related to the riverine sediment influx. Topographically, the highest silt concentrations are observed in water depths of between 20 and 40 m, with the exception of the Preveza Bay, where increased silt percentages are observed in water depths <20 m.

Clay percentages vary from 60% to 70% (Fig. 4c), in depths >3 m, reducing gradually towards the coast. The highest percentage (77%) was found in the deepest part of the eastern side of the Gulf, and the lowest (<30%) in the Preveza Strait and along the northern deltaic nearshore zone of the Gulf. The texture of the surficial bottom sediment of the Gulf, according to Folk's triangular textural classification (Folk, 1974), is presented in Fig. 5. In accordance to those mentioned above, most of the offshore area of the western and central part of the Gulf is covered by clay sediments (C: clay/silt content <2), whilst the eastern part is covered by mud (M: 1/2<silt/clay content<2). In the Preveza Strait and in most of the nearshore zone, the seabed sediments become coarser, varying from sandy clay/silt to muddy/silty sand.

4.2. Carbonate content

The spatial distribution of carbonate content (organic and inorganic) of the surficial sediment of the Gulf is presented in Fig. 6. In general, the carbonate content is rather low being in between 10% and 20% in the offshore area, as in the case of other river influenced coastal embayments, e.g. <20% in the western part of the Theraikos Gulf (Lykousis et al., 1981; Karageorgis et al., 2005) and in the prodelta area of the Bujuk Menderes River (east coast of the Aegean Sea) (Ergin et al., 2007). Increased values

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<th>Type of sediment</th>
<th>Terrigenous (%)</th>
<th>CaCO(_3) (%)</th>
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<tr>
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<td>&gt;90</td>
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<td>Tc</td>
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<td>B</td>
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The increased carbonate content in the nearshore zone is attributed mostly to the abundance of benthic communities (see below). The overall relatively low carbonate content of the Amvrakikos Gulf is indicative of the terrigenous (low carbonate) sediment influx and the rather low benthic activity (as discussed in Section 4.3.2). For comparison, carbonates in offshore sediment in Izmir Bay (Asia Minor) reach values up to 50% (Duman et al., 2004), while carbonate percentages from 50% to 75% up to 100% (non exclusively of biogenic origin) have been reported by Bayhan et al. (2001), in the case of offshore Aegean Seabed sediment in the vicinity of Dardanelles Strait.

4.3. Origin of bed surficial sediment

4.3.1. Terrigenous sediment

Microscopic examination has shown that the majority of terrigenous material of the offshore area consists of quartz and feldspars with some micas, whilst its fine-grained fraction is dominated by a sub-microscopic phase, characteristic of clay minerals with illite being the dominant mineral followed by smectite (Piper et al., 1982; Poulos et al., 1996). The above are encountered mainly in the northern and northeastern parts, which are influenced by deltaic sedimentation processes. This microscopic examination has further shown that part of the carbonate content is of inorganic (terrigenous) origin consisting mainly of small rock clasts, non-biogenic aragonite and dolomite. On the basis of a semi-quantified microscope analysis, the carbonate material of nearshore sediments of the northern coast is of biogenic origin, in percentages higher than 90%, while the offshore carbonate material in the Preveza Strait and along the southern coast of the Gulf is 40–50% inorganic. The offshore carbonate material in the northwestern part of the Gulf (Salaora Bay) is 15–30% inorganic, while in the central and eastern part of the Gulf, the percentages of inorganic carbonate range between 10% the 25%, increasing towards to the mouth of Arachthos River.

Therefore, it is indicated that the terrigenous material dominates in the greater part of the Gulf. This may be attributed to the sediment supply of Arachthos (7 × 10^6 m^3 a⁻¹) during the period before the construction of the Pournari-I Dam and of Louros (<1 × 10^6 m^3 a⁻¹). Moreover, the uniform distribution of terrigenous and fine-grained sediment throughout the offshore area of the Gulf basin could be explained by: (a) the eastward shift of the Arachthos River mouth over the last few thousand years (see Fig. 1b; Kapsimalis et al., 2005b); (b) the extension of the river plumes at distances of several kilometres seawards (Poulos et al., 1998); (c) the observed periodical clockwise surface water circulation (Marinos et al., 1984); and (d) the relatively low benthic biological productivity.

