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Geomorphological classification in Bay of Biscay

Morpho-sedimentary mapping of the seabed in selected areas

Part of CoralFISH D38 deliverable

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Summary

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1. Context

All along the northern margin of the Bay of Biscay, the succession of interfluves and deep canyons has shaped the passive margin. More than 130 canyons are organized into 8 large drainage basins (Bourillet & al. 2006). The complex hydrology (geostrophic and tidal currents, swells, internal waves) and the vast canyons systems play an important role in control of present sedimentary processes determining benthic habitat distribution and development.

The present document describes the variety of morphological aspects found in the Continental Slope of the Bay of Biscay, as can be observed at a «meso-scale» i.e. speaking of morphological features at decametric scale (ranging from ~10 or 25m which is the resolution of the underlying DTMs (Digital Terrain Model) supporting the classification to a few 100m). These features will be related to their main control and locations towards canyon paths and they are constitutive elements of the proposed classification: *morpho-sedimentary map of the seabed*. Typical mapping for these features would occur at 1/ 100 000 to 1/ 50 000 scales.

Although rather generic in its conception, one of the major end-use of this seabed classification (IFREMER contribution to the CoralFISH EU project) will be the contribution to habitat mapping or suitability modelling (HSM) for cold water corals environments in the Bay of Biscay. Input data used for such modelling include high resolution bathymetric and backscatter acoustic data, combined with pictures and videos observations acquired during recent dives. Besides an «historical dataset» database as for the scleractinians, namely the Reveillaud & Freiwald database can be used in the same way. This «final match» between classification and observations will not be presented in this report, which will stick to the generic morphological classification independently for its use in HMS, yet summary of the morphological observations per individual dives has been prepared in a separate Appendix. Besides, a joint relationship with other previously existing morpho-sedimentary classifications will be also considered (Greene, 2009) and CMECS (Madden & al, 2009).

Main first partition of the ocean bottom, which is very classical and adopted in all classification systems, concerns the very large scale or ***Mega-geoform classification*** and typically occurs at 1/1 000 000 scale. Starting from the shoreline and going towards the medio-Atlantic ridge, there are 4 mains units or domains encountered:

- Continental shelf (in general : *continental and island shelf*)
- Continental slope (in general : *continental and island slope*)
- Rise (in general : *continental and island rise*)
- Abyssal plain (in general : *abyssal plain and intraslope basin*)

The set of retained mega-geoforms and how limits are obtained is discussed in chapter 3 and summarized in Table 1. In fact, only two main attributes are necessary and used to define these limits: the bathymetry itself and the slope at a mesh of ~125 m were used in this study (can be multiples: 250 m or 500 m as is generally available).

As often for computer based classification, the principles and rules from a set of DTM derived attributes are leading to a first «automatized version», then some local revisions, taking into account morphological and continuity considerations occur in a second stage leading to the final retained limits.

In a further step the *geo-morphological* classification is applied in order to identify *meso-geoforms* which are morphological features at decametric scale. These are outlined and delineated thanks to a serial of morphological attributes all derived from the underlying DTM, as slopes , distances to specific elements of the drainage network, relative elevations (BPI), ... They are about a dozen of such input attributes, which will be defined and described more precisely in chapter 2.

Since earlier morphological analysis (Bourillet & al, 2003) and last *D9 report* in January 2010 (Schmitt & al, 2010), the morphological classification has been worked mainly for the continental slope (and kept unchanged for the shelf and rise). The revisions and larger number of classes proposed correspond to characteristic elements that appear in such canyon driven areas and are better revealed by the new survey data which enable an ~20m horizontal resolution in 4 specific areas (see next page), rather than in the previous 125m resolution.

Chapter 4 will present the revised *geo-morphological* classification for the continental slope, which has been since last report in January 2010 the main domain of new work and changes. The classification principles being kept nearly unchanged for the shelf and rise will be just recalled in chapter 3; for the time being they are based on the instant slope only. Besides only the shelf break, which is the transition between continental shelf and slope, and upper part of the continental slope are relevant for the CWC habitats study which is the general framework of these contributions.

Following this specific description of the context and objectives of the present Ifremer contribution to the CoralFISH program, this report will essentially focus on the description of the proposed methodology of seabed classification illustrated by the results of the Bay of Biscay in BOB2 and some zooms of BOB1 areas. Discussion on the results including an inter-comparison for the Bay of Biscay 4 different areas takes place at end of report in Chapter 5.

We just mention also that adaptations were made in order to apply these classification principles to some other CoralFish sites (as per January 2011 this was done already for the Northern Ionian Sea (SML: *SantaMaria di Leuca*) and part of the Porcupine seabight in Western Irish margin, including the *Belgica* and *Arc* mounds areas). Results for these regions are available through Powerpoint presentations and will be reported separately.

1.1 - HR surveyed areas in Bay of Biscay: BOB1 to BOB4

This classification has been applied globally first on the decametric scale bathymetric models available - for the time being which is the December 2010 status - in four different areas of the Bay of Biscay, mainly 4 «boxes» named BOB1 to BOB4, (see Figure 1).

The first two areas have been available in their high resolution version since the BOBGEO survey acquired in October 2009, merged with other previous data. These areas are namely: *Bob1_extended* in the BOB1 area (in Northern part of the «Armorican margin» of the Bay of Biscay) with a DTM mesh of 15m and *Bob2_extended* in the BOB2 area (in Central part of the bay, still Armorican margin) with a DTM mesh of 25m, this lower resolution being linked to worse weather conditions and more noise in the raw data. The *_extended* suffix indicates that data from other previous HR surveys were used.

The other two areas BOB3 & BOB4 have been available in their high resolution version since the BOBGEO 2 survey acquired in July 2010. BOB3 is representative of the southern part the «Armorican margin», whereas for BOB2, the influence of the Manche entries is no more present. The BOB4 area is representative of the «Aquitan margin», canyons (Cap Ferret and Arcachon). These areas present rather different morphologies than in Northern areas and in Bob4 area, the submarine landscape has more gentle slopes. The Bob3 and Bob4 areas were chosen to characterize the South part of the Bay of Biscay, where historical records of CWC are less numerous.

The respective extents and main characterisics of corresponding DTMs and grids have been summarised in Table 1 below. All DTM are built using a WGS-84 ellipsoid and a Mercator projection at N46°.

Table 1: Main DTMs characterisics (extensions) and statistics on input depths

DTM Name	title / area	NX	NY	mesh dx (=dy)	dy	elt area (m²)	grid area (km²)	informed area (km²)	E-W	N-S	% orig depth informed	% in cont. slope
MNT_Gasc_500	regional model *"manche Atlantique"*	2324	2065	500	500	250000	1,199,765	896,111	1,162	1,033	75%	
BOB1_ext	local model for BOB1 + extensions Blackmud & La Chapelle	8470	5326	15	15	225	10,150	2,927	**127**	**80**	29%	54%
BOB2_ext	local model for BOB2 extended	4516	3690	25	25	625	10,415	3,252	**113**	**92**	31%	56%
BOB3	local model for BOB3	3208	2667	15	15	225	1,925	726	**48**	**40**	38%	80%
BOB4	local model for BOB4 ("modèle bord")	3903	3305	15	15	225	2,902	972	59	50	33%	
BOB4_ext	local model for BOB4 + south extensions	5769	5458	15	15	225	7,085	5,159	**87**	**82**	73%	90%

	comments	***STATISTICS ON DEPTH*** def	*mini*	*Q.25=*	*Q.50=*	*Q.75=*	*maxi*	*MEAN*
MNT_Gasc_50	both on & off-shore	3584442	-4937	-135.5	-21	115	2493.5	-590.2
BOB1_ext	North of Armorican margin	13008422	-4102.2	-1535.4	-1035.6	-479.2	-141	-1134.47
BOB2_ext	Armorican margin	5202544	-4112.8	-1992.2	-1176.2	-720	-151.6	-1449.45
BOB3	South Armorican margin	3224698	-3223.2	-1924.3	-1372.4	-744.1	-165.3	-1368.91
BOB4	Aquitan margin	4319536	-2823.5	-1928.1	-1350.3	-1002.9	-159.9	-1424.98
BOB4_ext	""	22928257	-3569.19	-2281.4	-1356	-707.09	-116.96	-1492.02

