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Benthic foraminiferal response to sedimentary disturbance in the Capbreton canyon (Bay of Biscay, NE Atlantic)

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Abstract :

Living (Rose Bengal stained) and dead benthic foraminifera were investigated at 6 deep-sea sites sampled in the Capbreton canyon area (Bay of Biscay, France). Three sites were located along the canyon axis at 301 m, 983 m and 1478 m and 3 stations were positioned on adjacent terraces at 251 m, 894 m and 1454 m. Sedimentary features indicate that frequent sedimentary disturbances of different magnitudes occur along the Capbreton canyon axis and adjacent terraces. Such environmental conditions cause the presence of very particular benthic environments. Along the 6 studied sites, different foraminiferal responses to various sedimentary patterns are observed revealing the complexity of this canyon environment. Some sites (Gitan 3 (canyon axis), Gitan 5 (canyon axis) and Gitan 6 (terrace)) are characterized by moderate to low standing stocks and low diversity and are mainly dominated by pioneer taxa such as *Fursenkoina brady*, *Reophax dentaliniformis* and *Technitella melo* suggesting a recent response to turbidite deposits recorded at these sites. Others sites (Gitan 1 and Gitan 2) show extremely high standing stocks and are mainly dominated by the opportunistic *Bolivina subaenariensis* and *Bulimina marginata*. Such faunal characteristics belonging to a more advanced stage of ecosystem colonization indicates strongly food-enriched sediment but extremely unstable conditions. Moderate standing stocks and diverse assemblage composed of species such as *Uvigerina mediterranea* and *U. peregrina* has only been observed at the terrace site Gitan 4. More stable sedimentary conditions recorded at this terrace seem to be suitable to the development of a dense and diverse foraminiferal community. Numerous neretic allochtonous species were observed in the dead foraminiferal fauna. These allochthonous species mainly originate from shelf areas (< 60 m).

Highlights

► Live benthic foraminifera were studied at 6 deep stations in the Capbreton Canyon. ► Benthic foraminifera were sampled along canyon axis and its adjacent terraces. ► The aim is to use foraminifera as bio-indicators of hydro-sedimentary processes.

Keywords : Benthic foraminifera, Capbreton canyon, Habitat disturbance, Turbidite, Submarine canyon

0. Introduction

Active submarine canyons are characterised by intensive sediment transport along the canyon axis. This transport is caused by different, hydro-sedimentary processes such as sediment gravity flows (i.e. turbidity currents) (Mulder *et al*., 2001), slumps (Hsu *et al*., 2008) or shelf water cascading events (Gaudin *et al*., 2006). Such processes provide large quantities of marine and reworked terrestrial organic matter that are concentrated in canyon sediments (*e.g*. Rowe *et al*., 1982; Soetaert and Heip, 1995; Vetter and Dayton, 1998). All these processes are triggered by climatic, meteorological or geologic events. Submarine canyons, where such events occur frequently, are characterised by a high degree of sediment instability (associates with transport and deposition of organic and inorganic matter) which constrain benthic community survival. For instance, in December 1999, a violent storm that affected the Atlantic coast of southern France, triggered a turbulent surge which deposited a huge turbidite in the Capbreton canyon (Bay of Biscay, NE Atlantic) (Mulder et al., 2001). After this sedimentary event, benthic foraminiferal fauna recovery was studied by Anschutz *et al.* (2002), Hess *et al*. (2005), Hess and Jorissen, (2009) and Bolliet *et al*. (2014) at sites from 400 m to 800 m depth (Figure 1). These studies documented the recolonization and subsequent recovery of the foraminiferal fauna, 4 months (Anschutz *et al.*, 2002; Hess *et al.*, 2005), 1.5 year (Hess *et al.*, 2005; Hess and Jorissen, 2009) and 6 years (Bolliet *et al*., 2014) after the turbiditic event. Four months after this sedimentary disturbance, the living benthic foraminiferal fauna was almost entirely composed of *Technitella melo* in the coarse fraction (> 150 µm), a taxon that is usually very rare on the continental margin sediments. This species was accompanied in the 63-150 µm fractions by *Cassidulina carinata*, *Fursenkoina bradyi*, *Bolivina subaenariensis* and *Bulimina marginata*. This fauna represented the first stage of foraminiferal colonization after the turbidite deposition (Anschutz *et al.*, 2002; Hess *et al.*, 2005). One and a half year later, foraminiferal communities were dominated by other shallow infaunal species, *Bolivina subaenariensis* and *Bulimina marginata* that constitute the next phase of colonizers both in coarse and fine fractions. These species exhibited extremely high standing stocks (> 6 000 individuals per 100 cm²) (Hess *et al.*, 2005; Hess and Jorissen, 2009). Six years after the turbidite deposit, benthic foraminiferal fauna still remained in an early stage of recolonization suggesting recurrent sediment instability (Bolliet *et al*., 2014). At distal sites, unaffected by recent re-sedimentation processes, foraminiferal fauna was diverse and specialized species occupied deep ecological niches within the sediment (Hess and Jorissen, 2009; Bolliet *et al*., 2014).

In the present study, we document living and dead benthic foraminifera from new sites (*i.e.* 300, 1000 and 1500 m), along the Capbreton canyon axis and adjacent terraces (Figure 1). In addition to sedimentary features, the ecological features of living (Rose Bengal stained) benthic foraminifera (*i.e.* standing stock, diversity and vertical distribution) will allow us to determine which area is impacted by putative sedimentary disturbance (such as turbidite deposition), among the studied water depths. Foraminiferal response to potential sediment instability will be compared with previously documented studies in the Capbreton canyon (Anschultz *et al*., 2002; Hess *et al*., 2005; Hess and Jorissen, 2009; Bolliet *et al*., 2014; Figure 1, Table 1). The aim is to assess whether the foraminiferal response to sedimentary disturbance is the same in the entire Capbreton canyon area. In addition, dead foraminiferal fauna will be investigated at all sites in order to identify potential allochthonous individuals. Identification of such reworked foraminifera can give important clues about the downslope sedimentary dynamics and the source of sedimentary supplies (*e.g.* fluvial area, continental shelf, upper slope).

1. Study area

The Capbreton canyon is located in the southeastern Bay of Biscay (NE Atlantic) between 43°34'N and 43°42'N. It deeply incises the Aquitaine continental slope and shelf. With a length of about 300 km, Capbreton canyon is one of the longest canyons in Europe (Nesteroff *et al*., 1968). The canyon head is located only 250 m away from the French coastline at a water depth of 30 m and the canyon reaches up to 3000 m water depth at 133 km from the canyon head (Shepard and Dill, 1966). The canyon head was naturally disconnected from the Adour River in 1310 A.D., and in 1578 the river mouth was artificially relocated 15 kilometers south of the canyon head, preventing reconnection (Klingebiel and Legigan, 1978). Despite the disconnection from the Adour River, the canyon remains active. Hence, the Capbreton canyon is characterized by high organic matter input and substrate instability caused by bottom currents, small-scale environmental disturbances and re-sedimentation processes (Mulder *et al*., 2001; Anschutz *et al*., 2002; Gaudin *et al*., 2006). Sediment cores recovered in 2007 in the canyon axis, revealed high-frequency of small-scale gravity events (Mulder *et al*., 2012). Borcheray *et al*. (2014), based on sediment cores sampled in 2010, demonstrated a turbidite frequency of 1 per year. Moreover, according to Mulder *et al*. (2004), at least three massive turbidites have been deposited during the last century. One major turbidite occurred in December 1999 and was induced by a turbulent surge triggered by the large *Martin* storm.

2. Materiels and methods

2.1 - Sampling strategy

The oceanographic cruise GITAN (Toucanne, 2015) was organized on board the "*R/V Pourquoi Pas?"*in August 2015. Six stations were sampled in the Capbreton canyon area with a multicorer in order to obtain cores with a relatively undisturbed sediment-water interface. Three of the stations were located in the canyon axis at 301 m (Gitan 1), 983 m (Gitan 3) and 1478 m (Gitan 5). The other three stations, Gitan 2 (251 m), Gitan 4 (894 m) and Gitan 6 (1454 m) were located on the terraces, 50 m, 156 m and 24 m above the canyon axis, respectively (Figure 1). At each site one core was used for foraminiferal analysis, two cores were devoted to sedimentological analysis and one core was dedicated to radionuclide measurements (^{210}Pb).

2.2 - Sedimentological analyses

In order to appreciate downcore changes in lithology, the cores dedicated to sedimentological analyses were vertically split into two halves and photographed. At station Gitan 5, the two replicate cores available show different sedimentary records and are shown on Figure 2. Grain-size was measured on bulk sediment with a Malvern Laser Diffraction Mastersizer (type 3000). Since foraminifera can be the principal sedimentary components in the basal parts of turbidites, we decided not to apply carbonate dissolution prior to grain size measurements. Activities of ^{210}Pb in excess ($^{210}Pb_{xs}$) were calculated as the difference of the measured activities of ^{210}Pb and of its radioactive parent (^{226}Ra), both determined using a low-background, high efficiency, well-shaped γ detector (see Bolliet *et al*., 2014 for more details). Supported ^{210}Pb, *i.e.* ^{226}Ra, ranged between 18 and 28 mBq g^{-1}. Samples dominated by sand fraction were usually not measured as $^{210}Pb_{xs}$ is preferentially associated with the fine sediment fraction. The decay with time of $^{210}Pb_{xs}$ in the sediment column, according to its half-life of 22.3 years, is widely used to calculate sediment accumulation rates on decadal to century timescale. Here we have applied the CF:CS method (constant flux and constant sedimentation, Robbins and Edgington, 1975) to estimate sediment accumulation rates, in cm per year, by plotting $^{210}Pb_{xs}$ against depth (see Schmidt *et al*., 2009 for details). Sedimentation patterns in the Capbreton canyon do not exactly fulfill the conditions of the CF:CS model. Calculated sediment must be considered as maximum rates, as they include also displaced sediments (that could be considered as instantaneous regarding the decadal timescale) in addition to the hemipalegic particulate deposition.

2.3 - Foraminiferal fauna analyses

For faunal analyses, entire sediment cores (72.4 cm² surface area) were horizontally sliced into 11 intervals. Because of sampling artefact, the core was sliced in one interval of 1 cm between 0 and 1 cm. Otherwise, the topmost of the core, where foraminiferal fauna is usually concentrated, was thinly sliced into 2 intervals of a half cm between 1 and 2 cm. The core was sliced into 8 intervals of 1 cm down to 10 cm. Sediments were stored in 500 cc bottles, which were filled with 96 % ethanol containing 2 $g.L^{-1}$ Rose Bengal stain. All samples were gently shaken for several minutes in order to get a homogeneous mixture. In the laboratory, they were sieved through 63 and 150 µm mesh screens, and the sieve residues were stored in 96 % ethanol. All stained foraminifera belonging to the >150 µm fraction were sorted from wet samples, and stored in plummer slides. The small size fraction (63-150 µm) was qualitatively inspected (Table 2).

The Rose Bengal staining technique (Walton, 1952; Bernhard, 1988) is routinely used to recognise foraminifera that were alive at the time of sampling. However, Rose Bengal may also stain the protoplasm of dead foraminifera, which may be relatively well preserved for a considerable period of time under the anoxic conditions that generally prevail deep in the sediment (Bernhard, 1988; Corliss and Emerson, 1990; Bernhard, 2000). In order to minimise the risk of counting dead foraminifera, we use the same strict staining criteria as those detailed in Fontanier *et al.* (2008). Non-transparent agglutinated and miliolid taxa were broken in order to inspect the test interior. Fragments of the very fragile arborescent agglutinating foraminiferal fragments (such as *Hyperammina* spp.) were not included, since it is impossible to determine how many individuals they represent. Because samples were stored in ethanol, many soft-shelled monothalamous foraminifera may have shrunk and may have become unrecognisable during picking. Thus, our counts will likely underestimate the softwalled foraminiferal group. Using a scanning electron microscope (SEM) at Ifremer Brest (FEI QUANTA 200 equipped with an Oxford Instrument Energy Dispersive Spectroscopy), we obtained digital photographs of foraminiferal individuals belonging to dominant species (> 5%). The total abundance of living foraminifera per core was determined by summing up the number of all specimens of all sediment intervals (0-10 cm). When describing the vertical distribution of foraminifera in the sediment, abundances are standardised for a 50 cm^3 sediment volume. Diversity indices (species richness S, Shannon index H' and Evenness E index) were calculated with the software PAST (Palaeontological statistics - http://folk.uio.no/ohammer/past/) using the following equations:

Species richness S: it is the number of taxa at each station.

