Benthic boundary layer forcing on Iberian margin particle fluxes and accumulation

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Abstract

Transmission and optical backscatter measurements at 14 stations along two transects perpendicular to the Iberian Margin indicate that a strong decrease in transmission in the Surface Nepheloid Layer coincides with a distinct subsurface chlorophyll maximum. Detached intermediate nepheloid layers were found at the upper slope. Bottom nepheloid layers increased in thickness from some 40-100m from the shelf edge to the upper slope. Deeper down the middle and lower slope a thicker, two stepped, but relatively weak BNL, indicates a rather gradual sinking of particles in the watercolumn and local effects of currrent scour at the Galicia Bank Margin.

Relatively high mass accumulation rates are found at the shelf edge. Non-sedimentation, sediment bypassing or erosion is noticeable locally on the upper slope. An exceptionally high accumulation rate is found at the lower slope, a decrease occurs with greater distance from the coast. Lowest rates are found on the Galicia Bank margin.

Introduction

A major part (80-90%) of marine sedimentary organic carbon is stored on the continental margins (Berner, 1982; Jørgensen, 1983). Continental margins thus play an important role in the carbon cycle, and knowledge of the processes involved in the transport and burial of organic carbon on margins in different oceanographic settings is of great importance for understanding the global carbon cycle and budget.

Especially processes of organic and inorganic particle transport over the shelf edge is considered important, following suggestions by Walsh (1991) that a considerable part of the organic carbon buried on the continental slope is derived from shelf export. The occurrence of lateral transport over the continental margin is confirmed by recent research at the California margin (Jahnke et al, 1990), the eastern margin of the USA (Biscaye et al., 1994), the Gulf of Lions slope (Monaco et al, 1990), in the Norwegian-Greenland Sea (Graf et al, 1995) and at Goban Spur during OMEX I (Thomsen and Graf, 1996; van Weering and de Stigter, 1996).

During the OMEX I studies in the Goban Spur area, the presence of intermediate- and bottom nepheloid layers across the continental slope was well established (McCave and Hall, 1996; van Weering and de Stigter, 1996; Final Report OMEX I). It appeared that intermediate nepheloid layers were of a non-permanent character, and that the main lateral and resuspended flux was in the benthic boundary layer (BBL).

Long term current measurements in the lower 2 m of the BBL at the upper slope of the Goban Spur margin show that near-bed current velocities are sufficiently high to allow non-sedimentation or resuspension/erosion at the upper slope (van Weering and de Stigter, 1996) during a considerable part of the tidal cycle. This results in increased lateral advective transport of particles along and across the margin. Repeated short term current and particle measurements (Thomsen and Graf, 1996) at the same location, showed the importance of aggregate formation of POC in the BBL, thus providing another carbon input into the system.

Along the same transect, sediment traps below 1000m water depth (Antia et al, 1996) indeed showed a considerable input of laterally derived particles.

Evidence for redistribution of organic and inorganic matter in the BBL is also provided by enhanced sediment oxygen demand (SOD) observed on the middle slope (Helder et al, 1996; Duineveld et al., 1996), and by relatively high sediment accumulation rates at the middle and lower slope (van

Weering and de Stigter, 1996). Organic carbon burial rates were shown to be closely linked to sediment accumulation rates, with highest values (0.05-0.1 g/m^2/yr) occurring at the base of the slope. Overall C_{org} burial rates appear low at the Goban Spur margin .

By contrast, the slope and margin off the NW Iberian margin may receive a much higher supply of organic matter by the excess input of particulate organic matter derived from the highly productive, seasonally upwelled overlying waters. Filaments and patches of the upwelled water may be dispersed offshore in a northerly and northwesterly direction by the presence of eddies off Cape Finisterre (Pingree and LeCann, 1992; Pingree, 1995) and may extend 250-300 km offshore. The actual flux of particulate organic matter across the margin and to the deep sea, however, is virtually unknown for this area. In other upwelling areas, organic carbon in the sediments on the continental slope may reach values up to 6%, thus forming an important part of the carbon pool (e.g. Pedersen et al, 1992).