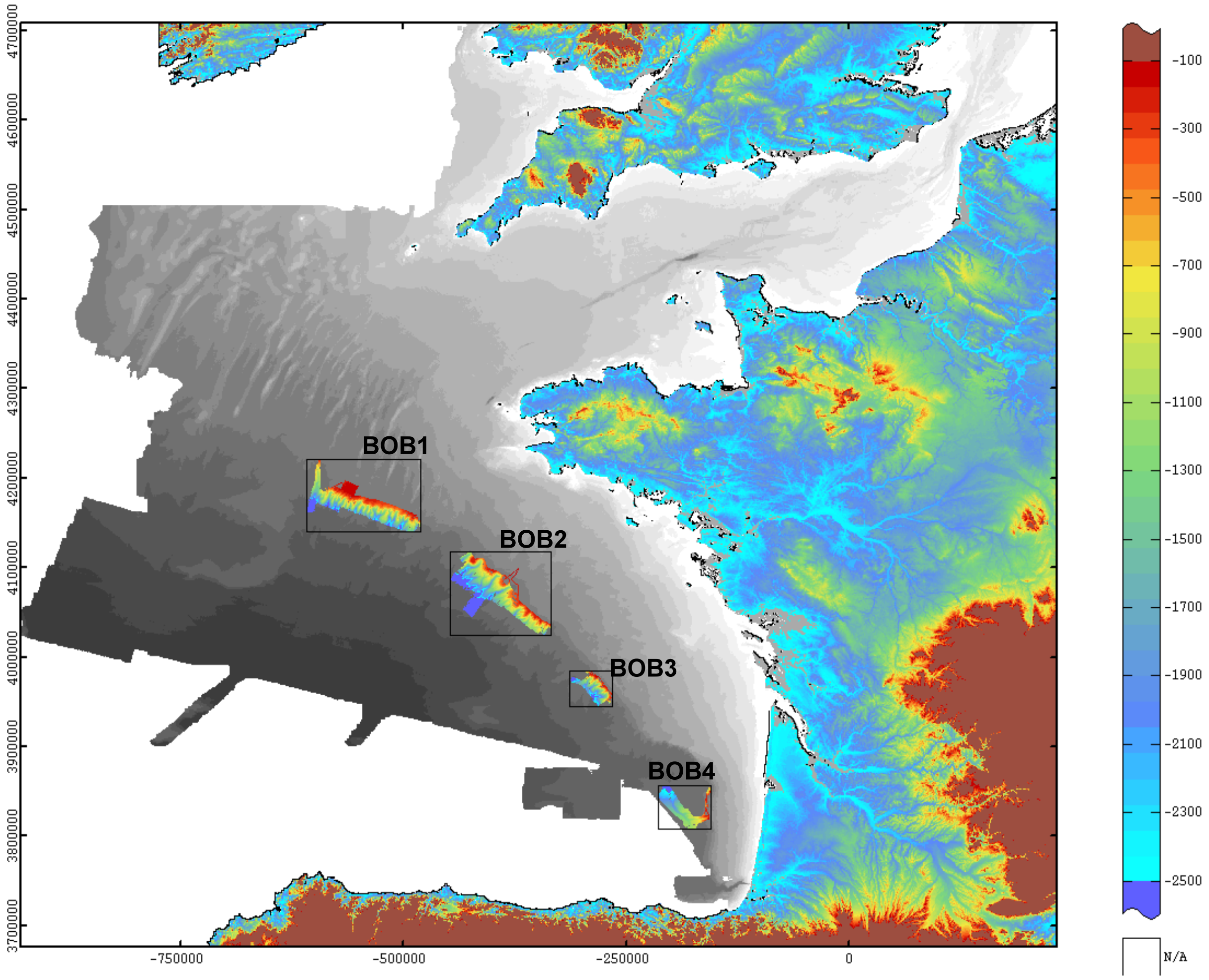

Figure 1 Local and regional bathymetric models of the Bay of Biscay and onshore.
Grey scale underground map of the ocean and English Channel is made using an isofrequency coding (for depth ranges 0 to - 4500 m) applied on the «Manche-Atlantic» regional model at mesh 500m. Detailed bathymetric models (resolution 15m to 25m) available for the 4 boxes: Bob1 to Bob4 from North to South, inside with corresponding color scale displayed on the right (depth ranges -100 to - 2500 m).
The altitude on continents is color coded from <+10m (grey) to >+500m (brown).

At a preliminary stage of processing, these local DTMs will be compared and merged to an earlier and «rougher» available more regional model, at resolution 125m referred as EEZ model (Le Suavé & al, 2000). This is necessary since, as will be seen later, the proposed classification also makes use of the drainage system network, which has to be determined on a rather regional scale and down to the rise or even abyssal plain when properly know.

1.2 - BOBGEO surveys and pre-processing

The first and longest (~20 days) BOBGEO survey took place in October 2009 on board the R/V Pourquoi pas?, equipped with a RESON multibeam echo-sounder. It permitted to efficiently map *Bob1 & Bob2* areas of the continental slope at a resolution of respectively 15 m & 25 m (or better for specific sites) down to water depth of 2500 m. This survey enabled also to acquire a few high resolution seismic profiles (11 with 5 in the BOB1 area, 3 in the BOB2 area and 3 in transition between both areas).

Multibeam echosounder bathymetric and backscatter data are in fact issued from two sounders used jointly or in alternance: the Reson 7150 at 24 kHz was used in the large depth profiles ~ below depth of -300m, whereas Reson 7111 at 100 kHz was used for shallower seabed depth areas when reaching the upper slope and continental shelf.

The second BOBGEO2 survey took place, during 10 days in July 2010, on board the R/V Le Suroit, equipped with SIMRAD EM302 & EM1000 multibeam echosounders. It permitted to efficiently map *Bob3 & Bob4* areas of the continental slope at a resolution of 25 m. CHIRP sub-bottom profiler was used simultaneously on all multibeam profiles and for both surveys.
Survey reports for both cruises are available in french asking the author (Bourillet 2009, 2010) or though CoralFISH website (partners only).

Navigation during these two surveys is shown on **Figure 2** (next page).

Each of these DTMs contains a joint set of bathymetric variables, from the initial bathymetry (as present in model provided by the CTDI service) to slightly filtered, then merged with regional model and averaged on different window sizes (but mainly using a 150 m circular radius) and finally trend surfaces models, the meaning and further uses of these variable will be discussed in further chapter 2.

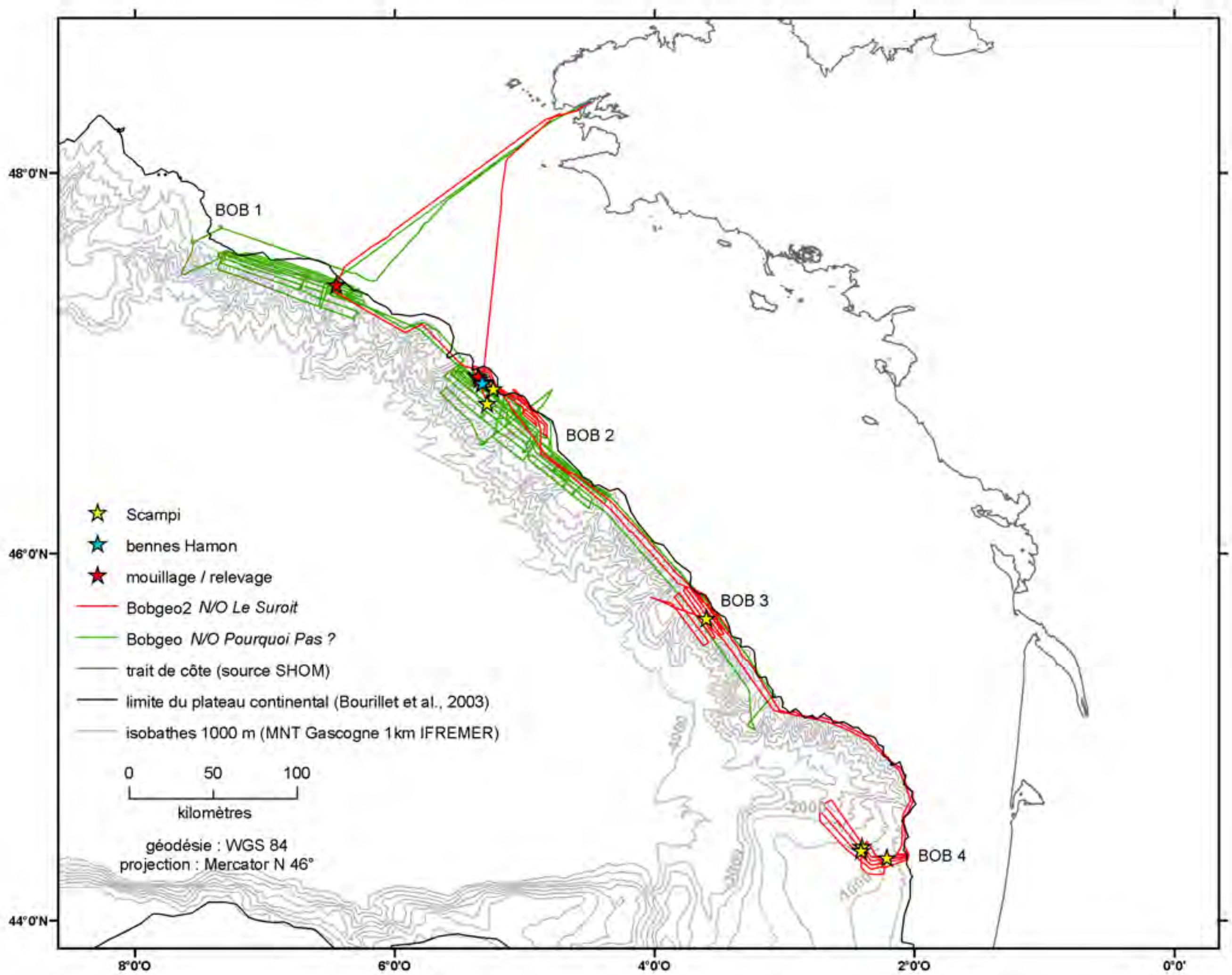

Figure 2 : Navigation during the 2 surveys BobGeo (2009) and BobGeo 2 (2010) in the Bay of Biscay

Red line: BobGeo ; green line : BobGeo2 campaign yellow star : still camera ; blue star : grab ; red star : mooring

2. Basis of classification: DTM derived attributes

The objective of such classification is an automatized approach as far as possible. This approach is based on easily computable variables (or *attributes* referring to the commonly used terminology in seismic works) derived from the bathymetric original DTM. After initialization runs based only on formulaes using these attributes, the "supervised classification» occurs and interpretative choices need to be done to confirm or modify some limits or classes.