Shannon H' index: $H' = -\sum_{i=S}^{i=1} \left(\frac{ni}{N} \right) \times \ln\left(\frac{ni}{N} \right)$

where *ni* is the number of individuals in the whole core for the species "*i*", *N* is the total number of individuals for all intervals and *S* the number of taxa. We distinguished between shallow and deep infaunal taxa. The former reach a maximum density in sediment layers just below the sediment-water interface, while the latter are most abundant in the slightly deeper suboxic and/or anoxic sediment layers.

Evenness E index: $E = \frac{e^{H'}}{S}$

where *H'* is the Shannon index and *S* the species richness. This index ranges from 0 to 1.

After picking out the stained fauna, the sample residues were dried (55°C, 48h). The dead assemblages of the >150-µm size fraction were studied in two sediment levels per sites according to their lithofacies. In the case of a turbidite deposit, the aim was to analyse a silty level, at the top of the core and a sandy level at the bottom of the turbidite to identify putative allochthonous foraminiferal tests. As suggested by Murray (2006), we counted 250 to 300 individuals per sediment interval for each core. If necessary, samples were divided into subfractions using an Otto microsplitter. We also used scanning electron microscopy (SEM) to examine the major (> 5%) dead specimens.

3. Results

3.1 - Sedimentological analyses

Along the canyon axis, station Gitan 1 (301 m) exhibits two sedimentary units, S1 and S2, separated by an erosive contact (Figure 2). The topmost unit S1 is 15 cm thick. It is a fining-upward sequence grading from coarse sands (500-600 µm) to silty clays (~10 µm). Sediment unit S2 is a silty clay sequence (Figure 2). $^{210}Pb_{xs}$ activities are measured in the muddy layer (0-8 cm). Data are rather constant between 0 and 5 cm and then, show a slight decrease (Figure 2). Station Gitan 3 (983 m) shows a single sedimentary unit of 21 cm thickness (Figure 2). Grain size observed at Gitan 3 grades up from fine sands (200 µm) to silty clays. $^{210}Pb_{xs}$ activities are rather constant between 0 and 8 cm, followed by a sharp decrease in the layer 8-9 cm, at the topmost of the sandy layer due to dilution by sand (low in $^{210}Pb_{xs}$) (Figure 2). Gitan 5 (1) (1478 m) exhibits one sedimentary unit of 12 cm thick which grades up from medium sands to silty clays. $^{210}Pb_{xs}$ activities in the topmost 5 cm silty-clay sediment of Gitan 5 (1) are almost constant (around 75 mBq g^{-1}; Figure 2) and lower than surface $^{210}Pb_{xs}$.of Gitan 6 (101 mBq g^{-1}). Gitan 5 (2) (1478 m) shows seven sedimentary units (S1 to S7, Figure 2). The topmost sequence S1 is 3 cm thick. This unit exhibits a grain size which grades up from fine sands to silty clays. The sedimentary unit S2 is a fining-up sequence of 6 cm thick which obliquely erodes all sequences from S3 to S7. Grain size observed at the sequence S2 grades up from very fine sands to very coarse sands with gravels (> 2 mm), large (0.5-1 cm) shelly fragments and dead gastropods (length 1-6 cm) (Figure 2). Sediment units S3 to S6 are fining-upward sequences from very fine sands to clayey silts. Sequence S7 is a silty clay unit with probably its base missing due to insufficient coring depth.

On adjacent terraces, stations Gitan 2 (251 m) and Gitan 4 (894 m) exhibit an homogeneous sediment composed of silty clays (D_{50} values close to 10 µm at Gitan 2 and 7 µm at Gitan 4, Figure 3). At Gitan 2, $^{210}Pb_{xs}$ values exhibit only a slight decrease with depth, from 186 mBq g^{-1} in surface to 160 mBq g^{-1} at 50 cm (Figure 3). At Gitan 4, $^{210}Pb_{xs}$ activities decrease regularly down-core. Station Gitan 6 (1454 m) shows at least 12 sedimentary units (sequences S1 to S12, Figure 3). For each sequence, grain size grades up from very fine sands (86 µm) to clayey silts (7 µm). The base of sequence S12 is missing due to insufficient coring depth. Superposed to the classical exponential decrease down to 50 cm, $^{210}Pb_{xs}$ profile shows interbedded layers of low $^{210}Pb_{xs}$ and probably older sediment (Figure 3).

3.2 - Living foraminiferal data (> 150 µm size fraction)

4.2.1. Standing stocks

Each terrace site exhibits higher foraminiferal standing stocks than adjacent stations situated along the canyon axis (Figure 4, Table 2). Very high standing stocks are recorded at the two shallowest sites. Gitan 1 (301 m), located along the canyon axis shows 6 548 individuals per 100 cm² and Gitan 2 (251 m), from adjacent terrace exhibits three times more individuals with 21 490 ind./ 100 cm^2 (Figure 4, Table 2). Gitan 3 (983 m), from the canyon axis exhibits 564 ind./ 100 cm^2 and Gitan 4 (894 m), located on the terrace shows twice more specimens with 1046 ind./ 100 cm^2. The lowest standing stock is observed at the deepest canyon station Gitan 5 (1478 m) with 242 ind./ 100 cm^2. The adjacent terrace Gitan 6 (1454 m) shows a higher value with 1090 ind./ 100 cm^2. To summarize, standing stocks decrease downstream, but are always higher on the terraces than in the adjacent canyon axis.

4.2.2. Diversity

Along the canyon axis, species richness (S) decreases with water depth from 44 at station Gitan 1 (301 m) to 13 at station Gitan 5 (1478 m) (Figure 4, Table 2). The Shannon index (H') ranges from 2.14 (Gitan 3, 983 m) to 1.66 (Gitan 5, 1478 m) and the Evenness index (E) varies from 0.41 (Gitan 5, 1478 m) and 0.14 (Gitan 1, 301 m), both without a bathymetric trend (Figure 4, Table 2). On adjacent terraces, species richness (S), the Shannon index (H') and the Evenness index (E) do not show any relationships with water depths. S values range from 47 at station Gitan 4 (894 m) to 12 at station Gitan 6 (1454 m) (Figure 4, Table 2). H' and E show maximum values at station Gitan 4 (894 m) (2.77 and 0.34, respectively). The lowest H' and E values are recorded at the shallowest site Gitan 2 (251 m) (0.95 and 0.07, respectively) (Figure 4, Table 2).

4.2.3. Faunal composition and vertical distribution along the canyon axis

At station Gitan 1 (301 m), living foraminiferal fauna is dominated by *Bolivina subaenariensis* (39 %, 2564 individuals per 100 cm^2), *Bulimina marginata* (26 %, 1 695 ind./ 100 cm^2) and *Leptohalysis scottii* (15 %, 972 ind./ 100 cm^2) (Figure 5; Figure 6A). *Bolivina subaenariensis* and *Bulimina marginata* exhibit a density maximum between 1 and 1.5 cm (Figure 6B). *Leptohalysis scottii* occupies an intermediate infaunal microhabitat, with a clear density maximum between 2 and 3 cm (Figure 6B). *Fursenkoina bradyi* (30 %, 168 ind./ 100 cm^2), *Bolivina subaenariensis* (20 %, 109 ind./ 100 cm^2) *Reophax dentaliniformis* (16 %, 88 ind./ 100 cm^2) and *Technitella melo* (12 %, 50 ind./ 100 cm^2) are the dominant taxa at station Gitan 3 (983 m) (Figure 5; Figure 6C). Both species *T. melo* and *R. dentaliniformis* show a clear surface maximum (*i.e.* 0-1.5 cm, Figure 6D). *Bolivina subaenariensis* exhibits a density maximum between 1 and 1.5 cm. *Fursenkoina bradyi* occurs in an intermediate infaunal microhabitat with a density maximum between 1.5 and 2 cm (Figure 6D). *Fursenkoina bradyi* (41 %, 98 ind./ 100 cm^2), *Reophax dentaliniformis* (30 %, 72 ind./ 100 cm^2), *Haplophragmoides bradyi* (9 %, 21 ind./ 100 cm^2) and *Uvigerina peregrina* (7 %, 17 ind./ 100 cm^2) are the main species at the deepest station Gitan 5 (1478 m) (Figure 6E). *Reophax dentaliniformis*, *Haplophragmoides bradyi* and *Uvigerina peregrina* show a clear surface maximum (< 2 cm) (Figure 6F). *Fursenkoina bradyi* shows a density maximum between 1 and 1.5 cm (Figure 6F).

4.2.4. Faunal composition and vertical distribution on adjacent terraces

Bolivina subaenariensis strongly dominates the foraminiferal fauna at the shallowest station Gitan 2 (251 m) with 78 % (16 704 ind./ 100 cm^2) (Figure 7A). *Valvulineria bradyana* and *Bulimina marginata* are subsidiary species with 8 % (1640 ind./ 100 cm^2) and 5% (1133 ind./ 100 cm^2), respectively (Figure 7A). These three species occupy a shallow infaunal microhabitat (< 2 cm) (Figure 7B). Station Gitan 4 (894 m) shows 6 main species (> 5 %), *Uvigerina mediterranea* (27 %, 278 ind./ 100 cm^2), *Uvigerina peregrina* (11 %, 109 ind./ 100 cm^2), *Melonis barleeanus* (10 %, 101 ind./ 100 cm^2), *Bolivina alata* (9 %, 90 ind./ 100 cm^2), *Siphogenerina columellaris* (6 %, 61 ind./ 100 cm^2) and *Reophax scorpiurus* (5 %, 55 ind./ 100 cm^2) (Figure 7C). *Uvigerina mediterranea*, *Uvigerina peregrina* and *Reophax scorpiurus* occur in a shallow faunal microhabitat with a density maximum between 1 and 1.5 cm (Figure 7D). *Melonis barleeanus*, *Bolivina alata* and *Siphogenerina columellaris* occupy an intermediate infaunal microhabitat with a density peak in the 1-3 cm interval (Figure 7D). *Fursenkoina bradyi* (66 %, 722 ind./ 100 cm^2), *Haplophragmoides bradyi* (22 %, 238 ind./ 100 cm^2) and *Chilostomella oolina* (5%, 57 ind./ 100 cm^2) are dominant at station Gitan 6 (1454 m) (Figure 7E). *Fursenkoina bradyi* shows a density maximum between 1 and 2 cm (Figure 7F). *Haplophragmoides bradyi* does not exhibit a clear microhabitat preference. This species shows a bimodal distribution with a first maximum abundance between 1-1.5 cm and a second density peak between 2 and 3 cm (Figure 7F).

3.3 - Qualitative observations of the living fauna in the 63-150 µm size fraction

The surficial sediments (0-1 cm) at all sites were qualitatively inspected for smaller (63–150 µm) foraminifera. Main species observed are indicated in the Table 2. The species *Bolivina subaenariensis* is mainly dominant in the fine fraction of stations Gitan 1, Gitan 2 and Gitan 3. Others sites exhibit only few smaller individuals. Some individuals of *Reophax scorpiurus*, *R. dentaliniformis* and *Fursenkoina bradyi* are observed at Gitan 4, Gitan 5 and Gitan 6, respectively (Table 2).