In the first year of OMEX II, cruise 64/109 of RV "Pelagia" was held from July 15-August 6, 1997, to collect material to partially fulfill the tasks outlined in the TA of OMEX II WP3. During this cruise, CTD watercolumn profiling and sampling of the water column by NOEX bottles was done at 14 stations, followed by bottom sampling (multicorer, box or pistoncorer) at the same sites (Fig. 1). 3.5 kHz penetrating echosounder bottom records perpendicular to the bathymetric contours were made to study seabed morphology and variability of the sedimentary cover. In addition, two sediment trap moorings of the Institut für Meereskunde (Kiel) were deployed at locations discussed during OMEX II SciCom meetings. The BOBO lander for recording of benthic boundary layer dynamics was deployed at 2152 m water depth, near the location of sediment trap mooring OMEX II-II.

NIOZ (5a) is involved in the following tasks and subtasks described under WP3:

Task 1. Particle transport, settling, accumulation, mixing and burial fluxes. Temporal and spatial variability

1.1 Amount, character, distribution and composition of suspended particulates in nepheloid and clear water layers

1.2 Spatial and temporal variability of the benthic boundary layer dynamics

1.3 Particle fluxes to the seabed, accumulation and mixing rates

1.4 Sediment distribution, properties and composition along selected transects

1.5 Dominant sediment transport processes at contrasting margins

Task 2. Sediment/water exchange processes and early diagenesis

2.2 Organic matter diagenesis and burial

Methods

The water column was sampled at 14 stations along two transects perpendicular to the Iberian Margin (Fig. 1) by a CTD with a 25 cm beam Sea Tech Transmisso- meter, a Chelsea mark III fluorometer and a Seapoint Optical Back Scatter (OBS) instrument, all mounted to the Rosette frame. SPM samples were then obtained by filtration of fixed volumes of water from distinct levels in the watercolumn, characterized by elevated presence of particles in Intermediate (INL) or Bottom Nepheloid Layers (BNL), as indicated by the transmissometer and OBS records.

Lander BOBO (5a), equipped with acoustic current meters at four levels above he seabed, a Seacat CT probe, a Sea Tech transmissometer and a Seapoint OBS at 1 and 2m above the seabed as well as with an Camera Alive underwatercamera, was deployed for long term measurements at a waterdepth of 2152 m near IfM sediment trap IM 3, and will be recovered during the forthcoming OMEX II-Leg 1 cruise of R.V. "Pelagia" from 30 July to August 17,1998.

To study the sediment distribution 3.5 kHz penetrating echosounder profiling was done at transects across the Iberian margin off Vigo.

Sediment samples (box-, multi- and pistoncores) were taken along transects perpendicular to the margin (Fig. 1) to measure and calculate particle fluxes, accumulation and mixing rates. Properties and composition were studied by onboard macroscopic description of the collected sediment cores.

Subsamples for the determination of ^{210}Pb, organic carbon, carbonate and grain size, were made by slowly inserting 9 cm diameter PVC liners in the sediment, after having siphoned off the overlying water. Subsamples were sliced in 0.5 cm intervals down to 5 cm core depth and subsequently in 1 cm intervals. A first estimate of sedimentation rates was derived by biostratigraphical dating of the sediments as late Holocene (0-7000 yrs BP), early Holocene (7000-10000 yrs BP) or Late Pleistocene (>10000 yrs BP).
Subsequently, downcore ^{210}Pb analysis and dry bulk density (DBD) determination was done in the laboratory on the sliced subsamples for determination of recent sediment accumulation and mixing rates. Organic carbon will be determined by instrumental Carlo-Erba analysis.

Results

1. Amount, character and distribution of suspended particles in the water column

Surface nepheloid layers (SNL), characterized by reduced transmission, are present over the entire study area. The thickness of the SNL varies between 40-100 m at the shelf and shelf edge stations (PE109/2, -11 and -12), and increases with increasing distance from the slope to about 200-250 m thick at the saddle between Galicia Bank and the Iberian slope. The transmission profiles show that strongest decrease in transmission/increase in attenuation in the SNL coincides with the presence of a distinct subsurface chlorophyll maximum. Sometimes a two-stepped transmission profile is observed in the SNL, the maximum peak coinciding with a small salinity peak.

Intermediate nepheloid layers (INL) do occur at a number of stations, notably at shelf edge station PE109/12, where at about 200 m depth a 125 m thick INL was observed. At station PE109/10 an INL was detected at some 100-160 m water depth, directly below, but clearly distinct from the SNL, and at station PE109/5 an INL was observed between 200 and 500 m water depth. However, this was not measured at nearby stations PE109/4 and -3 or PE109/13, indicating a possible detached origin for the INL found at stations PE109/10 and PE109/5.