The *DTM derived attributes* used for this classification can be regrouped in 4 categories as follow:

1 – Bathymetry itself and various averaging at different scales
2 - Residual bathymetry and related attributes (rugosity, BPI ...);
3 - Slope and aspect variables;
4 - Attributes linked to the drainage network.

2.1 - Raw, filtered and averaged bathymetry

The input or *"processed bathymetry"* is defined as the input provided bathymetry on the working DTM , as issued by the CTDI service and resulting from a local averaging (done in Caraibes software ©Ifremer / *Mailla* module*)* process from the punctual (or *ping)* data from the multibeam at a given grid mesh (eg 25m). Only validated data (after using mainly Caraibes / *Filtri* module*)* were considered as input, meaning that some spatially unconsistant echosounds have been discarded.

From this input DTM, different averaged or trend bathymetries, corresponding to increasing neighborhoods around the DTM cells can be considered.
Here for the classification we work mostly with three averaging of bathymetries, first is made within a circular radius = 150 m, second with radius 500 m both using the classical arithmetic mean (moving average of cells). The 3rd bathymetric variable we use is trend bathymetry within a 2km radius; the term *trend* means that we use a quadratic polynomial fitting surface. When working with averaged bathymetry rather than trends, it is important to avoid bias that in case of «holes» or missing values in the DTM, these specific cells with missing data inside the informed DTM are preliminarily re-interpolated.

In general, a slightly filtered bathymetry has been computed also, process is not described in detail per area but most often, we used a geostatistical approach based on the residual bathymetries (see next page): variogram computation and modeling then filtering by factorial kriging. As last step to obtain the reference bathymetry used further, this filtered bathymetry is then merged by interpolation to the re-interpolated regional EEZ model (previously mentioned, available at mesh 125 m). An illustration of the filtered and merged bathymetry for the Bob2 area can be seen in **Figure 3**, highlighting the HR and regional areas.

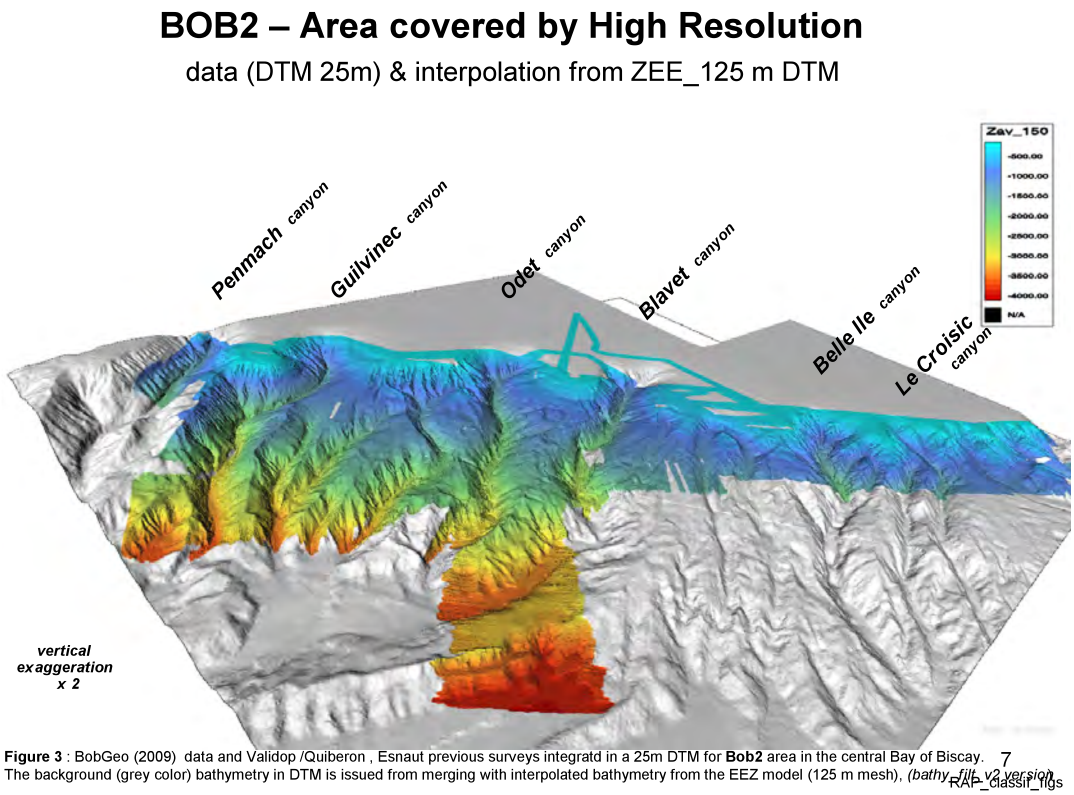

Figure 3 : Bathymetry on Bob2 area: block diagram

Color coding - using the right color scale – is restricted to the HR initial model before merge

Same block diagram representation (color coding with other variables) will be used to illustrate the main other attributes described next.

2.2 - Residual bathymetry attributes

Residual bathymetry is defined as the local difference of *"punctual"* bathymetry minus *averaged* bathymetry on the working grid mesh (eg 25m). Different residuals, corresponding to increasing neighborhoods to compute the averaged bathymetry can be considered.
Here for the classification we work mostly with the "small scale" residual, where the averaging of bathymetries is made within a circular radius = 150 m. Unless specified (using the term *trend* in this case we use a quadratic polynomial fitting surface) the average bathymetry is the classical arithmetic mean, to avoid bias is it important that in case of «holes» or missing values in the DTM these specific cells with missing data inside the informed DTM are preliminarily reinterpolated.

This depth difference basically indicates local *highs* and *lows, when* normalized this residual gives the *bathymetric position index* or BPI. This normalization step can be useful if one wish to compare different BPI in the same region, computed using different neighborhoods; it is not used in present classification, and we rather use directly the residual bathymetry for extraction of the *crests* and *troughs* especially in the gullied canyons areas as we shall see in chapter 4.

By definition, these variables tend to be zero centered and higher the rugosity or roughness of the terrain, higher will be the residual bathymetries in absolute values.

In a standard QC report linked to a given DTM, these residuals are mapped using different color scales (typically a [-30m , +30 m] color scale for major residuals highlighting in the canyon areas and then a [-6m , +6 m] color scale for more detail and for instance study of channel or crest structures in the interfluves). Statistics are also produced, including histograms and variograms in the restriction to each domain (continental shelf /slope / rise). Residuals are the key input variable used in geostatistical filtering applied, since they present «stationary» (no drift) behaviour.

An illustration of such residual maps in the BOB2 area is provided on **Figure** 4.

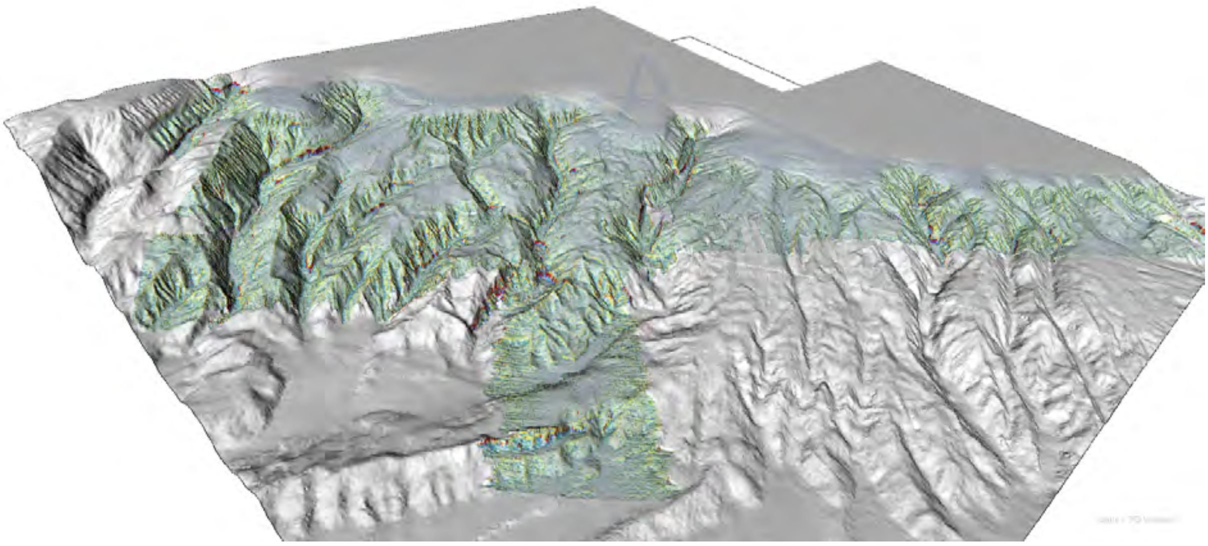

Figure 4 : Residual bathy on Bob2 area – using the +- 30 m color scale

Other related variables are drawn from the residual bathymetry:

- Proportions of residuals above a cutoff within a neighborhood (rectangular set of blocks or «kernel»- we have used kernel 11*7 meaning +- 5 cells extensions along the X direction and +- 3 along the Y direction); this attribute was used initially to distinguish the «incised» / «non incised" regions and can be a help for the canyons / interfluves areas distinction as will be discussed further in chapter 4.
- Standard deviation map of residuals (all values) within a neighborhood (we have used the same rectangular kernel 11*7) , which can be also an indicator of rugosity; it is not directly used yet in the routine classification as proposed for now but we have included the maps and statistics of this attribute in the QC reports joined to each DTM. In regions where artifacts remain, this parameter as the residual map itself will highlight the influence of these artifacts and could help to correct them.