4.3.2. Biogenic sediments

The biogenic component of the surficial sediments of the Gulf represented by foraminifera and ostracode assemblages of up to 5 mm in size is rather low, as indicated by the low (<20%) total carbonate percentages, with the exception of the Preveza Strait and some nearshore (mostly lagoonal) zones. Nikolaidou et al. (1983) have argued that benthic organisms could reach low concentrations (<10 indiv./0.2 m²) in offshore areas; this does not comply with the high levels of primary production of the surface Gulf waters (up to 50 times higher than that of the adjacent surface waters of the Ionian Sea; Friligos et al., 1977). This may be explained by the two-layer inter-seasonal strong stratification of the water column (see above), which inhibits the down-welling of the eutrophic surface and oxygated waters; the latter leading also to low-oxygen conditions near the seabed, in water depths >40 m.
An additional process, which is responsible for the limited presence of benthic organisms in the eastern part of the Gulf (where the subaqueous deltaic prism of the Arachthos River progrades), is the high deposition associated with the high sediment fluxes of the Arachthos River; the latter decreases the relative proportion of microfauna growth in the subaqueous delta area.

Increased percentages of microfauna assemblages have been found in the offshore sediments of the Preveza Strait, where the ongoing vertical mixing of the outflowing Gulf water together with the inflowing Ionian waters permits the oxygenation of the lower layer. The richest in biogenic material sediments lie along the shore zone of the lagoons in the northern deltaic margin of the Gulf, where mixing occurs between the outflowing lagoonal waters and the eutrophic nearshore surface Gulf waters.

Following the microscopic examination, 106 species have been identified with 70 of them characterised as foraminifera and 37 as ostracodes. Among the foraminifera, only one may be considered as pelagic, found in a Preveza Strait sample, whilst 64 of them have been identified in offshore sediment samples (27 found in both nearshore and offshore areas). Five (5) foraminifera species have been found exclusively nearshore (Milionella sidobottomi, Quinqueloculina laevigata and sp.1, Trochamina inflate and Vertebralina striata). Among the ostracodes, 26 have been found in...
offshore sediments (13 of them have been found in both nearshore and offshore areas). Eleven (11) ostracode species have been traced exclusively nearshore (Aurila woodwardii, Basslerites berchani, Candona spp., Carinocythereis sp., Cypris spp., Cytherella vulgata, Cytheris sp., Cytherura gibba, liyocupris gibba, Leptocythere rara, Lineoecris sp., Loxoconcha agilis and L. elliptica).

Considering the foraminifera population, the species Ammonia beccarii is the most abundant in both offshore and nearshore sediments, while a wide distribution characterises those of the Elphidium family, such as E. complanatum, E. crispum and sp.1 osshore and Elphidium sp. nerashore. Other foraminifera species most common in the offshore waters of the Gulf are: Bulimina elongate, Nonionella opina, Planorbulina meditteranensis and Triloculina trigonula, together with some species of the Quinqueloculina (e.g. Q. seminulum) and Textularia (e.g. T. sagitula) families. The most widespread species of ostracodes are: Loxoconcha pellusida, Loxoconcha turida, Propondocypris pirifera and to a lesser degree Carinocythereis carinata, Cytheroma variabilis and Paradoxostoma similie; these species are highly tolerant to the variable environmental conditions of the Gulf and are distributed regardless of the bathymetric fluctuations (Tziavos and Vouloumanos, 1994).

Nearshore, the most abundant species is that of the Cyprideis torosa, whose presence is favoured by the mixing of freshwater with Gulf waters.

The only planktonic foraminifera identified in the Preveza Strait is the Globigerinoides rubber; this is attributed to the influx of the (open) Ionian Sea waters.

The nearshore benthic community has the characteristics of a rather shallow marine, low-energy environment with low salinity and a high-nutrient content similar to those found in other estuarine environments, such as that of the Nantucket Bay in Massachusetts (Lidz, 1965), the Odell Estuary (SW Spain; Ruiz et al., 2004) and the Kiel Bight (Nikulina et al., 2007). Moreover, the most abundant species (see above) are those more tolerant to environmental conditions, e.g. salinity and nutrient content.

The diversity of species and abundance of individuals are limited in the offshore sediments with benthic fauna presenting only subtle differentiations among the bio-communities of the Gulf. Furthermore, the differentiations observed in the microfaunal distribution are not strictly related to depth, but mainly to the texture of the substratum. For example, Textularia sp. and Bulimina aculeata prefer a muddy substrate (Dermitzakis and Kourouni, 1982) in contrast to Elphidium spp., which prefers a sandy substratum (Tziavos and Vouloumanos, 1994). Although, the reported disoxic conditions do not favour the bio-communities of the deeper parts of the Gulf (water depths >45 m), some species show greater tolerance to these conditions, such as Nonionella opina.