Significant bottom nepheloid layers (BNL) increased in thickness from some 40-100 m from the shelf edge (stations PE109/2, -11) to the slightly deeper located upper slope station PE109/12. A distinct BNL was furthermore present at Vigo transect upper slope station PE109/13, while deeper middle and lower slope stations PE109/14 and -15 showed a thicker, two-stepped, but relatively weak BNL, indicating a rather gradual sinking of particles in the water column at the middle and lower slope. The northern transect showed a similar pattern.

The eastern slope of the Galicia Bank shows at station PE109/8 a distinct 70 m thick BNL. On station PE109/9 this was also measured.

2. Regional sediment distribution, properties and composition

The regional sediment distribution appears strongly affected by bottom currents and reworking at the shelf and shelf edge, and is apparently influenced by the stepped, very irregular topography and morphology of the upper part of the middle slope. The 3.5 kHz penetrating echosounder profiles allow characterization of the seabed reflectivity of the sedimentary layers at the surface and directly underneath, following the definitions of Damuth (1974, 1979). Results are shown on Figure 2.
The shelf and shelf break are characterized by a strong slightly diffuse reflector representing the seabed, with a lack of well defined layers below (Type 1 reflector). Occasionally patches of finer grained sediment of a more transparent character fill the irregularities in the seabed morphology.

The upper and middle continental slope are characterized by strong irregular hyperbolic reflectors (Type 2), indicating local outcrops of indurated rocks and lack of an appreciable sediment cover. The lower part of the continental slope and part of the channel floor between Galicia Bank and the NW Spanish margin is characterized by well-layered, continuous reflectors (Type 3), consisting of intercalations of transparent and strongly reflective beds, with a strong reflector forming the seabed in the deepest part of the channel and with less reflectivity at the slope. This indicates current scour in some part of the deep channel in combination with a coarser grain size or stronger compaction of sediments caused by high current velocities. Finer grained sediments at the lower slope have a lower reflectivity and somewhat more transparent character, the echo character is also described as Type 3 (well bedded and continuous).

Occasionally, in the deepest part of the channel irregular, discontinuous reflectors, with strong reflectivity at the surface and little penetration or diffuse character (Type 4) is found, forming the channel floor.

The eastern slope to the Galicia Bank shows a characteristic pattern of well-layered and subsequently truncated layers (Type 5), the structural depressions of the truncated layers having been filled up and again current scoured.

At stations PE109/3 and -10 sediments were either absent or very thin, indicating local erosion. Station PE109-11 showed at 30 cm below top the presence of numerous in-situ oyster shells, indicating possibly a relict of a sea level low stand.

Stations PE109/4, -5, -8, -9 and -13 to -15 consist of carbonate-rich mud, with abundant foraminifera and pteropod skeletons. At a few stations gravel was found in the surface sediments in amounts below 3%, predominantly fine gravel. Shallow station PE109/6 at the Galicia Bank yielded coarse carbonate (foraminiferal) sand with gravel and biogenic clasts, representative of absence of (or low) recent sedimentation and confirming the local occurrence of seabed winnowing.

3. Particle fluxes to the seabed, accumulation and mixing rates

Mass accumulation rates were estimated on the basis of biostratigraphically determined age boundaries in the box- and piston core sediments and the DBD determinations, and show a strong variability along the transects, although a clear trend is present (Figure 3).

Relatively high mass accumulation rates of around 5.9 g/cm^2/1000 yr are found at the shelf edge stations PE109/02, -11 and -12. Non-sedimentation, sediment bypassing or erosion is noticeable at slope stations PE109/3 and -10. At stations PE109/4 and -5, at a distinct promontory of the slope, rates are around 3.1 g/cm^2/1000 yr. An exceptional high accumulation rate (11.43 g/cm^2/1000 yr) is found at lower slope station PE109/13, with a decrease towards deeper water and greater distance from the coast. Stations PE109/15 and -1, in the axis of the channel, have lower accumulation rates (3.45 and 3.85 g/cm^2/1000 yr). Lowest values (between 1.09 and 2.06 g/cm^2/1000 yr) however, are found at the margins of Galicia Bank.

When these results are combined with those of stations PE95-01 and PE95-02 at the axis of the channel further to the north it appears as if there is increasingly higher mass accumulation to the north, with rates increasing from 3.45 g/cm^2/1000 yr at station PE109/15 to 8.09 g/cm^2/1000 yr at station PE95/02.