2.3 - Instant slopes and aspect variables

The slope as we mention and use it must be understood as the maximum gradient value in the direct vicinity of a grid node, hence the name «instant slope». It provides a set of simple yet very representative characteristics of the terrain morphology and we are using different variants of such instant slopes. First, depending on the input bathymetric variable involved (but defined on the same mesh which is the one from the working DTM, eg. 25 m for Bob2), different slopes can be computed and at least 3 slopes are used:

- *High resolution instant slope :* slope (°) from the input bathymetry on the working grid mesh
- *Medium (or hectometric) resolution instant slope :* slope (°) from the averaged bathymetry (here within circular radius = 150 m) on the working grid mesh
- *trend (or kilometric) instant slope :* slope (°) from the trend bathymetry, here polynomial fitting trend surface of order 2, computed using neighbouring points in a circular radius of 2000 m, on the working grid mesh.

For each of these slopes one can also derive the azimuth (or orientation) of the maximum slope direction, also called *aspect* in ArcGis software. This variable is not directly used yet in the routine classification but can be of help in some troubles as the falls vs banks distinction (discussed later in chapter 4).

If we had to distinguish, in each canyon area, between the left and right side flanks, the azimuth of trend bathymetry would be the helpful variable to be used. This was not considered as necessary nor implemented / tested in the classification so far.

An illustration of such slope maps in the Bob2 area is provided on **Figure** 5.

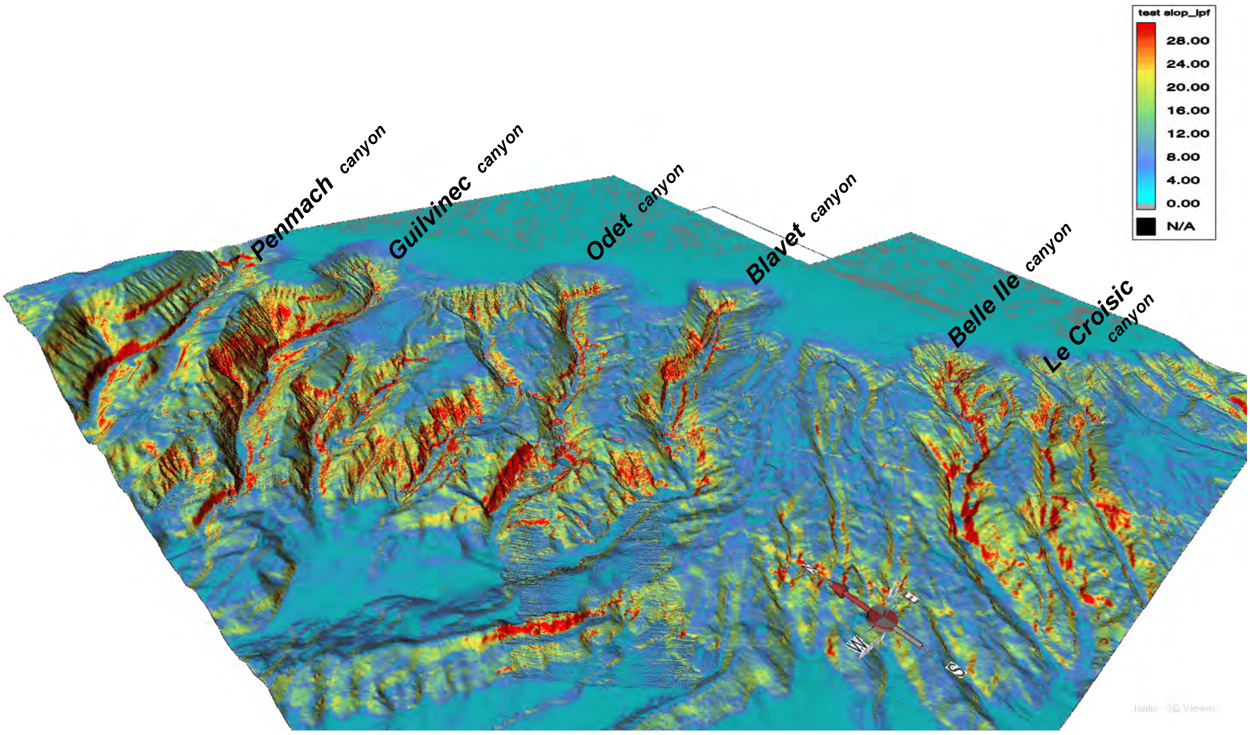

Figure 5 : High resolution instant slopes on Bob2 area

Slope is in ° and applies for the "high resolution" bathymetry (DTM 25m) in this bloc diagram.

Other derived attributes linked to the slopes can be easily derived and are quoted as well since they are mentioned in several references or articles in *geomorphology*. These are:

- standard deviation on slopes
- *"slope difference"* this could be defined in several ways :
  - local – medium range slope (combining slopes from different scaled bathymetries : local DTM & averaged)
  - Slope (e.g. local) - average of slopes in a given neighborhood (e.g. kernel 3*3)

    both being from the same bathymetry
- curvature
- Laplacian (second derivative on depth ⇔ first derivative on slope)
- …]

In general, these attributes related to second derivatives of bathymetry are difficult to support morphological interpretations because they are very sensitive and can be mostly influenced by artifacts and the discretised nature of DTM (squared mesh patterns).

2.4 - Attributes linked to the drainage network

The drainage network extraction algorithm used is the one coming from (P Souille & al, 1994), adapted by V. Quiniou (1998) and implemented in Isatis. Other algorithms exist as the «flow accumulation» in ArcGis (see ArcGis software & ESRI documentation).

- The algorithm first computes the number of drained cells for each cell of the DTM as a new grid attribute; cells receiving a high number of drained cells correspond to the thalwegs and location of preferential drainage path. It is interesting and recommended to first have a map and histogram of the log transformed variable (*LogNDB = log10 (number of drained cells)*). This is a way to control the algorithm's consistency and also to decide on what can be a relevant cutoff (on *number of drained cells*) for the next step which is the vectorization of the network.
- The second step which is vectorization provides a hierarchical lines structure which is in practice a sequence of connected grid cells and corresponds to the drainage path (or thalwegs). Each branch of the network is identified and receives a «line number» in this processing , together with a set of other interesting attributes (or variables) :

➔ the thalweg ***order*** **(**also referred to the Strahler stream order and used to define stream size based on a hierarchy of tributaries (Horton,1945), (Strahler,1952), (Schumm, 1961)) : when two (or more) distinct branches of thalweg meet themselves, they build a new portion of thalweg with increased rank order; thalwegs of order 1 are the more «upstream» (and with lower number of drained cells), they will flow in a «order 2» branch , etc ... In practice this order variable is useful to selectively discard some branches of the network

➔ the thalweg (branch) ***length*** and ***drained area***

➔ any other DTM attribute, as bathymetry or the drainage basin number and the number of drained cells at a local point can then also be interpolated on these vector lines.

Orders and location of the extracted drainage network on a bathymetric map will enable to decide and select the set of thalwegs belonging to the canyons.
In practice, this interpretative step is a key point for further classification since we have to decide what is a canyon path and not. For each region we did this by interactive edition, taking advantage of the present «branch» hierarchy and masking selectively some branches. Here are some general rules we used:

- In our classifications for the 4 BOB* areas, the order 1 thalwegs have been discarded, unless some rare exceptions in the upstream parts (near upper slope), generic name for this automatic selection is *sel O2*

- If some thalweg branches clearly appear as artifact, as in the case of long strictly horizontal or vertical long lines or as in the foot of a dip slip fault, these should be discarded also to avoid let them appear as thalwegs in the classification.

- Small lateral branches (order 2 or more thalweg branches not discarded by previous masks) from the main canyon paths should be discarded also.

The generic name for this retained selection is *sel O3_ok* and the result, for the Bob2 area can be seen when comparing Figure 6 (all thalwegs, color coding by thalweg order) and Figure 7 (selected branches and distance coding)).

Once the selections on the thalweg branches made, one can compute euclidian distances for each cell of the DTM

- distance to nearest path for each grid cell of the DTM with 2 distance functions, corresponding to both previously defined selections