3.4 - Dead foraminiferal data (> 150 µm size fraction)

4.4.1. Main species (> 5 %) along the canyon axis

Planorbulina mediterranensis (24 %), *Elphidium* spp. (22 %), *Bolivina subaenariensis* (13 %), *Bulimina marginata* (11%), *Cibicides lobatulus* (9 %) and *Cassidulina carinata* (5 %) are the main species in the 2-3 cm level at station Gitan 1 (301 m). The two species *Planorbulina mediterranensis* and *Cibicides lobatulus* are also dominant in the 9-10 cm level with 71 % and 6 %, respectively (Figure 8). At station Gitan 3 (983 m), *Fursenkoina bradyi* represents 32 % of the dead assemblages in the 2-3 cm level. *Cassidulina carinata* (12 %), *Planorbulina mediterranensis* (8%), *Cibicides lobatulus* (8 %), *Bolivina subaenariensis* (7.5 %) and *Elphidium* spp. (5 %) are other dominant species (Figure 8). In the 9-10 cm level of site Gitan 3, *Planorbulina mediterranensis* is the main species with 38%. *Planorbulinella larvata* (9 %), *Labrospira jeffreysi* (9 %) and *Chilostomella oolina* (8 %) are subsidiary species (Figure 8). At the deepest station Gitan 5 (1478 m), *Fursenkoina bradyi* is the main species of the 2-3 cm level but with only 4 individuals per 100 cm^2 (Figure 8). In the 9-10 cm level of site Gitan 5, *Quinqueloculina* sp. 1 (33 %), *Ammonia beccarii* (19 %), *Cibicides lobatulus* (12 %), *Bolivina subaenariensis* (8 %), *Elphidium* spp. (7 %) and *Bulimina marginata* (7 %) are the main species (Figure 8).

4.4.2. Main species (> 5%) on adjacent terraces

At the shallowest site Gitan 2 (251 m), *Bolivina subaenariensis* and *Bulimina marginata* are the main species in the 2-3 cm level with 89% and 6 %, respectively (Figure 9). *Bolivina subaenariensis* is the only dominant species in the 9-10 cm level with 85 % (Figure 9). At station Gitan 4 (894 m), *Cassidulina carinata* (29 %), *Cibicides lobatulus* (14 %), *Bulimina marginata* (11 %), *Gavelinopsis translucens* (5 %) and *Textularia sagittula* (5 %) are the main taxa in the 2-3 cm level (Figure 9). *Cassidulina carinata*, *Cibicides lobatulus* and *Bulimina marginata* are also dominant in the 9-10 cm level with relative abundances of 27 %, 18 %, and 14 %, respectively (Figure 9). In the 3-4 cm level of site Gitan 6 (1454 m), *Fursenkoina bradyi* represents 80 % of the dead assemblages (Figure 9). In the 7-8 cm level, *Planorbulina mediterranensis*, *Fursenkoina bradyi* and *Haplophragmoides bradyi* are the three main species with 34.5 %, 28 % and 7.5 %, respectively (Figure 9).

4. Discussion

4.1 - Sedimentary features

All cores sampled along the canyon axis (stations Gitan 1 (301 m), 3 (983 m) and 5 (1478 m)) exhibit at least one fining-upward sequence grading from sand (medium or fine) to fine silt, interpreted as fine-grained turbidites (Bouma, 1962; Stow and Shanmugam, 1980). At station Gitan 5, the coarse fraction of the topmost unit (medium sand) is also composed of gravel (> 2 mm), large shell fragments (1 cm) and gastropods (1-6 cm) indicative of turbidity currents able to mobilise very coarse particles.

The terraces Gitan 2 (251 m) and 4 (894 m), located 50 m and 156 m above the canyon axis, respectively, exhibit homogeneous silty-clay. As observed by Brocheray *et al*. (2014), it seems that both sites receive only gently settling fine particle (around 10 µm), typical of the upper part of the suspension cloud of turbidity currents, which is dispersed over a larger surface than the lower coarse-grained part. At Gitan 2, $^{210}Pb_{xs}$ activities show only a slight decrease with depth (Figure 4). This could be explained by an extremely high sediment fluxes (maximum accumulation rate > 15 cm year^{-1}) resulting from continuous inputs of organic and inorganic sediment particles. At the highest terrace Gitan 4 (156 m above the canyon axis), no peculiar sedimentary feature is observed and ^{210}Pb activities decrease regularly down-core. A maximum sedimentation rate of 0.82 cm year^{-1} has been derived from $^{210}Pb_{xs}$ profile which is still high compared to hemipelagic sedimentation outside the Capbreton canyon. In fact, Schmidt *et al*. (2009) recorded present-day sedimentation rates of 0.05 to 0.2 cm year^{-1} on the Landes Plateau, at equivalent water depths. Therefore, both terraces Gitan 2 and Gitan 4 seem act as depocenters for fine-grained particles. This is consistent with the study of Gaudin *et al*. (2006) in which the terraces are interpreted as primary sedimentary depocenters in the Capbreton canyon. The deepest terrace Gitan 6, located only 24 m above the canyon axis, shows successions of twelve sedimentary units, graded from very fine sands to fine silts interpreted as fine-grained turbidites. At Gitan 6, a maximum sedimentation rate of 1.8 cm year^{-1} has been derived from $^{210}Pb_{xs}$ profile which is in correspondence to an estimate frequency of 1 turbidite every 3 years (Figure 3). This is consistent with the work of Brocheray *et al*. (2014) that demonstrated that fine-grained turbidites are preferentially recorded on the shallower terraces near the Capbreton canyon axis. According to ^{210}Pb dating, the sediment unit S4 could correspond to the 1999 turbidite triggered by the *Martin* storm (Figure 3).

5.2 - Living benthic foraminiferal assemblages

5.2.1. Foraminiferal standing stocks

All terraces sites exhibit higher standing stocks than adjacent canyon axis stations. For instance, the terrace site Gitan 6 shows four times more living individuals compared to the adjacent canyon site Gitan 5 (Table 1). Similar observations were made by Koho *et al*. (2007) in the Nazaré canyon area. These authors recorded the highest standing stocks in the canyon terrace stations with at several sites ten times more living fauna than the stations in the adjacent canyon axis. In both canyons, environmental conditions are more stable on canyon terraces compared to canyon axes which results in the accumulation of fine-grained sediment and organic carbon. These preferential conditions seem responsible for higher foraminiferal standing stocks.

5.2.2. Foraminiferal response to sedimentary disturbance

Foraminiferal communities with low to moderate standing stocks (< 1100 ind./ 100 cm^2), low diversity, and the dominance of species such as *Fursenkoina bradyi*, *Reophax dentaliniformis* and *Technitella melo*, are observed at the canyon axis sites Gitan 3 (983 m) and Gitan 5 (1478 m) and at the deepest terrace station Gitan 6 (1454 m, Table 1 and Figures 6 and 7). Such foraminiferal characteristics are very similar to those described by Anschutz *et al.* (2002) and Hess *et al.* (2005) at a site recovered 4 months after the turbidite deposition triggered by the *Martin* storm in 1999 (site OB10 K (647 m); Figure 1, Table 1). *Fursenkoina bradyi* and *Technitella melo* were documented by Hess *et al.* (2005) as opportunistic species, first recolonizers after the turbidite deposition. These species appear to thrive in organically enriched sediments and to quickly colonize habitats after sedimentary disturbance (r-strategist) (*e.g.* Koho *et al*., 2007; Bernhard, 1992). *Reophax dentaliniformis* was documented by Hess and Kuhnt (1996) as one of the first pioneers to recolonize the barren substrate after an ashfall layer deposit triggered by the 1991 eruption of Mt. Pinatubo. Moreover, *Bolivina subaenariensis* is a subsidiary species at Gitan 3 (Figure 6C). This species was documented by Hess *et al*. (2005) as a secondary colonizer after *Technitella melo* and *Fursenkoina bradyi*, in the Capbreton canyon after turbidite deposits. Then, to have an idea of the population dynamics and how the foraminiferal fauna will evolve, the smaller fraction (63-150 µm), was qualitatively inspected (Table 2). At Gitan 5 and Gitan 6, few individuals of *Fursenkoina bradyi* and *Reophax dentaliniformis* were observed. At Gitan 3, the fine fraction is mainly represented by juvenile *Bolivina subaenariensis*. Other species such as *Fursenkoina bradyi* or *Technitella melo* are almost absent in the smaller fraction. Therefore, this suggests an ongoing recovery process at Gitan 3, slightly more advanced than at Gitan 5 and 6 (Figure 10). Turbidite deposits recorded at the deeper sites could be more recent compared to Gitan 3. But, it seems that it is the repeated frequency of sedimentary disturbances recorded at Gitan 5 and 6 (*i.e.* record of several turbiditic events, Figures 3 and 4, and see section 5.1) which probably sustain foraminiferal fauna in an early stage of recolonization.

A foraminiferal fauna with an extremely high standing stock (> 20 000 ind./ 100 cm^2), a low diversity and high dominance of the secondary colonizer *Bolivina subaenariensis* is recorded at terrace site Gitan 2 (251 m). Similar faunal characteristics were observed by Hess *et al*. (2005) and Hess and Jorissen (2009) at two sites recovered at about 600 m depth, one and a half year after the turbidite deposition caused by the *Martin* storm (stations L (632 m) and K (646 m); Figure 1, Table 1). Hence at station Gitan 2, where a very important accumulation of sediment particles where recorded (see section 5.1), foraminiferal fauna seems to be in a more advanced stage of colonization compared to sites Gitan 3, 5 and 6 (Figure 10).

The upper canyon site Gitan 1 (301 m) exhibits a lower standing stock (~ 6550 ind./ 100 cm^2), and a more diverse assemblage, dominated by *Bolivina subaenariensis* and *Bulimina marginata*, compared to Gitan 2 (Table 2, Figure 6A). Such foraminiferal characteristics are very similar to those described by Hess *et al*. (2005) and Hess and Jorissen (2009) at three sites recovered one and a half year after the 1999 turbidite deposit (*i.e.* Stations Z2 (400 m), Z1 (406 m) and S (786 m), Table 1 and Figure 1). Many ecological observations reported also *Bulimina marginata* in organic matter-enriched sediment (*e.g.* Langezaal *et al*., 2006; Duchemin *et al*., 2007, Fontanier *et al*., 2008). *Leptohalysis scotti* is also a subsidiary species (> 5 %) at this canyon site (Figure 6A). *Leptohalysis scotti* was also described as an opportunistic species able to quickly reproduce in response to episodic input of organic matter (Goineau *et al*., 2011). This species was also documented as an early colonizer of the 1991 Mt. Pinatubo ashfall deposit (Hess and Kuhnt, 1996) and after a physical disturbance experiment (*e.g.* Ernst *et al*., 2002). At Gitan 1, this species occupies a rather deep microhabitat (2-3 cm, Figure 6B). As documented by Hess *et al*. (2005) and Hess and Jorissen (2009), the more diverse assemblage dominated by *Bolivina subaenariensis* and *Bulimina marginata* with a lower standing stock and a more developed microhabitat compared to Gitan 2 can be interpreted as a second generation of colonizers. Foraminiferal fauna at Gitan 1 appears to represent a more advanced stage of ecosystem colonization compared to all other sites discussed above (Figure 10).

Compared to all other stations, the highest terrace site Gitan 4 (894 m, 156 m above the canyon axis) exhibits the highest diversity and a moderate standing stock (Table 1, Figure 4). Foraminiferal fauna is dominated by *Uvigerina mediterranea* and *Uvigerina peregrina* (Table 1, Figure 7C). No pioneer species is observed. These faunal characteristics are similar to those found in a terrace site described by Hess and Jorissen (2009) in the Capbreton canyon area at 664 m depth (*i.e.* station SCII-A, Figure 1, Table 1). *Uvigerina* spp. are generally described in rather well-oxygenated sediment enriched in labile organic matter (*e.g.* Fontanier *et al.*, 2005; Duros *et al.*, 2013). In addition, some species exhibit strictly intermediate infaunal microhabitat (*e.g. Melonis barleeanus* and *Bolivina alata*, Figure 7D). According to Hess and Jorissen (2009), the terrace site described in their study is not influenced by the sedimentary disturbance processes which seems also to be the case for Gitan 4, according to structureless silty-clay lithofacies. Hence, due to its higher location above the canyon axis (156 m), this terrace exhibits much quieter hydro-sedimentary processes than all other sites (*e.g.* no turbidite deposit). Such stable conditions appear to be suitable to the development of a dense and a diverse foraminiferal community (Figure 10).

5.3 - Dead benthic foraminiferal assemblages

As shown by our results and other works (Mulder *et al.*, 2001; Gaudin *et al.*, 2006; Brocheray *et al.*, 2014), the Capbreton canyon is active and characterized by massive and frequent sediment transport and deposition. Because of their small size, benthic foraminiferal faunas can be easily transported by sedimentary processes (*e.g.* bottom nepheloid layers, sediment gravity flows) (Murray, 1991, 2006; de Stigter *et al.*, 1999). An important question is whether these sedimentary processes induced any post-mortem transport and redeposition of foraminiferal tests from shallower depths. This can be estimated by the identification of reworked allochthonous foraminifera (*e.g.* from fluvial areas, continental shelf, upper slope).