Conclusions

The diffusive, locally strongly reflective character of the shelf break, with local acoustically transparent fill in topographic lows indicates a coarse grained, sandy shelf break with irregular patches of fine grained sediments filling the lows. Reworking may have caused the discontinuous character of the shelf break and lower shelf sediments. This is confirmed by the observed BNL's at the shelf edge stations PE109/2 and -11, and the presence of an INL at the slightly deeper located upper slope station PE109/12 as well as by the measured mass accumulation rates at the shelf edge.

The hyperbolic reflectors (Type 2) characterizing the upper middle and middle slope indicate the irregular, steep character of the slope and the local outcropping of older compact and indurated, presumably pre-Quaternary sediments. This part of the margin apparently receives only a minor amount of sediments, or sedimentation is only temporarily, as is confirmed by the lack of recent sedimentation noticed on stations PE109/3 and -10.

Sedimentation is mainly on the lower and lower middle slope, where the well-layered Type 3 sediments drape the slope, indicative for sedimentation dominated by pelagic settling. This is confirmed by the mass accumulation rates measured here (stations PE109/1, -4, -5 and -14) The latter is more clearly illustrated along 42.20°N and becomes less along the northern transect at 42.40°N. Cretaceous microfossils present in Holocene sediments indicate reworking of upper slope sediments and redeposition at greater depths.

A bottom current appears to sweep the margins of the Galicia Bank and, possibly also the deeper part of the channel between the Galicia Bank and the Iberian slope (creating Type 5 and 4 seabed reflectors, indicative for local current scour). This might cause the locally observed strong BNL at station PE109/6. This pattern is also reflected in the relatively low mass accumulation rates and the sediment composition and grain size observed at stations PE109/9, -8 and -6.

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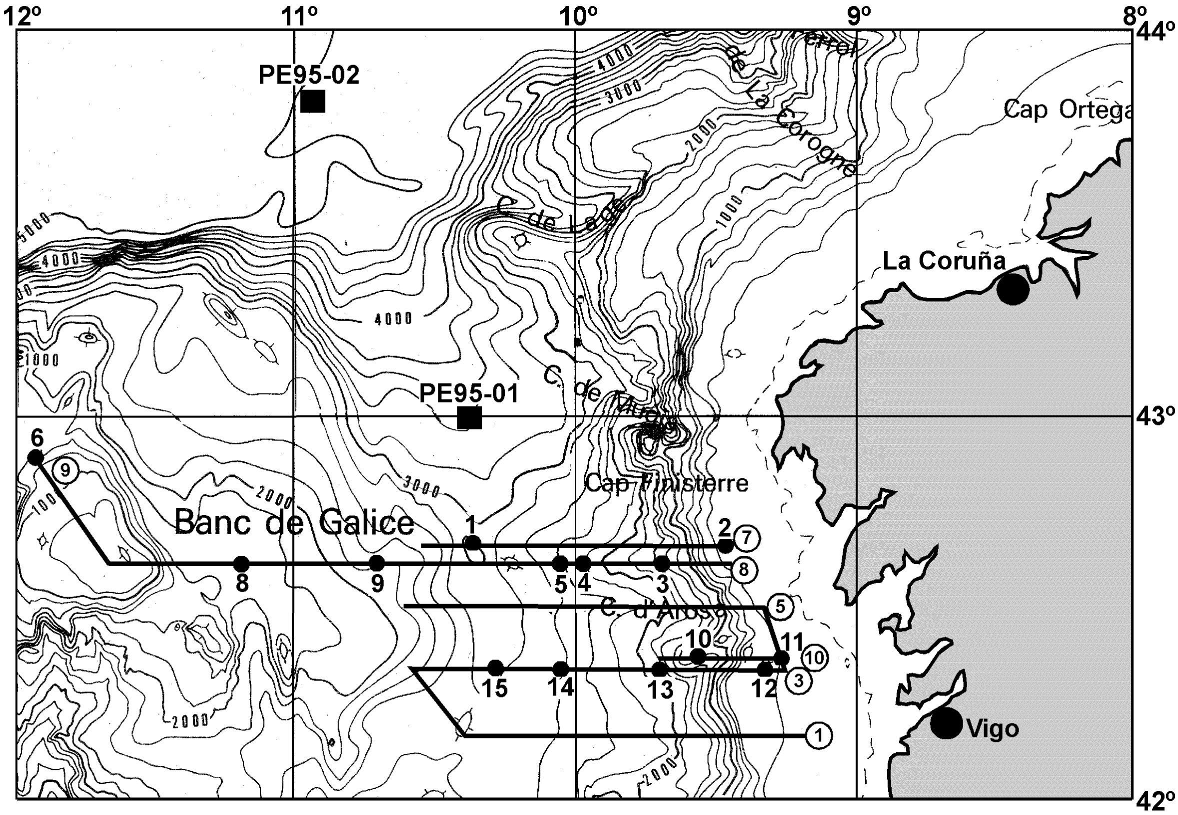

Figure 1. Location of study area showing transects studied and stations made during cruise Pelagia 109 in 1997.