These distances will be used later in classification, at various stages as will described later (chapter 4), one should just mention now that another derived distance: ***weighted distances to canyon thalwegs*** is used in the classification and the canyons / interfluves limits computations in order to account that canyons lateral extensions should appear less broad in the upper part of canyons. The used transformation formula, function of (negative) depth is:

distc_w = distc * aux1 , with *aux1* (weight) defined as a function of depth Z

aux1 (w) = 1 / (1+ (Z+1000) /800) if Z > - 1000 m ; 1 else

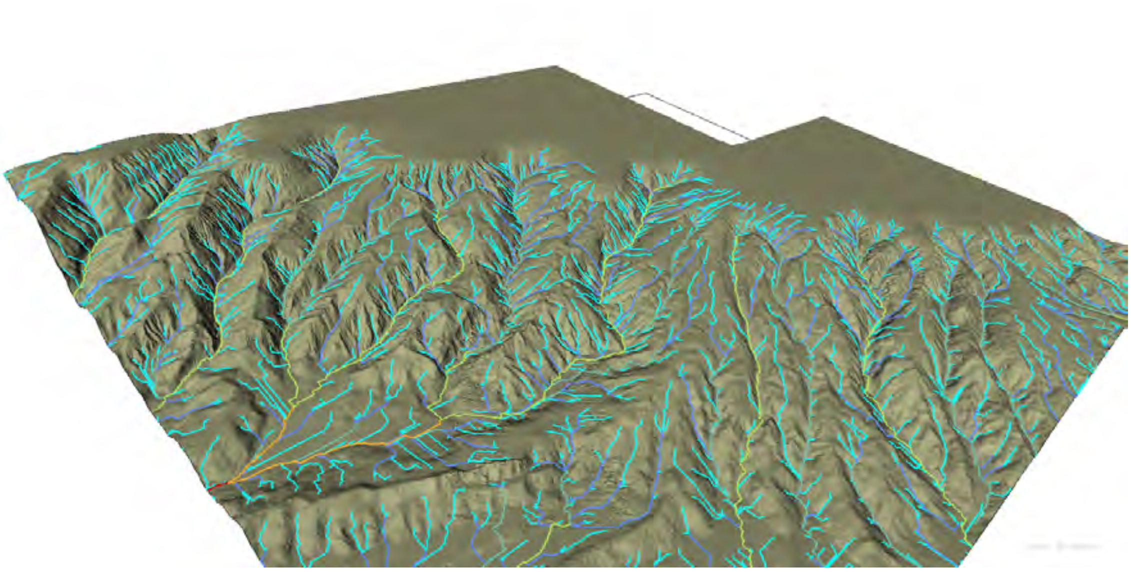

Figure 6 : Drainage network (color coded by thalweg order) on Bob2 area

At this stage the full drainage network is considered, later (Figure 7) thalweg branches when retaining a selection of the order 2 and above branches is considered.

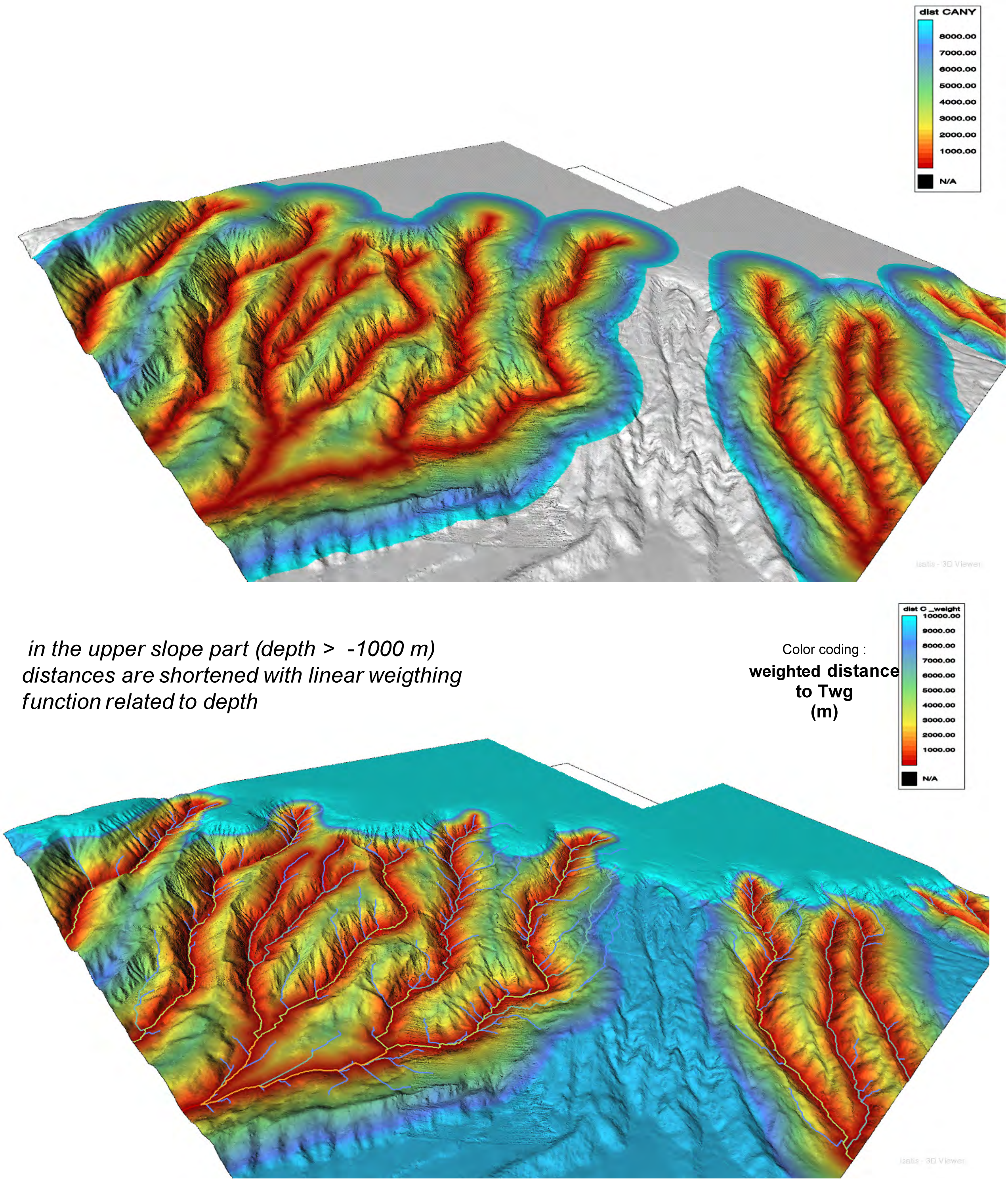

Figure 7 : Distance functions to drainage network (selected thalwegs) on Bob2 area

At this stage the selected drainage network is considered, corresponding to main canyon pathes distance function to the thalweg (unweighted) is shown on top and weighted version on base image of the figure.

3. Mega-geoform classification

Mega-geoform classification is the first step to be run, prior to the more detailed classifications as appears in the general flowchart given below on **Figure 8**.

Mega-geoforms, as called in the CMECS classification – see Appendix II and (Greene, 2009)- correspond to main units or domains, or pluri-kilometric extensions, typically observed when mapping at the 1 /1 000 000 scale. Starting from the shoreline and going towards the open sea, there are 4 mains units or domains encountered:

1) Continental shelf (in general : *continental and island shelf*) - code = S
2) Continental slope (in general : *continental and island slope*) - code = F
3) Rise (in general : *continental and island rise*) - code = A
4) Abyssal plain (in general : *abyssal plain and intraslope basin*) - code = P

(Abbreviation codes given here refer to first letter in CMECS classification)

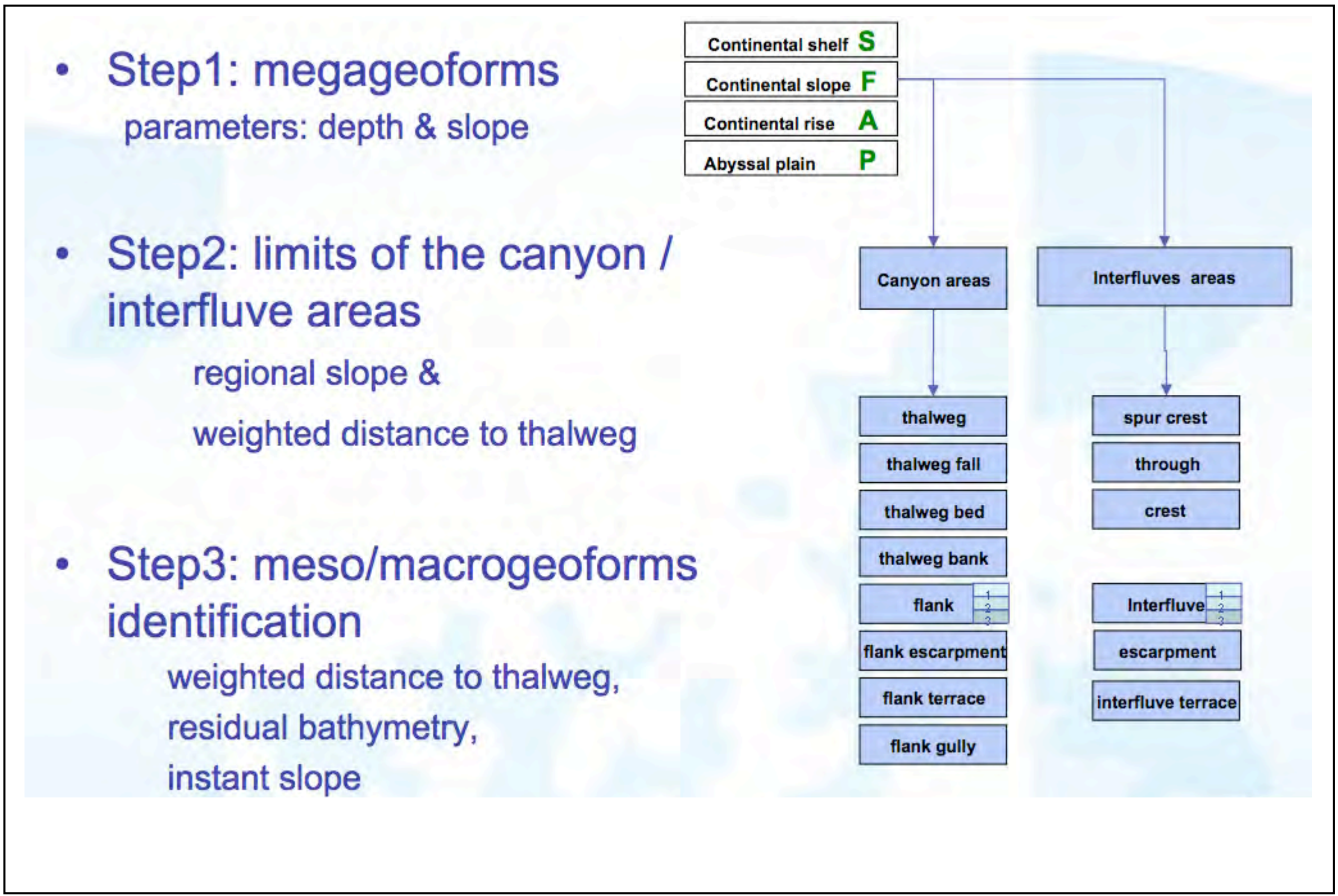

Figure 8 : General flowchart of the geo-morphological classification

The first limit to be determined corresponds to the shelf break or transition from continental shelf to continental slope. A slope limit of 2° (Bourillet & al., 1996), occurring around the -200 m depth (and with the condition for depth < - 180 m & slope >2° => inside continental slope), is used to produce this limit. It has been set so as indeed this limit is quite clearly continuous when using the *Medium (or hectometric)* resolution instant slope. Such threshold would have to be adapted for other areas.