In the present study, some species such as *Elphidium* spp., *Planorbulina mediterranensis*, *Planorbulinella larvata*, *Cibicides lobatulus* and *Ammonia beccarii* occur exclusively in the dead foraminiferal fauna (Figure 5; Figures 8 and 9). *Elphidium* spp. (*E. crispum, E. granosum* and *E. williamsoni*) are usually described in nearshore environments at water depths between 0 and 35 m (*e.g.* Sen Gupta, 1999). *Planorbulina mediterranensis*, *Planorbulinella larvata* and *Cibicides lobatulus* are epiphytic perforate species thriving in the inner shelf. For instance *Planorbulina mediterranensis* and *Cibicides lobatulus* have been documented living at depths of 15-30 m attached on seagrass (*Posidonia*) and algae (Sturrock and Murray, 1981; Vénec-Peyré and Le Calvez, 1988; Murray, 2006). *Ammonia beccarii* has been reported from the interdistributaries (*i.e.*, inner shore environments) to shallow coastal sandy areas (0 to ~60 m water depth) in the Bay of Biscay and within the Rhône deltaic system (*e.g.* Pascual *et* al., 2008; Goineau et al., 2011). It seems therefore that all these shallow water species, exclusively present in the dead fauna, have been transported into this area (*e.g.* gravity flows, by bottom currents, in suspension or attached to floating sea grass or algae). To estimate the contribution of allochthonous (neritic) transported foraminifera, we determined cumulative percentages of such species that occur exclusively in the dead fauna (Table 3).

5.3.1. Allochthonous taxa transported to the Canyon sites

At Gitan 1 (301 m) several allochthonous taxa were recorded, especially in the sandy 9-10 cm level, located at the bottom of the turbidite deposit (Figure 8, Table 3). All these reworked species (*e.g. Elphidium* spp., *Planorbulina mediterranensis* and *Cibicides lobatulus*) have been transported from neritic areas (water depths < 35 m) to this upper canyon site by a turbidity current.

At the canyon site Gitan 3, the 2-3 cm sediment level, which corresponds to an hemipelagic silty facies, is mainly composed of autochthonous taxa (75 %). *Cibicides lobatulus* is the main allochthonous taxon. The sandy 9-10 cm level predominantly consists of the epiphytic *Planorbulina mediterranensis* species. Both allochthonous taxa have been carried along the canyon axis from inner shelf (~30-60 m) by the gravity event recorded at this site.

The silty 2-3 cm level of the deepest canyon axis site Gitan 5 (1478 m) exhibits only few dead individuals (Figure 8, Table 3). In the 9-10 cm level, dead individuals are diluted into high quantities of medium sands. This sediment level is mainly composed by allochthonous species. *Quinqueloculina* sp. 1 (cf. *seminula*) which is completely absent in the living fauna is the main species in the dead fauna. All dead individuals observed at this site are highly broken and damaged (Figure 5X). Several authors documented *Quinqueloculina* spp. as characteristic of sandy sediment in very shallow-water environment (< 60 m) (*e.g.* Ikeya, 1970; Cearreta, 1989; Donnici and Serandrei Barbero, 2002; Frezza and Carboni, 2009; Goineau *et al*., 2011). This taxon seems reworked from neritic areas. Moreover, this species is accompanied in the dead fauna by the inner shelf (< 60 m) taxa *Ammonia beccarii* and *Cibicides lobatulus* (Table 3). It seems that all these species have been carried from nearshore areas to this deep site through a massive sediment transport. Therefore, allochthonous species recorded at this deepest site, mainly dominated by *Quinqueloculina* sp. and *Ammonia beccarii* are quite different than those observed at shallower sites Gitan 1 and 3 where the epiphytic *Planorbulina mediterranensis* is the main neritic taxon. This may suggest a different source for the sediment transported by the turbidity currents.

Along the canyon axis, there is no substantial evidence of an effective downslope transport originating from upper canyon sites, towards deeper canyon sites. For instance, only few individuals of dead *Bolivina subaenariensis* (< 10 ind./ 100 cm^2) are recorded at the deepest Gitan 5 where this species is absent in the living fauna suggesting a possible downslope transport of some dead individuals from upper canyon sites (*i.e.* Gitan 1) where this taxon is dominant. Therefore, transport of tests seems mainly carried from inner continental shelf to the Capbreton canyon axis. Along the inactive nearby Cap-Ferret canyon axis, Duros *et al*. (2014) observed the opposite pattern. No substantial transport of shells > 150 µm from the inner continental shelf to the Cap-Ferret Canyon axis was observed. However, transport of tests from outer shelf or upper canyon axis towards deeper sites mainly occurred, triggered by suspension/resuspension events and not by turbidity currents.

5.3.2. Allochthonous taxa transported to terrace sites

On the terrace Gitan 2 (251 m), both levels analyzed (*i.e.* 2-3 cm and 9-10 cm) are composed of homogeneous silty-clay and mainly contain autochthonous species (Figure 9). The high abundance of dead individuals (> 7000 ind./100 cm^2) seems indicated that several generations of this early colonizer have been succeeded. Diluted in the high abundance of dead *Bolivina subaenariensis*, some individuals (256 ind./100 cm^2)) of the shallow-water species *Planorbulina mediterranea* are recorded in the 9-10 cm level. This indicates that transports of reworked sediment from inner shelf may occur.

At Gitan 4 (894 m), both studied sediment levels (2-3 cm and 9-10 cm) are composed of homogeneous silty-clay and exhibit similar dominant species. The composition of the dead foraminiferal assemblage shows important differences with the living fauna found at the same site. Dead fauna is mainly dominated by *Cassidulina carinata*, *Cibicides lobatulus* and *Bulimina marginata*. The epiphytic taxon *Cibicides lobatulus* usually thrives between 15 and 30 m (*e.g.* Murray, 2006). *Cassidulina carinata* and *Bulimina marginata*, almost absent in the living fauna exhibit fairly contributions in the canyon sites Gitan 1 and Gitan 3. Therefore, even if sedimentary features and living foraminiferal fauna indicate a quite quiescent environment at this terrace site, the occurrence of large quantities of inner shelf and upper canyon axis taxa throughout the core suggest the presence of processes other than turbidity currents responsible for downslope transport. As documented in the inactive Cap-Ferret canyon, downslope transports of foraminifera can also take place in bottom nepheloid layers (Duros *et al*., 2014). Bolliet *et al*. (2014) observed such phenomena at a flank site located at 560 m in the Capbreton canyon (site FC9 K, Figure 1, Table 1). They observed exactly the same dominant species in the dead fauna (*i.e. Cibicides lobatulus*, *Cassidulina carinata* and *Bulimina marginata*) and concluded that these taxa were supplied by recurrent nepheloid currents. Hence, the study of dead assemblages, especially the identification of reworked foraminifera, can also give important clues about the sedimentary dynamics.

On the terrace site Gitan 6, the 3-4 cm sediment level which may corresponds to an hemipelagic or turbiditic silty-clay is mainly composed of autochthonous taxa (Figure 9, Table 3). The sandy 7-8 cm level is constituted by an admixture of autochthonous (60 %) and allochthonous (40 %) species. The main dead species is the epiphytic *Planorbulina mediterranensis*. Consequently, this deep terrace (1454 m), located 24 m above the canyon axis, constitutes a deposition area of inner shelf species.

5. Conclusions

Sedimentary features indicate that frequent sedimentary disturbances of different magnitudes (*i.e.* turbidite deposits, sediment resuspension and accumulation) occur along the Capbreton submarine canyon. Along the 6 studied sites, different foraminiferal responses to various sedimentary patterns are observed revealing the complexity of this canyon environment (Figure 10):

(1) Foraminiferal communities with low to moderate standing stocks and low diversity, which are dominated by pioneer species such as *Fursenkoina bradyi*, *Reophax dentaliniformis* and *Technitella melo*, are observed in middle canyon axis and lower canyon axis and lower terrace sites (Gitan 3, Gitan 5 and Gitan 6). Repeated frequency of sedimentary disturbances recorded at Gitan 5 and 6 may probably sustain foraminiferal fauna in an early stage of recolonization.
(2) A low-diversity with an extremely high density of secondary colonizer, *Bolivina subaenariensis* is observed at the terrace site Gitan 2. This opportunistic taxon occupies a superficial microhabitat. Such peculiar faunal feature indicates strongly food-enriched sediment but extremely unstable conditions. This is consistent with the very high amount of fine-grained sediment which accumulates at this terrace.
(3) At the upper canyon site Gitan 1 (301 m), the more diverse assemblage dominated by *Bolivina subaenariensis* and *Bulimina marginata* with a lower standing stock compared to Gitan 2 seems to belong to a second generation of colonizers. Foraminiferal fauna at Gitan 1 appears to represent an advanced stage of ecosystem colonization after the occurrence of a turbidite deposit.
(4) Moderate standing stocks, diverse assemblage, a quite deep microhabitat and an absence of pioneer species is only observed at the terrace site Gitan 4. According to sedimentary features, this terrace seems more quiescent in terms of hydro-sedimentary conditions compared to all other sites. Such stable conditions appear to be suitable to the development of a dense and diverse foraminiferal community.

To monitor the subsequent development of the living foraminiferal fauna resamplings of the same locations are planned in future at the same seasonal period.

Finally, the identification of numerous neritic allochthonous species in the dead foraminiferal fauna at all studied sites indicates that reworked tests are mainly transported from inner shelf areas (< 60 m) into the Capbreton canyon area.

Appendix A.

Taxonomic list of major benthic foraminifera species (>5%).

Appendix B.

Census data (non normalized values) for living benthic foraminifera in the >150 µm size fraction for all 6 stations.

Appendix C.

Absolute and relative abundances of dead benthic foraminifera in the >150 µm size fraction for all 6 stations.