The great quantities of sediment discharged by the Arachthos River, also inhibits the population growth of marine microfauna in the eastern part of the Gulf. Consequently, shells are absent from the subaqueous deltaic sediments, whereas only a small number of species were traced in the regions neighbouring the river mouth area. Thus, it is concluded that freshwater and high sediment deposition rate hinder or even eliminate microfaunal growth in the area affected by the river. Only a certain species of the Textularia family seems to be tolerant to the conditions mentioned above.

4.3.3. Terrigenous vs. biogenic material

The dominance of terrigenous material over that of biogenic origin has already been demonstrated. In Fig. 7, the spatial distribution of the four categories identified in the case of the Amvrakikos Gulf, according to the Emelyanov classification (1992) (see Table 2), is given schematically. Terrigenous, low-calcareous sediments (Tc: terrigenous material = 90–70%) cover most of the western and central part of the offshore floor of the Gulf, while pure terrigenous material (carbonates <10%) cover the eastern part, indicating the influence of Arachthos in modern sedimentation processes as well. Terrigenous-biogenic (bT: carbonates = 50–70%) and/or biogenic carbonate (Bc: carbonates = 70–90%) sediments exist along the shore zone of the Tsoukalio and Logarou lagoons (Salaora Bay) and in Preveza Bay.
4.4. Human interference

Human intervention upon recent sedimentation processes, related to the reduction of the sediment fluxes of the Arachthos River can be identified from textural changes in the surficial sediments of the northeastern deltaic margin of the Gulf. The clay/silt ratio of the surficial sediments collected in 1979 (Piper et al., 1982) and in 1986 (the present study) are shown in Fig. 8.

Only 5 years following the operation of Pournari-I Dam, in 1981, the clay content increased substantially against that of silt, in response to the dramatic reduction of the Arachthos River sediment fluxes and in particular of its coarse-grained suspended. Besides, water flow regulation due to electrical power demand has eliminated the occurrence of flood events during which the sediment laden river plume could reach distances of several kilometres offshore. In addition, textural changes can be observed in the southeastern part of the Gulf.

Such changes in the texture of the Gulf bottom sediments, which have become progressively finer (more clayey) are expected to affect the benthic ecosystem, i.e. the characteristics of the benthic micro and macrofauna will be modified, whilst the reduction in terrigenous material will increase ultimately the biogenic component of the bottom sediments. Furthermore, this sediment reduction is expected to affect the deltaic evolution in terms of coastline retreat and associated subaqueous erosion, as it has been reported elsewhere (e.g. Axios River in NW Aegean Sea by Kapsimalis et al. (2005a), the Yangtze River in China by Yang et al. (2003), the Nile Delta by Frihy and Dewidar (2003)).

5. Conclusions

Sedimentation processes in the Amvrakikos Gulf, a semi-enclosed and shallow-silled marine embayment of the NE Ionian Sea, are controlled by the water and sediment fluxes of Arachthos and Louros, in combination with the prevailing oceanographic conditions. The Arachthos River plays a dominant role in sediment transport processes in the eastern and central part of the Gulf due to its high sediment fluxes. The Louros River plays a secondary role, due to its low-suspended sediment supply, mainly influencing the northwestern part of the Gulf (Salaora Bay).

Offshore (water depths > 10 m) surficial sediments are fine-grained (silty and clayey), of terrigenous origin (> 70%). The low presence of biogenic material (mostly benthic foraminifera) in sediments, in contrast to the eutrophic character of the surface waters, can be explained by the inter-seasonal strong two-layer stratification of the water column; the latter not only inhibits the downward flux of the eutrophic surface water, but also induces disoxic nearbed conditions in the deeper (> 40 m) parts of the Gulf.

Nearshore sediments along the northern margin of the Gulf consist mostly of biogenic sands; these are the result of water exchange between the freshwater lagoonal waters and the surface Gulf waters. In general, ostracodes are more abundant in the nearshore areas (favoured by freshwater mixing), in comparison with foraminifera benthic assemblages, which dominate the offshore areas.

The presence of dams along the river courses, reducing dramatically the riverine water/sediment influx, not only affects the deltaic progradation but also modifies the textural character of seabed sediments making them more fine-grained. Such a process may, in turn, alter the composition of the associated benthic community and the ratio between the terrigenous and biogenic components of the sediments to the favour of the latter.

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