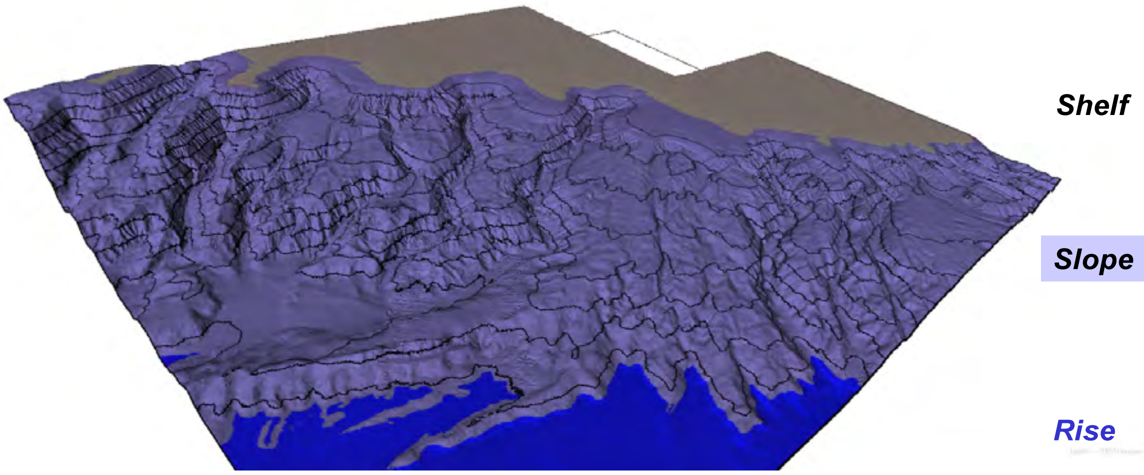

Figure 9 : Deterministic limits for the shelf break and slope to rise in Bob2 area
***(using { (** depth < - 180 m) & (slope_150 >2°) }) ; 500 m step isobathymetry contours*

Morphological selections are used to discard some "inside shelf" slope components higher than 2°, such as sandbanks, that can occur using the automatic condition.

The rise is the domain of channel type prolongation of canyons, with the siding levees (lateral deposition) when reaching more flat areas. For the transition from continental slope to the rise, the limit and rise domain can be obtained using a condition which fits well for the northern part of Bay Of Biscay: ***{ (*** depth < - 4000 m) & (slope_150 < 1°)} , as discussed in (Bourillet,2003) . Again morphological constraints must be taken to get a single continuous limit. Notice that the rise domain is reached only in Bob2 in this study. The full set of retained mega-geoforms is summarized in **Table 2**.

Table 2: Mega-geoform classification (1/1000000 scale)

Unit	Code	Greene	Morpho-sedimentary characteristics	Main morphologigal attributes	Typical accoustic signature	Relation to EUNIS[1] Relation to CMCES
Continental and island shelf	S	S	Summit of the permanently immerged part of the continental margin. Ranges from the coastline down to the summit of the shelf break. Area characterised by sedimentary processes related mainly to tidal/wave energy	Slope between 0 and 2 degrees on a regional scale. Water depth ranging between 0 and 200 m (generally)	Mixed backscatter	Circalittoral rock and other hard substrata (A4); Sublittoral sediment (A5); Deep-sea bed (A6) Continental shelf, island shelf (8)
Continental and island slope	C	F	Major escarpment, located beyond the shelf break, where sedimentary processes are mainly gravitary driven and canalised in canyons.	Slope above 2 degrees on a regional scale. Water depth ranging from few hundreds of meters down to more than 4000 meters.	Mixed backscatter (Generally strong). Artefacts are to be expected because of the slope and the quick variation of the bathymetry	Circalittoral rock hand other hard substrata (A4); Sublittoral sediment (A5); Deep-sea bed (A6) Continental, Island slope (6)
Abyssal plain and intraslope basin	P	P	Wide area basin characterized by an extensive flat area dominated by pelagic and hemipelagic draping and that are bordered by important breaks of slope from the adjacent sloping areas (continental rise or continental slope) Abyssal plain extend below the continental rise. Intraslope bassin extended large areas	Slope negligible Water depth below few thousand meters	Generally low backscatter values and draping signature on the seismic records.	Deep-sea bed (A6) Abyssal plain (3); basin floor, borderland (9)
Seamount, large bank and terraces (intraslope reliefs)	R	R	Seamount are local conical positive reliefs. Intraslope reliefs are positive features well distinct from the adjacent areas and can have different genesis (volcanic, tectonic,) Their elevation with respect to surrounding environments tend to enhance the current speed.	Relatively strong slopes, rapid variation in the morphology. Water depth ranging from those known from the continental slope to those known for the continental shelf.	Mixed backscatter. The strength is related to the nature of the processes from which they originate	Circalittoral rock hand other hard substrata (A4); Sublittoral sediment (A5); Deep-sea bed (A6) Continental slope, island slope (6); ocean bank (4)
Ridges	V	R	Positive structures, marked by a highly variable morphology and characterised by a relatively young seafloor	Varying morphology. Water depth of several thousand meters for the ridges, up to the coast for volcanic islands	High backscatter related to the nature of the seafloor. Seismic records and backscatter might	Vents, seeps, hypoxic and anoxic habitats of the deep sea (A6.9) Mid-oceanic ridge (2)
Continental and island rise	CR	A	Bottom of the continental slope characterised by a gentler slope where most of the sediment issued from the continental shelf and canalised by the continental slope are deposited.	Slope is gentle. Generally of the order of 1 or 2 degrees. Water depth is of the order of 2 to 4 thousand meters.	Mixed backscatter. Generally low. Seismic records will show numerous termination related to the different processes of deposition	Continental, island rise (5)

The respective surface areas and proportions of the (continental shelf and slope) partition in each box have already been mentioned in the Table 1. In the present study, classification of smaller scale geofeatures in the continental shelf has not really been extensively worked and can be considered out of the scope of this report. Besides, the DTMs produced here inherit lower resolution data in these areas (excepted possible contributions of more local models in some areas, used in previous sedimentologic studies).

A possible Intra- megageoform partition can be derived using the slope and specific classes to these low sloping areas, as the large sand banks present in the Manche entries.

4. Morphological elements present in the Continental slope

4.1 - Input of the HR data and first partition

Considering the continental slope of the Bay of Biscay, the «submarine landscape» is shaped by a succession of interfluves and canyons which deeply incise the termination of the shelf and passive margin. These canyons and tributaries can be clearly identified at several mapping scales: 1/ 500 0000 to 1 / 50 000. Hence, already in the previous systematic cartography and terrain modeling from the French EEZ in the bay of Biscay, which was run on the basis of a 125 m DTM, more than 130 canyons have been identified and named, it has been determined also that they are organized into 8 large drainage networks (Bourillet & al , 2006).

The better resolution brought by the last 2 BOBGEO cruises (2009 & 2010) - at 15 m or 25 m depending on the areas which was mentioned before does not bring a discovery of new canyons or drastically different view of the drainage network but instead will highlight some structures such as intraslope flats («terraces») or escarpments, falls and canyon banks, ... that can be delineated more accurately or even would not have appear at the 125m resolution scale.

On a physiographic point of view these canyons constitute the main path of currents (mainly of hyperpycnal or turbiditic types) and drainage system, they can be characterized as a convergent network that ends in the continental rise, where the canyon driven waters flows continue their path in a divergent channel system network.

The link with complex hydrology (geostrophic and tidal currents, swells, internal waves) and the morphological aspects of these canyons systems has not been yet directly investigated in this study and could be a future challenge since it is known to play an important role in determining benthic habitat distribution and development.

The classification work inside continental slope begins with a 4 subset areas partition for which delineation criterions will be detailed:

- The upper slope (including the more local «small mounds areas»),
- Canyon heads areas,
- Canyon areas sensu stricto,
- Interfluves

4.2 - Upper Slope and Canyon heads

As a transition after the continental shelf and near shelf break, one can define also two specific areas:

- **Upper slope** which are areas continuously attached to the shelf break, with an intermediate low slope (generally increasing with depth , from 2° to 5°) and above a threshold depth (- 500m to -700 m which can be tested and adapted according to the area) : retained criterion being the instant slope of trend bathymetry < 5° .