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Duros *et al*., Figure 1

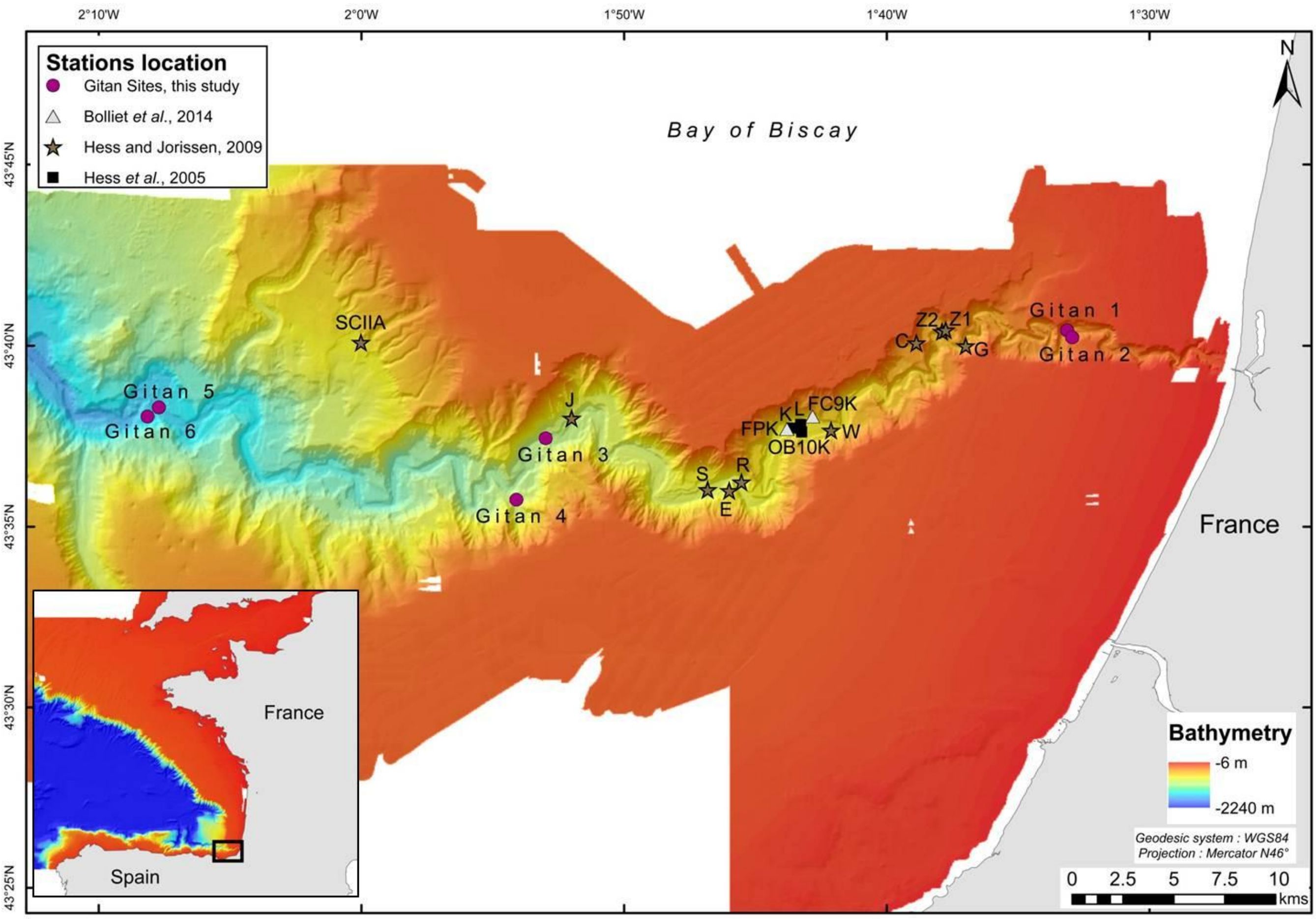


Figure 1 – Study area, bathymetry and geomorphological position of the 6 investigated sites. Gitan 1, 3 and 5 are located in the Capbreton canyon axis and Gitan 2, 4 and 6 are positioned on the adjacent terraces (from Le Suavé *et al*., 1999 and Bourillet *et al*., 2006). All cores previously documented by Hess *et al*. (2005), Hess and Jorissen (2009) and Bolliet *et al*. (2014) are also located.

Duros *et al*., Figure 2

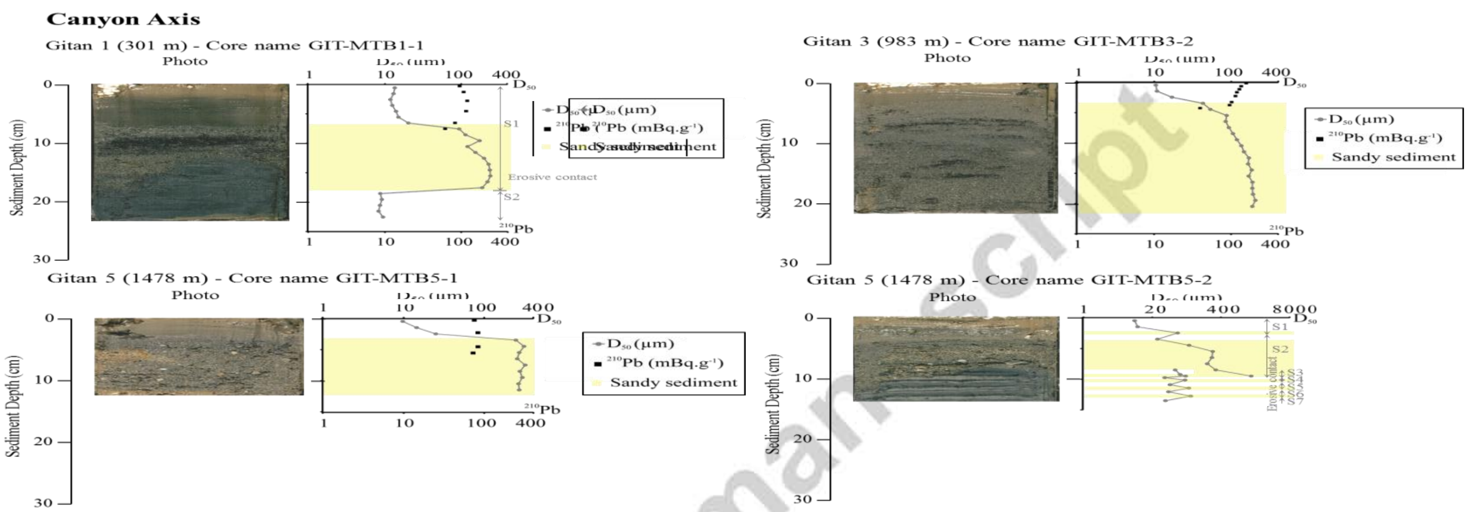
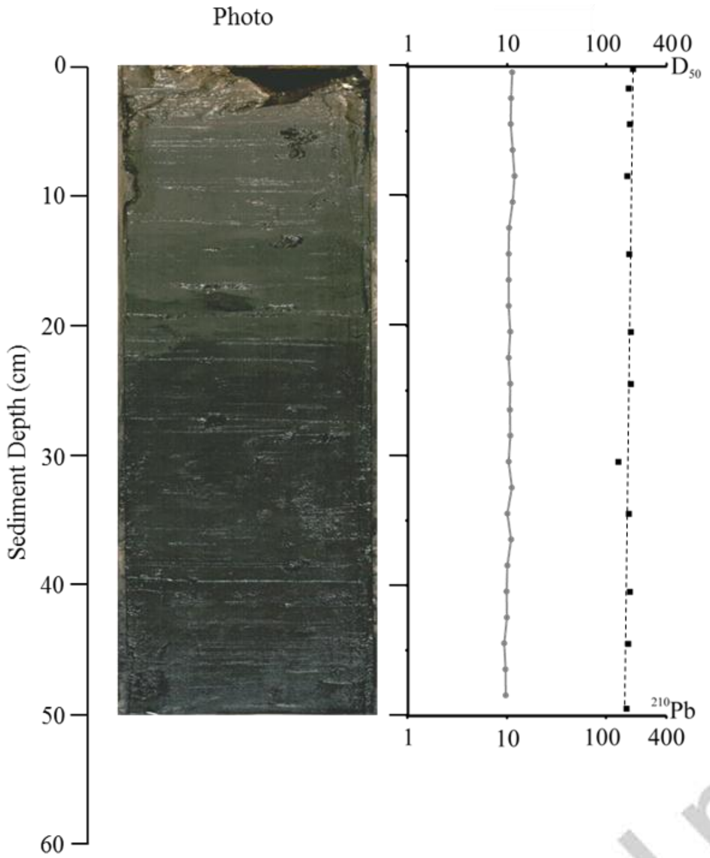


Figure 2 – Photographs, grain sizes of the 50th percentiles (D_{50}, µm) and $^{210}Pb_{xs}$ activity profiles ($mBq.g^{-1}$) of cores collected along the Capbreton canyon axis. The two sediment cores from site Gitan 5 (GIT-MTB5-1 and GIT-MTB5-2) show different sedimentary records and are presented on this figure. $^{210}Pb_{xs}$ activities were determined in the topmost silty-clay sediment unit (no data below 9 cm) of one core per station.

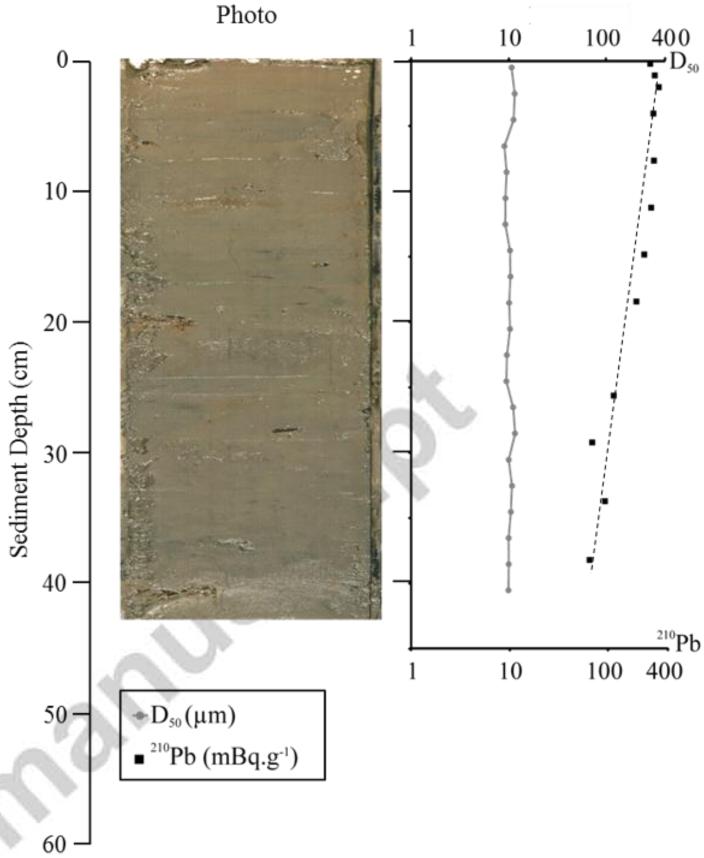
Duros *et al*., Figure 3

Terraces

Gitan 2 (251 m) - Core name GIT-MTB2-2



Gitan 4 (894 m) - Core name GIT-MTB4-1



Gitan 6 (1454 m) - Core name GIT-MTB6-1

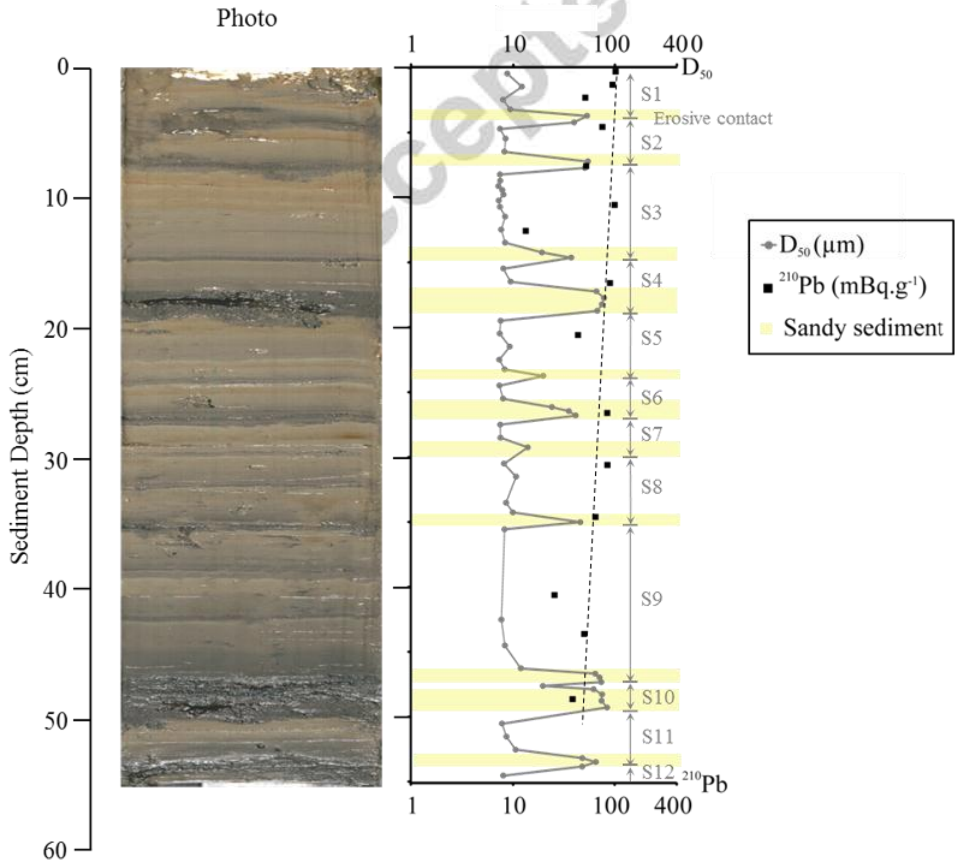


Figure 3 – Photographs, grain sizes of the 50th percentiles (D_{50}, µm) and $^{210}Pb_{xs}$ activity profiles ($mBq.g^{-1}$) of cores collected along the Capbreton canyon terraces. The dashed lines show the regression used to estimate sedimentation rate.