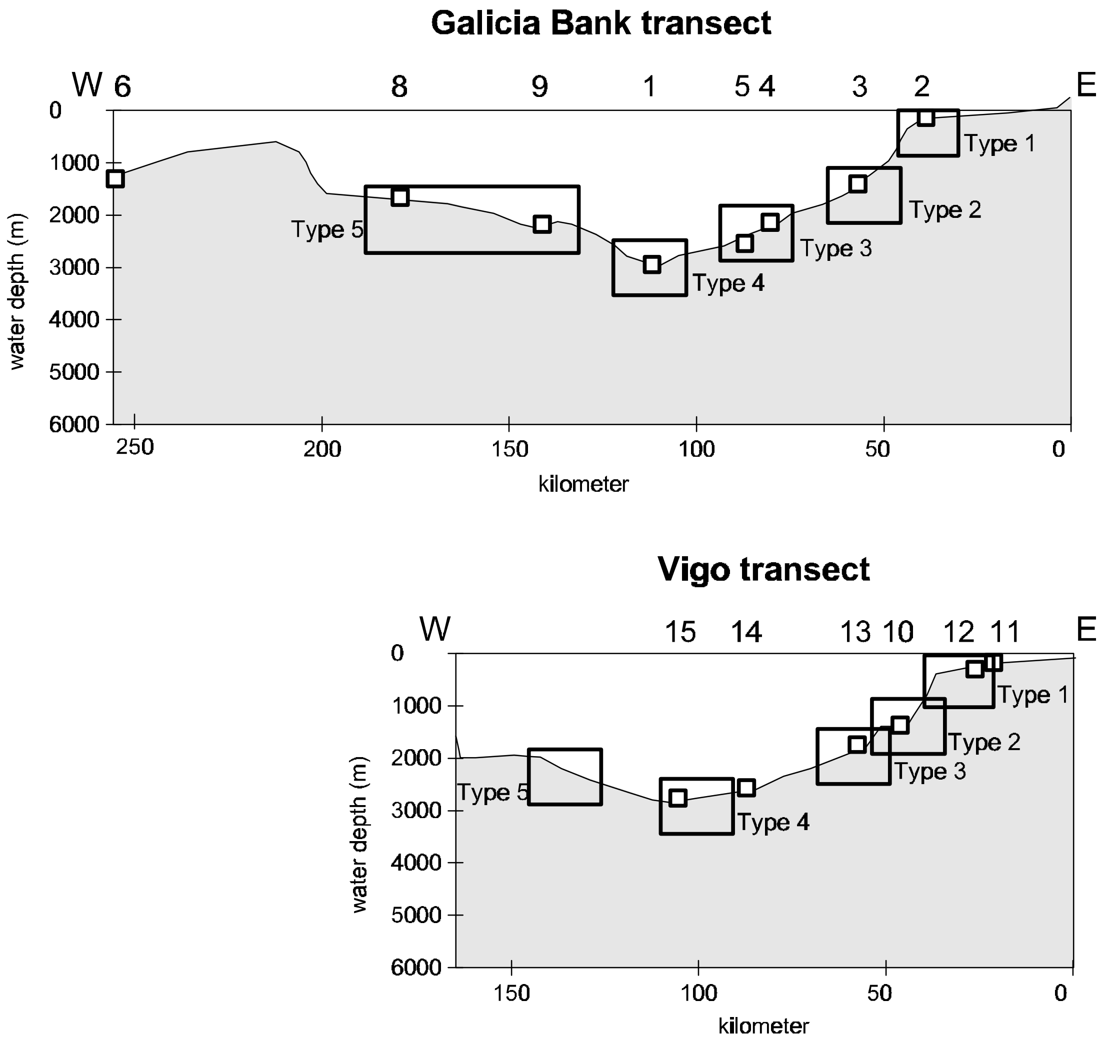

Figure 2. Distribution of echo reflection types along the Galicia Bank (north) and Vigo (south) sampling transects.