- **Canyon heads areas**, which occur in the beginning of mostly each canyon, where a serial of converging secondary thalwegs (with associated crests) are present.

  These areas often begin with a sharp and narrow slope break and slump scars indicating a landslide process.

  Ultimately, for a simplified version of classification these areas have been incorporated to the *canyon areas* sensu stricto. In fact they will appear with a predominance of narrow incised regions and the classification will still highlight them as crests and troughs from gullies will be clearly visible and identified.

A full view of BOB2 and zoom in the Guilvinec to Odet canyon area have been selected to illustrate these *canyon heads areas* in addition to the Canyon and Interfluves areas described next : Figures 11.a (global view) and 11.b (partial view).

No automatic process was in fact really found to robustly identify the canyon heads areas and these were just delineated by a set of digitized polygons, making the junction with identified canyons (for BOB1 and BOB2 only), then the idea of using these areas as a separate group of subclasses was abandoned.
More recently (January 2010) attempts have been tested for a possibly automated delineation of canyons heads once canyons are defined, with following method:

- Build a dilation area of canyons (from unweighted distance to thalwegs)
- Cross and restrict these areas to a given depth range (that may be different per canyon but set up by default to -900m)
- Ultimately discard the areas classified as upper slope

4.3 - Canyon / Interfluve inital partition

When looking at the canyon paths and, as side information to the bathymetric maps themselves, the *Residual bathymetry*, it appears that a subdivision can be first proposed between two other sets of large areas that can constitute a first partition of the continental slope:

- Mainly *incised areas*, which are the areas of the canyons, structured around the thalweg, bed and their immediate vicinity: flanks (sloping and where medium to high residuals can be found mostly everywhere). In terms of sedimentary geology these are the areas submitted to erosion and also stronger currents. These will be referred later as the ***canyon areas***.
  Some specific features such as: river banks (French names: *berges du thalweg*), falls (*chutes*), gullies (*ravines*), terraces (*terrasse*) ... are present in these canyon areas and will be defined and described later.

- None *incised areas*, which are the areas between the canyons, with a variable lateral extension depending on the areas (rather narrow to null extensions in the BOB1 area, more wide extensions in the BOB2 area). These non-incised areas can be defined also as locations where only low to null residual bathymetries can be found mostly everywhere. In terms of sedimentary geology these are also the areas submitted to less erosion processes and locally sedimentation. These areas will be designated later as *the* ***Interfluves areas.***

These areas being by definition more homogeneous in terms of seafloor rugosity, present less specific features than in the canyon areas and classification will be based mainly on average slope, one can find nevertheless features such as: crests and spur crest lines which are typically frontiers between different drainage (sub-) basins (*éperons, lignes de crêtes*); channeling systems that are also part of the drainage network but with much lower incision, terraces.
These components of interfluves areas will also be defined and described later (chapter 4.5).

The distinction between Canyon and Interfluves areas is illustrated for the Bob2 areas in **Figure 10**. Process to obtain this partition can be initiated by automatic methods, with two alternatives described further, but have been often then locally modified or simplified.

The process to define the limits of these canyon / interfluves areas was initially based on a conjunction of two criteria: first a corridor notion around the thalweg path, then criteria on rugosity and sloping of the flanks. More precisely, a DTM cell will be initiated as belonging to a *canyon area* if:

- 1° a cell is located with a minimal distance interval *Dist_c_min* towards the canyon thalweg path (without other condition), or for larger distances upto *Dist_c_max* , the second criterion is ensured (sloping & incised nature). These distances are chosen as a *Dist_c_min* = 1.5 km (for all regions) and *Dist_c_max* up to 3 km setup for the Bob1 & Bob2 areas, or even 6 km necessary in Bob3 area.

In order not to exaggerate the influence area around thalwegs in the upper part of continental slope or the vicinity of canyons heads, we have introduced the use of a ***weighted distance*** rather than the original distance to thalweg path which effect is to decrease (linearly with a smoothed depth function) the distance in the upper slope part - ie the -200 m to -1 000 m depth range.
This would have been equivalent to apply a variable cutoff on distance but has the advantage of keeping track of the transformation in a new target variable.
This was quoted and illustrated in chapter 2 – (see Figure 7).

- 2° for intermediate distances towards the canyon thalweg path (distances above *Dist_c_min* and below *Dist_c_max*) when the seabed bottom is significantly incised as in gullied flanks or steep flanks.
Two methods were proposed and used then to identify and fix the Canyon /interfluves limits.

Method 1: this was the first used (until end December) and it makes use of the variable *prop_res: proportion of bathymetric residual whose absolute value is above a cutoff (generally taken as +- 3m) within a 7*3 kernel neighborhood*. The strict cutoff on this variable gives sometimes too complex and non continuous limits; therefore morphological operations (opening + closures) were applied to obtain rather contiguous canyons areas.

Method 2 : this makes use of a very regional slope variable : slope from bathymetric trend at 2km, since we have noticed there is generally a slope break around 12 to 10° in the canyon flanks and such method can be more general and robust.
The canyon areas limits can be obtained using a multiple condition on the weighted distance to canyon function and on the slope from trend:

***{(distC**_w* < 1500 m) OR *(distC_w* < 6000 m) & (*slope_trend2k* < 10°)}
condition.

This was introduced and tested end December 2010 (and this corresponds to V2.4 internal reference version of classification, vs. V2.3 for method 1 after morphological cleaning). Comparisons of canyon limits obtained with these two sets of criteria are presented in next Figures.

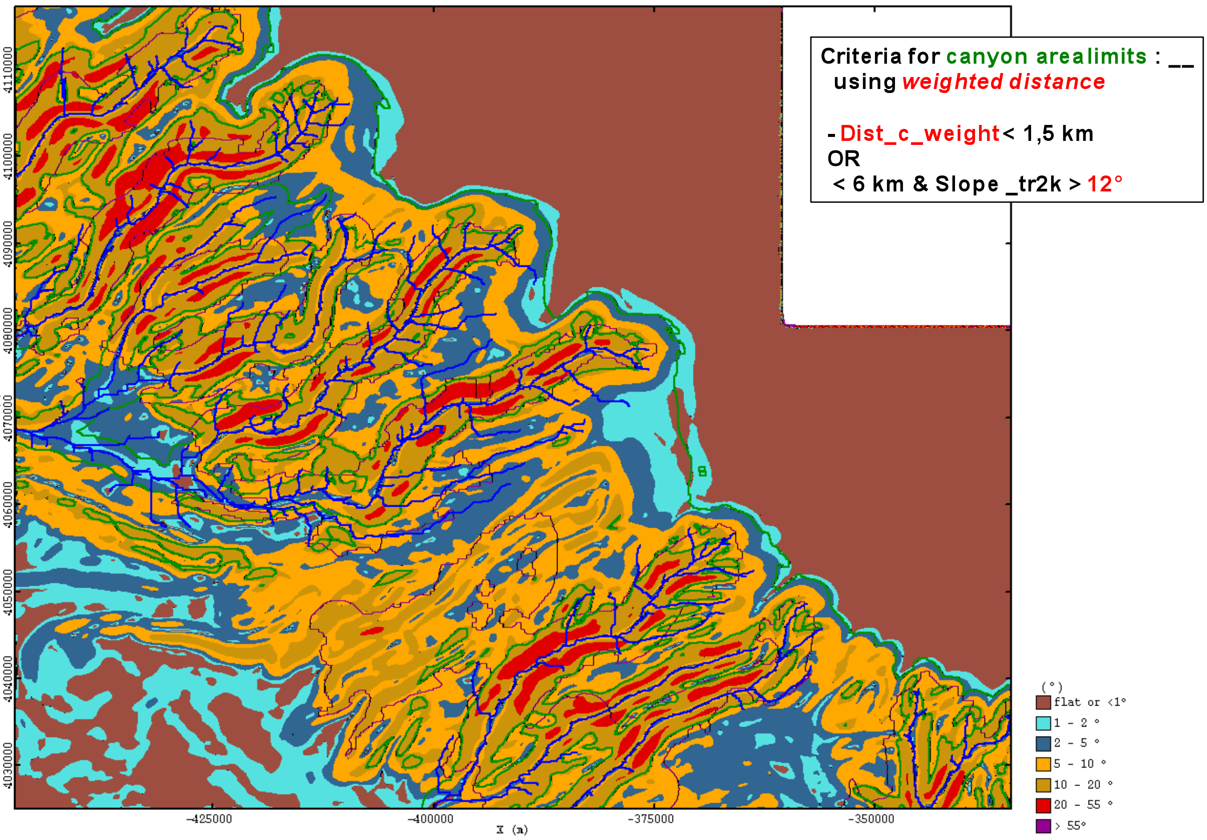

Figure 10 : Bob2 - slope from trend: *slope_trend2k* and Initial setup for the Canyon areas - condition for method 2
{(*distC_w* < 1500 m) OR *(distC_w* < 6000 m) & (*slope_trend2k* < 12°)}

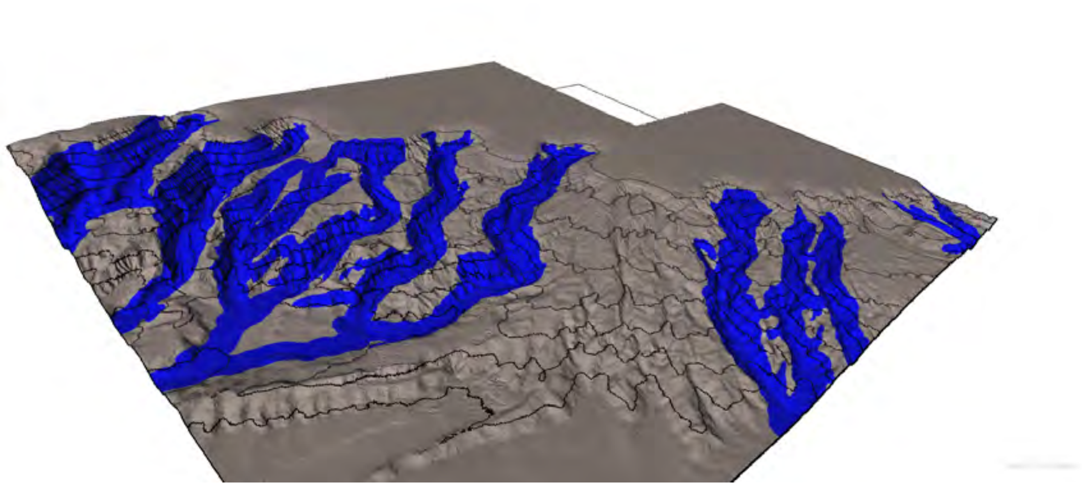

Figure 11 : Bob2 Canyon areas extensions (blue colored areas) based on «method 2» from trend: *slope_trend2k*

These appear as the ***green outlines*** on map, later the limits are edited to account continuity constrains and mask isolated elements, resulting limit gives the blue coloured areas in 3D view below.