Duros *et al*., Figure 4

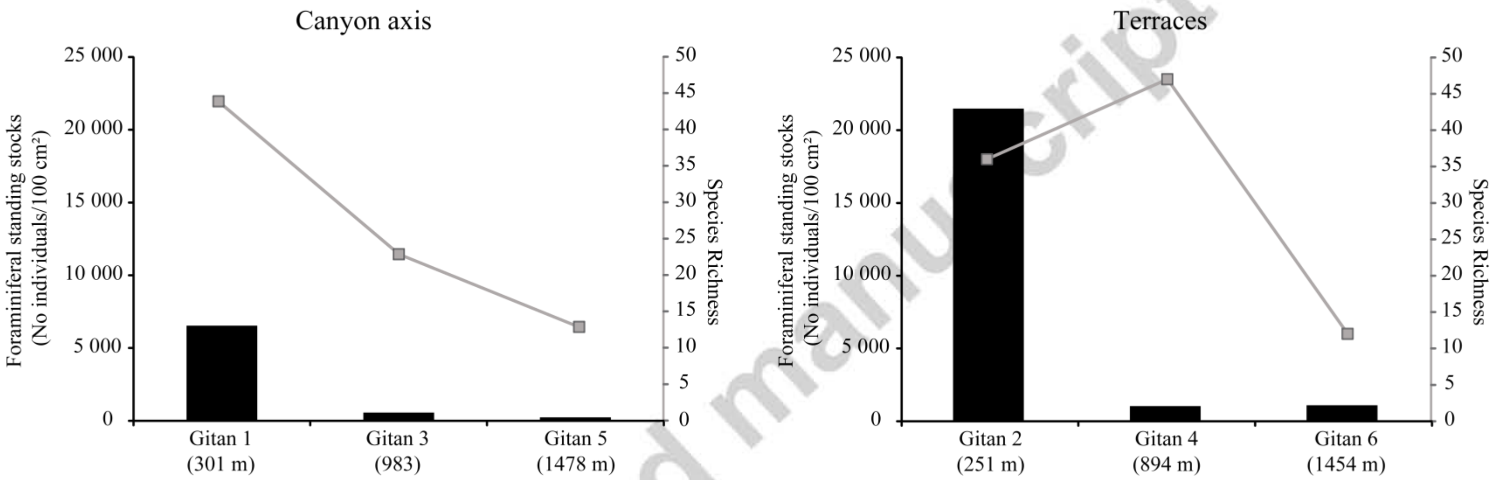


Figure 4 – Standing stocks (number of living individuals per 100 cm², black columns) and species richness (grey line plots) of living benthic foraminifera (> 150 µm) along the Capbreton canyon axis and adjacent terraces.

Duros *et al*., Figure 5

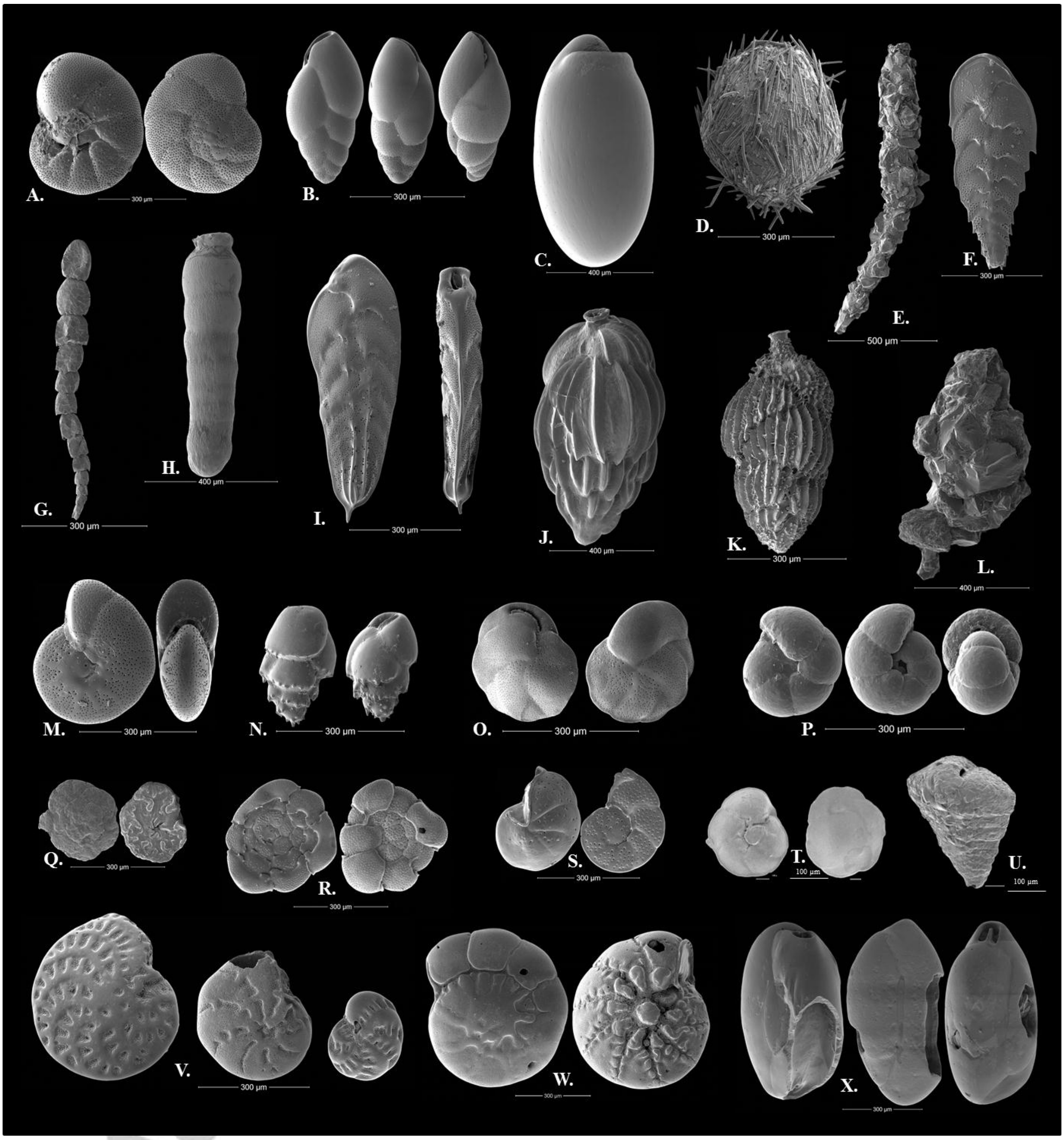
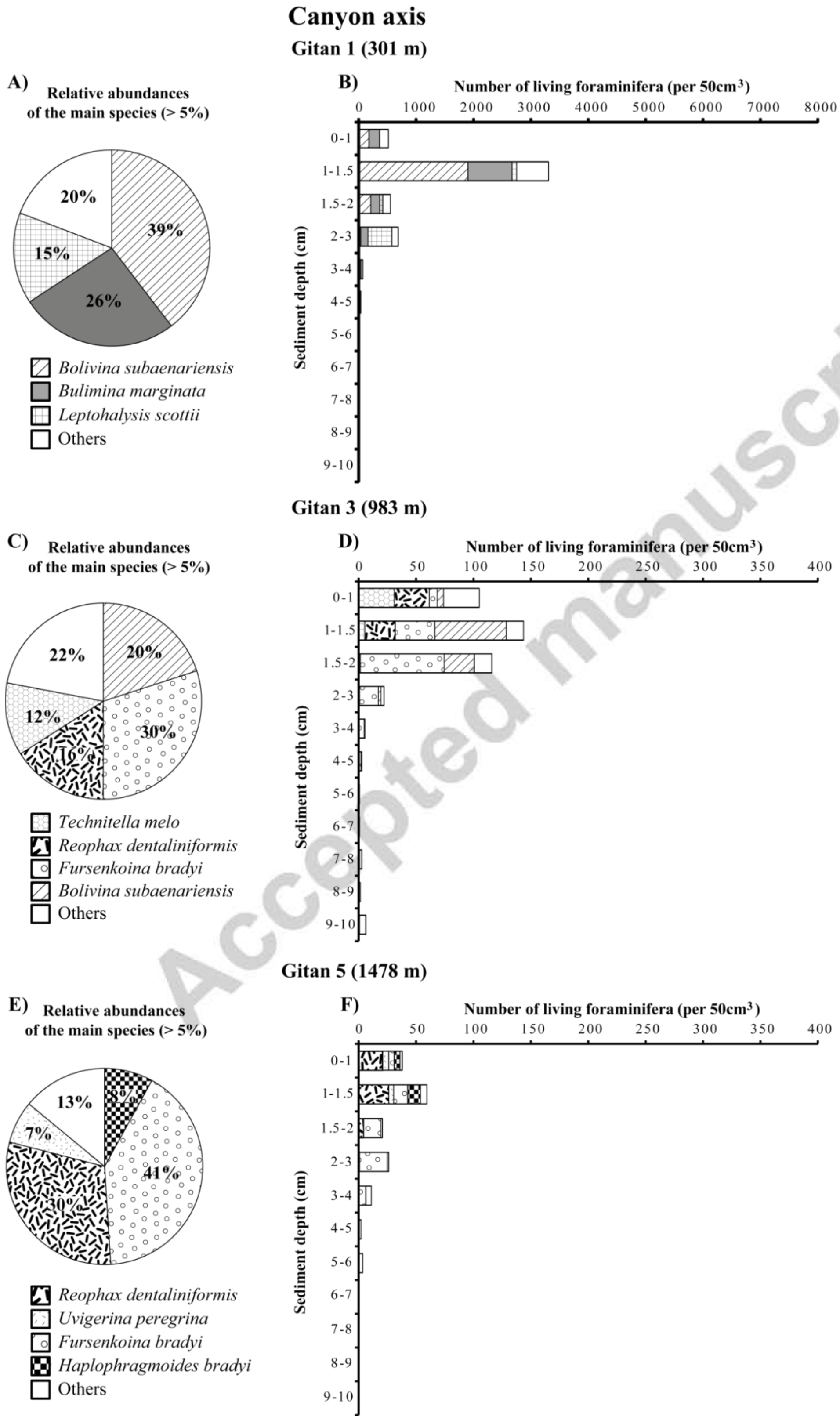


Figure 5 – SEM photographs of main foraminiferal species (> 5 %; > 150 µm size fraction) observed at all investigated sites in the living (stained) and dead (unstained) faunas. **A.** Living *Valvulineria bradyana* (station Gitan 2, 0-1 cm). **B.** Living *Fursenkoina bradyi* (Gitan 3, 0-1 cm). **C.** Living *Chilostomella oolina* (Gitan 6, 0-1 cm). **D.** Living *Technitella melo* (Gitan 3, 0-1 cm). **E.** Living *Reophax dentaliniformis* (Gitan 3, 0-1 cm). **F.** Living *Bolivina alata* (Gitan 4, 0-1 cm). **G.** Living *Leptohalysis scottii* (Gitan 1, 0-1 cm). **H.** Living *Siphogenerina columellaris* (Gitan 4, 0-1 cm). **I.** Living *Bolivina subaenariensis* (Gitan 2, 0-1 cm). **J.** Living *Uvigerina mediterranea* (Gitan 4, 0-1 cm). **K.** Living *Uvigerina peregrina* (Gitan 4, 0-1 cm). **L.** Living *Reophax scorpiurus* (Gitan 4, 0-1 cm). **M.** Living *Melonis barleeanus* (Gitan 4, 0-1 cm). **N.** Living *Bulimina marginata* (Gitan 1, 0-1 cm). **O.** Living *Cassidulina carinata* (Gitan 6, 0-1 cm). **P.** Living *Haplophragmoides bradyi* (Gitan 6, 0-

1 cm). **Q.** Dead *Planorbulinella larvata* (Gitan 3, 9-10 cm). **R.** Dead *Planorbulina mediterranensis* (Gitan 1, 9-10 cm). **S.** Dead *Cibicides lobatulus* (Gitan 1, 9-10 cm). **T.** Dead *Gavelinopsis translucens* (Gitan 4, 2-3 cm). **U.** Dead *Textularia sagittula* (Gitan 4, 2-3 cm). **V.** Dead *Elphidium* spp. (Gitan 1, 9-10 cm). **W.** Dead *Ammonia beccarii* (Gitan 5, 9-10 cm). **X.** Dead *Quinqueloculina* sp.1 (Gitan 5, 9-10 cm).