sediment mass flux (g/cm2/1000y)

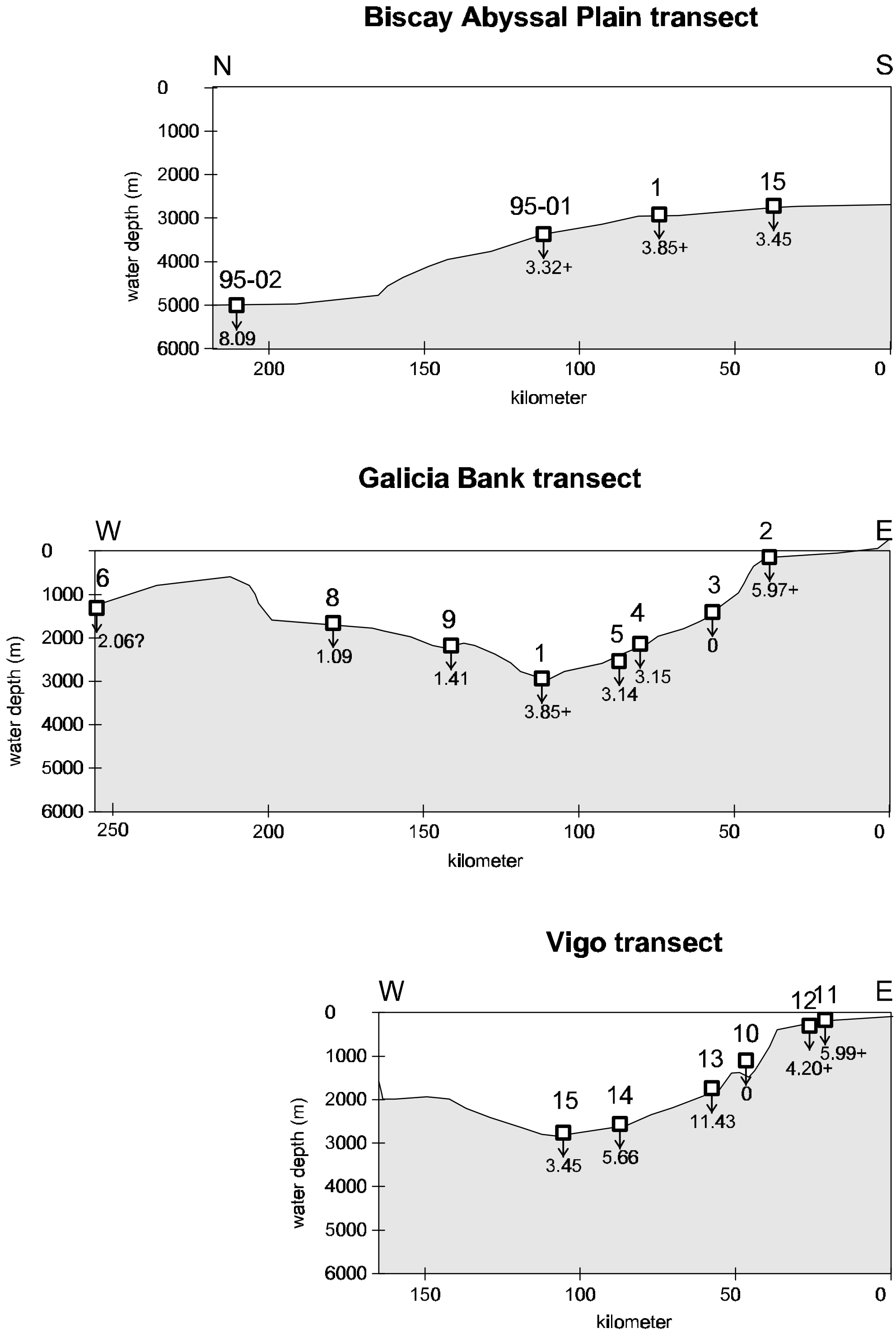

Figure 3. Sediment mass fluxes along the Galicia bank (middle panel) and Vigo (lower panel) transects. The Biscay Abyssal Plain transects shows the change in accumulation rates along the axis of the channel between the Iberian Margin and the Galicia Bank to the Biscay Abyssal Plain stations PE95-01 and -02.