Duros *et al.*, Figure 6

Figure 6 – (A, C, E) Relative abundance (%) and **(B, D, F)** vertical distribution (standardized for a 50 cm^3 sediment volume) of the main living species (> 5 %; > 150 µm) observed along the canyon axis. Note the scale changes.

Duros *et al*., Figure 7

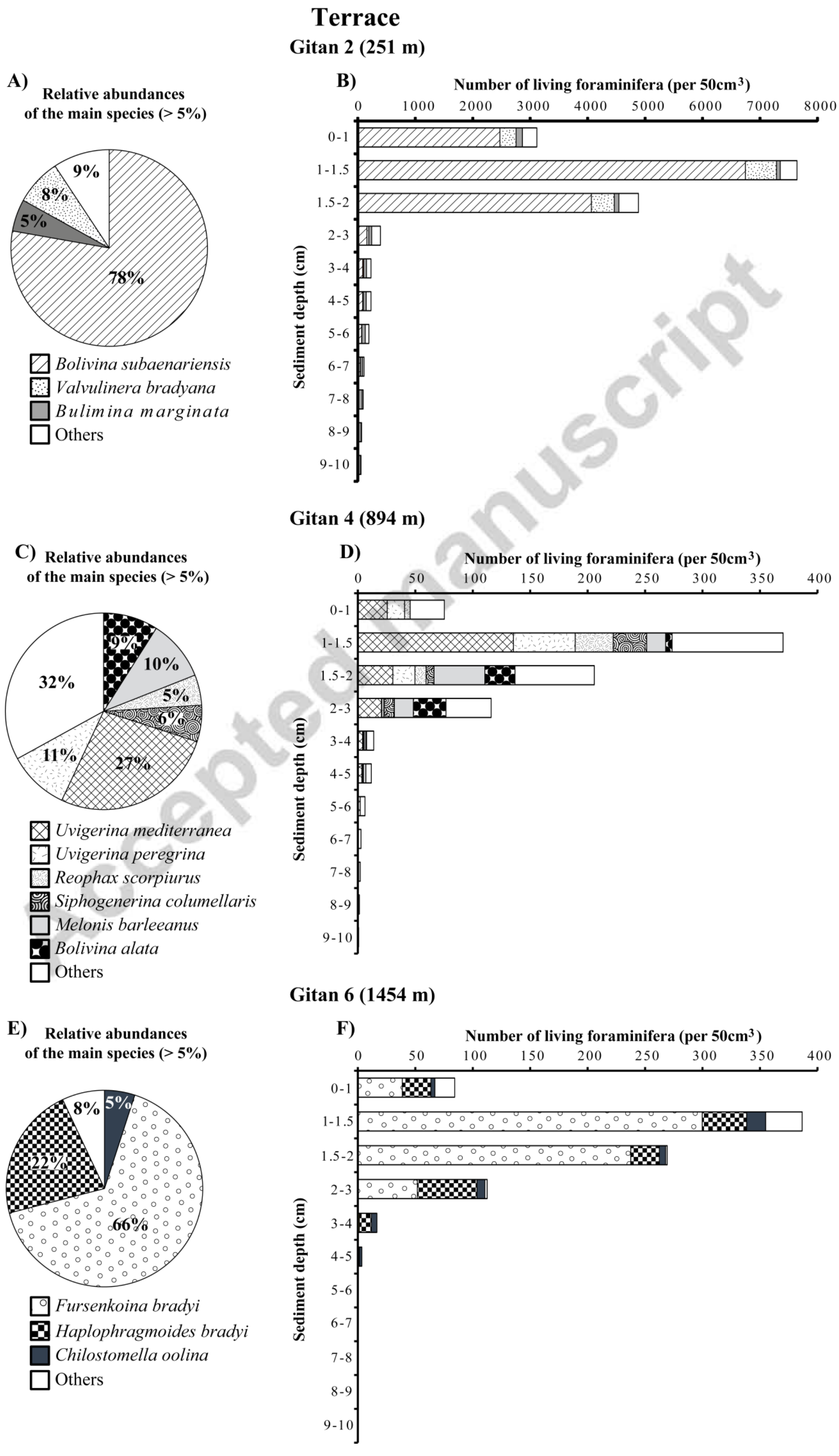


Figure 7 – (**A, C, E)** Relative abundance (%) and (**B, D, F)** vertical distribution (standardized for a 50 cm[3] sediment volume) of the main living species (> 5 %; > 150 µm) observed on adjacent terraces. Note the scale changes.

Duros *et al*., Figure 8

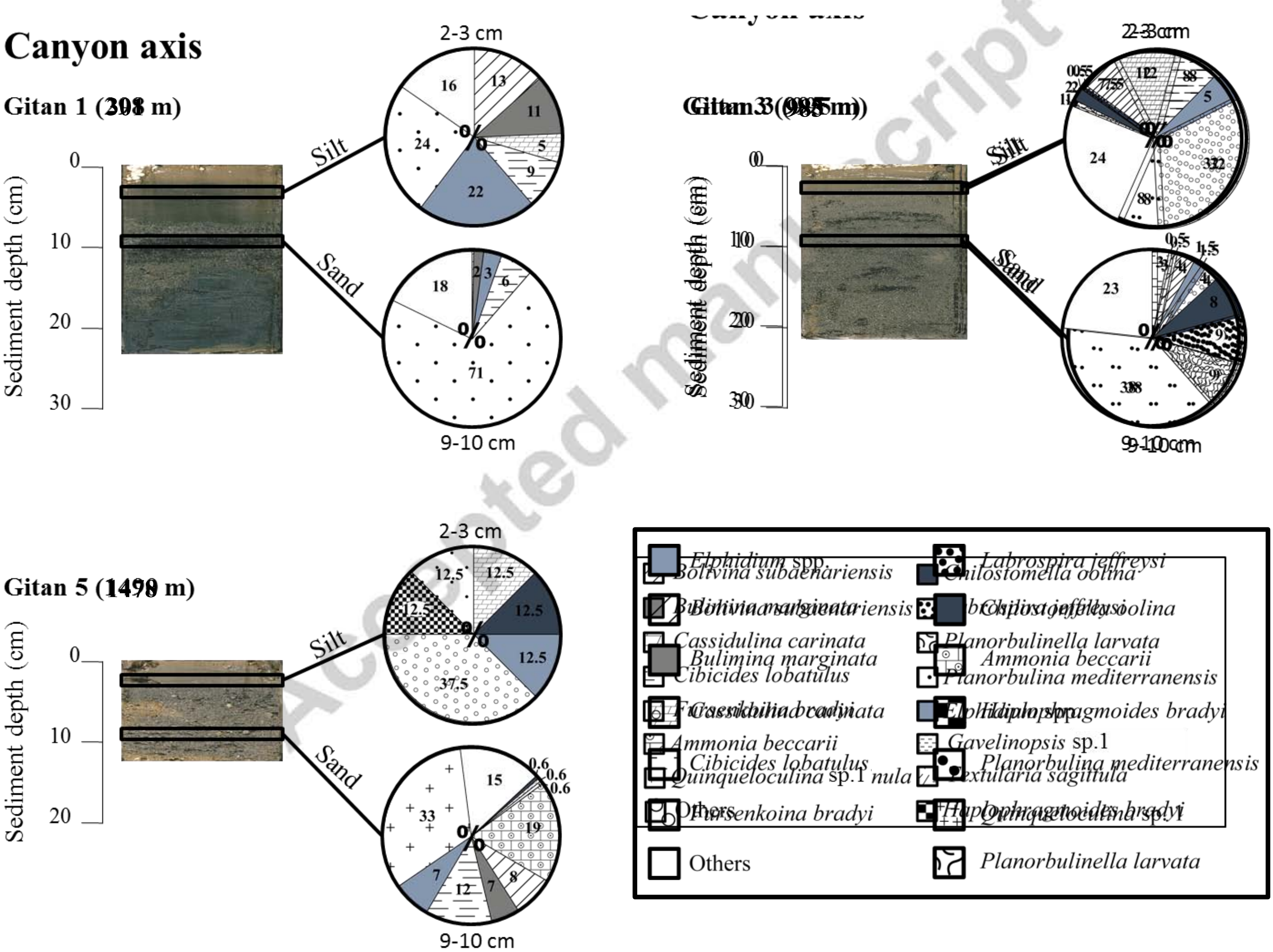


Figure 8 – Relative abundance of the main species (> 5 %) observed in the dead fauna (> 150 µm) along the canyon axis in two different sediment levels, 2-3 cm (silty level) and 9-10 cm (sandy level).

Duros *et al*., Figure 9

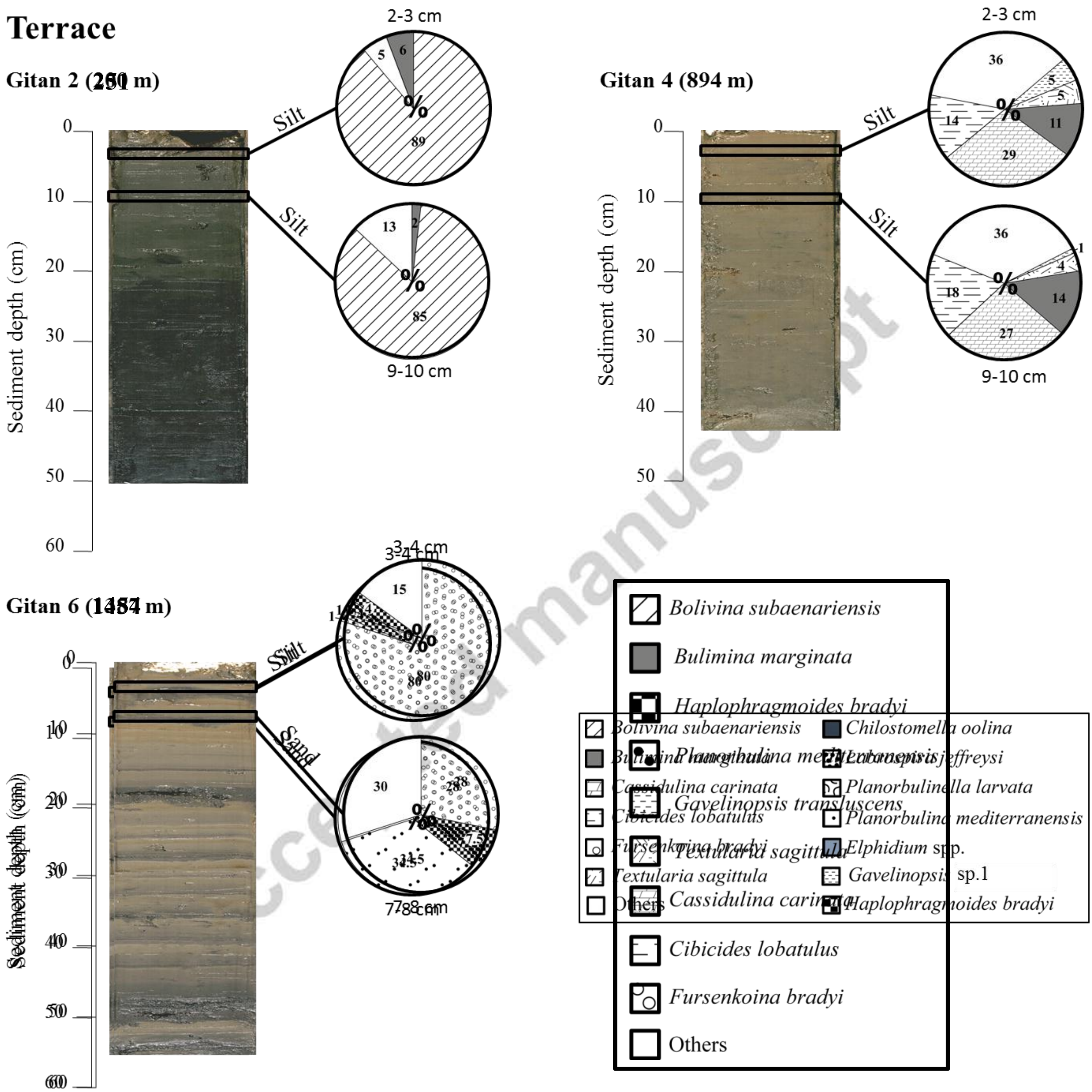


Figure 9 – Relative abundance of the main species (> 5 %) observed in the dead fauna (> 150 µm) along adjacent terraces in two different sediment levels, 2-3 cm (silty level) and 9-10 cm (sandy or silty level).

Duros *et al*., Figure 10

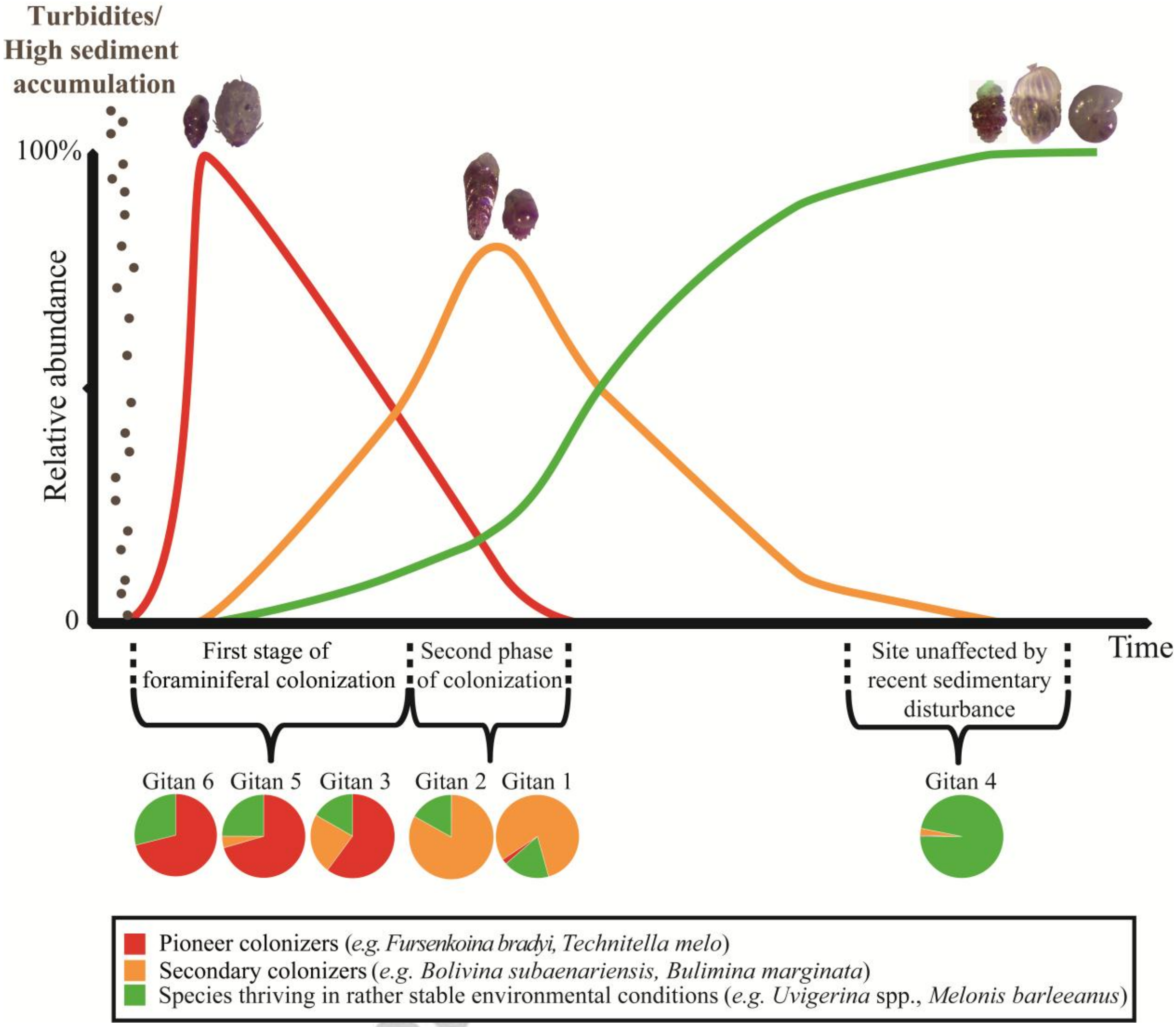


Figure 10 – Summarized schema which documents the various foraminiferal responses observed along the 6 studied sites sampled in August 2015. Gitan 1 (301 m), Gitan 3 (983 m) and Gitan 5 (1478 m) are located along the Capbreton canyon axis and Gitan 2 (251 m), Gitan 4 (894 m) and Gitan 6 (1454 m) on terraces at 50 m, 156 m and 24 m above the canyon axis, respectively.

Table 1 – Geographical position, water depth and sampling date of the 6 investigated stations in this study (Gitan 1 to Gitan 6) and of all previously documented sites in the Capbreton canyon area (Anshutz *et al*., 2002; Hess *et al*., 2005; Hess and Jorissen , 2009; Bolliet *et al*., 2014).

Station	Location	Latitude	Longitude	Depth (m)	Sampling date
Gitan 1	Canyon axis	N 43° 40,4264'	W 1° 33,1405'	301	August 2015
Gitan 2	Terrace	N 43° 40,23303'	W 1° 32,94270'	251	August 2015
Gitan 3	Canyon axis	N 43° 37,445'	W 1° 52,989'	983	August 2015
Gitan 4	Terrace	N 43° 35,7500'	W 1° 54,1075'	894	August 2015
Gitan 5	Canyon axis	N 43° 38,29704'	W 2° 07,72299'	1478	August 2015
Gitan 6	Terrace	N 43° 38,0427'	W 2° 08,1528'	1454	August 2015

Previously investigated sites	Location	Latitude	Longitude	Depth (m)	Sampling date	References
C	Terrace	N 43° 40,08'	W 1° 38,87'	235	October 1997	Hess and Jorissen, 2009
Z2	Abandoned Canyon axis	N 43° 40,44'	W 1° 37,76'	400	September 2001	Hess and Jorissen, 2009
Z1	Abandoned Canyon axis	N 43° 40,40'	W 1° 37,90'	406	June 2001	Hess and Jorissen, 2009
G	Canyon axis	N 43° 40,20'	W 1° 37,00'	453	October 1997	Hess and Jorissen, 2009
FC9 K	Canyon flank	N 43° 38,05'	W 1° 42,83'	560	February 2011	Bolliet *et al*., 2014
L	Canyon axis	N 43° 37,62'	W 1° 43,24'	632	September 2001	Hess *et al*., 2005
W	Canyon axis	N 43° 37,67'	W 1° 42,12'	636	June 2001	Hess and Jorissen, 2009
K	Canyon axis	N 43° 37,73'	W 1° 43,62'	646	June 2001	Hess *et al*., 2005
OB10 K	Canyon axis	N 43° 37,83'	W 1° 43,28'	647	May 2000	Anschutz *et al*., 2002 Hess *et al*., 2005
FPK	Canyon axis	N 43° 37,70'	W 1° 43,80'	650	August 2005	Bolliet *et al*., 2014
SCII A	Distal terrace	N 43° 40,10'	W 2° 00,02'	664	September 2001	Hess and Jorissen, 2009

R	Canyon axis	N 43° 36,24'	W 1° 45,54'	748	June 2001	Hess and Jorissen, 2009
E	Terrace	N 43° 36,00'	W 1° 46,00'	765	June 2001	Hess and Jorissen, 2009
S	Canyon axis	N 43° 36,03'	W 1° 46,82'	786	June 2001	Hess and Jorissen, 2009
J	Canyon flank	N 43° 38,00'	W 1° 52,00'	860	June 1999	Hess and Jorissen, 2009

Table 2 – Standing stocks and biodiversity of living (stained) foraminiferal faunas (> 150 µm) and qualitative observations (main species) of the 63-150 µm size fraction (0 - 1 cm) for the 6 stations in the Capbreton canyon area.

Stations	Depth (m)	Location	Standing stocks (per 100 cm^2)	Species Richness (S)	Shannon Index (H')	Evenness Index (E)	Qualitative observations (main species) of the 63-150 µm fraction (0 - 1 cm)
Gitan 1	301	Canyon axis	6548	44	1.82	0.14	High number of *Bolivina subaenariensis*
Gitan 2	251	Terrace	21490	36	0.95	0.07	High number of *Bolivina subaenariensis*
Gitan 3	983	Canyon axis	564	23	2.14	0.37	High number of *Bolivina subaenariensis*
Gitan 4	894	Terrace	1046	47	2.77	0.34	Very few individuals (*Reophax scorpiurus*)
Gitan 5	1478	Canyon axis	242	13	1.66	0.41	Very few individuals (*R. dentaliniformis*)
Gitan 6	1454	Terrace	1090	12	1.02	0.23	Few *Fursenkoina bradyi*

Table 3 – Lithology, number of dead individuals (per 100 cm2), contribution of the dead allochthonous (neritic) individuals (per 100 cm2) and main species observed in the living and dead faunas in both sediment level studied at each station from Capbreton canyon axis and terraces (> 150 µm size-fraction). Species included in the allochthonous taxa are *Elphidium* spp., *Planorbulina mediterranensis*, *Planorbulinella larvata*, *Cibicides lobatulus*, *Ammonia beccarii*, *Gavelinopsis transluscens*, *Rosalina* spp., *Hanzawaia boueana*, *Planulina ariminensis* and *Quinqueloculina* sp.1.

Canyon axis

	Gitan 1 (301 m)		**Gitan 3 (983 m)**		**Gitan 5 (1478 m)**	
Studied level	**2-3 cm**	**9-10 cm**	**2-3 cm**	**9-10 cm**	**2-3 cm**	**9-10 cm**
Lithology	Silts	Very fine to coarse sands	Silts	Fine sand	Silts	Medium sands
Number of dead individuals (per 100 cm^{-2})	3315	29348	349	3613	11	238
Number of dead allochthonous (neritic) ind. (per 100 cm^{-2})	1878	25547	86	1989	3	91
% of dead allochthonous (neritic) ind.	57	87	25	55	25	71
Main species in the dead fauna (> 5%)	*Planorbulina mediterranensis* *Elphidium* spp. *Bolivina subaenariensis*	*P. mediterranensis*	*Fursenkoina bradyi* *Cassidulina carinata* *Cibicides lobatulus*	*P. mediterranensis*	*Fursenkoina bradyi*	*Quinqueloculina* sp.1 *Ammonia beccarii* *Cibicides lobatulus*
Main species in the living fauna (> 5%)	*Bolivina subaenariensis* *Bulimina marginata*		*Fursenkoina bradyi* *Bolivina subaenariensis*		*Fursenkoina bradyi*	

Terraces

	Gitan 2 (251 m)		**Gitan 4 (894 m)**		**Gitan 6 (1454 m)**	
Studied level	**2-3 cm**	**9-10 cm**	**2-3 cm**	**9-10 cm**	**3-4 cm**	**7-8 cm**
Lithology	Silts	Silts	Silts	Silts	Silts	Very fine sands
Number of dead individuals (per 100	12331	11845	7094	12416	148	961

cm^{-2})						
Number of dead allochthonous (neritic) ind. (per 100 cm^{-2})	88	530	1967	3200	7	381
% of dead allochthonous (neritic) ind.	1	4	28	26	5	40
Main species in the dead fauna (> 5%)	*Bolivina subaenariensis*	*Bolivina subaenariensis*	*Cassidulina carinata* *Cibicides lobatulus*	*Cassidulina carinata* *Cibicides lobatulus*	*Fursenkoina bradyi*	*P. mediterranensis* *Fursenkoina bradyi*
Main species in the living fauna (> 5%)	*Bolivina subaenariensis*		*Uvigerina mediterranea* *Uvigerina peregrina*		*Fursenkoina bradyi*	

Highlights

- Live benthic foraminifera were studied at 6 deep stations in the Capbreton Canyon.
- Benthic foraminifera were sampled along canyon axis and its adjacent terraces.
- The aim is to use foraminifera as bio-indicators of hydro-sedimentary processes.