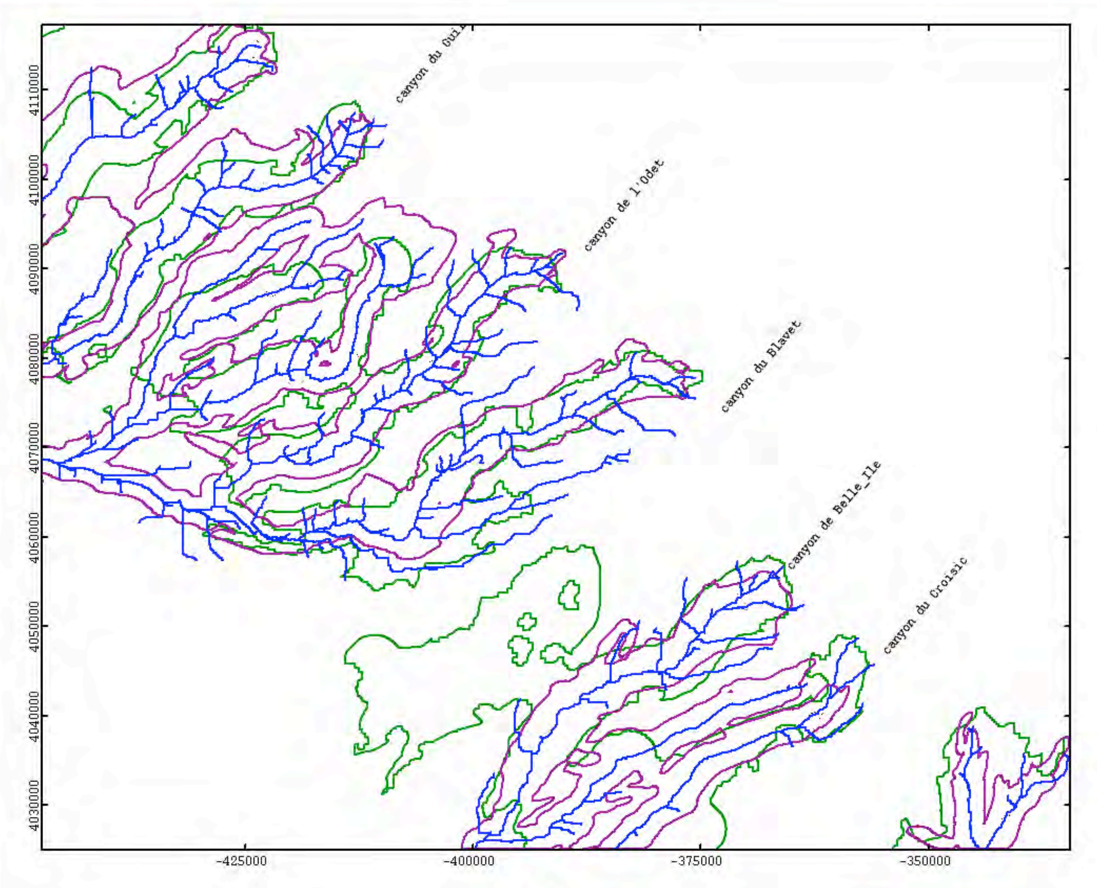

Figure 12 : Comparison of 2 versions giving limits for the Canyon areas in Bob2

green outline
{ (*distC_w* < 1500 m) OR *(distC_o2* < 2500 m) & (*Prop_res* > 10%) }
condition for method 1 (v2,3) , followed by morphological editing.

purple outline
{ (*distC_w* < 1500 m) OR *(distC_w* < 6000 m) & (*slope_trend2k* < 12°) }
condition for method 2 (v2,4).

4.4 - Morphological elements present in Upper Slope

Three classes have been defined so far in these **Upper Slope** areas. Two first specific classes (with corresponding *name in French*) are the following:

236 = mounds area in the Upper Slope *(zones de monticules dans le haut de pente)*

These areas have been seen from specific circular shapes visible mostly on the backscatter data, and corresponding to slight dome shapes with relative crests elevations approximately 3 to 5 m from the surrounding bathymetry and lateral extensions of around 100 to 200 m. These shapes can also be confirmed and have been analyzed in the Chirp sections. More details and comments can be found in the CoralFish 2010 Milan presentation.

237 = Crests of mounds in the Upper Slope (*sommets des monticules)*

Each of the individual mounds summits can indeed be found and limited from a cutoff on the residual bathymetry, with realistic results if the DTM is accurate enough. This is the case in some specific areas where the mounds have been initially found, East from the upper area of Guilvinec canyon for the main one, for which a 5m mesh DTM was produced (instead of overall 25m resolution for the overall model in Bob2 area).

In the case of the general 25m resolution model, the mounds crests have finally not been reported on the classification maps.

The remaining part of upper slope (which is the majority and does not belong to mounds areas) is classified with code 235.

4.5 - Morphological elements present in the Canyon areas

Twelve classes have been defined so far in these **canyon** areas. These classes (*with corresponding name in french*) are the following:

232 = thalweg from gullies (*Thalweg de ravines)*
231 = falls *(chute)*

230 = crest from gullies *(arrête des ravines)*

229 = escarpment (escarpement)

228 = flank - high slope] 20 - 40°] *flanc à pentes élevées] 20 à 40°]*
227 = flank - medium slope] 10 – 20°] *moyennes*
226 = flank - moderate slope [5 - 10°] *modérées*
225 = terrace (low slopes : < 5°) *terrasse (pentes faibles : > 5°)*

and within a ~500m proximity distance from canyon Thalweg :
224 = canyon bank *berges*
223 = canyon bed - medium slope] 10 – 20°] *Lit, à pentes moyennes] 10 à 20°]*
222 = canyon bed – low slope [0 – 10°] *Lit, à pentes faibles [0 à 10°]*
221 = Thalweg

Each class or item will be described together with its (semi-)automatic detection process and illustrated by pointing on some 3D views characteristical locations. A more global view for both the legend and the result before starting the individual description is provided on a 3D view for Bob2 area in Figure 13, next page.

Same views for the 3 other boxes will be provided in the next Atlas of morphological maps to be published (Bourillet, 2012).

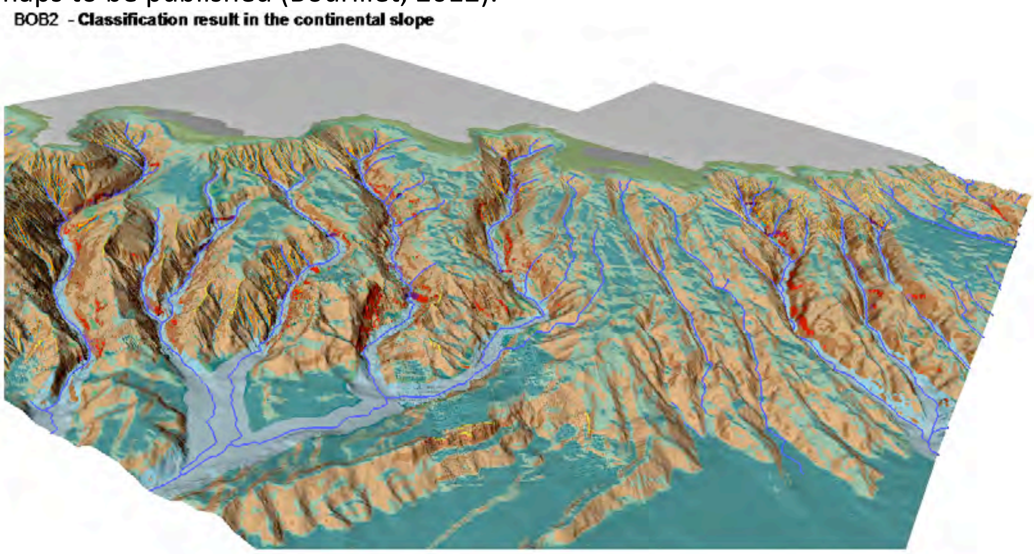

Figure 13 : BOB2 – Global view of classification map color coding the depth

Thalweg

Thalweg (CMECS code Fmc(t)_* ; internal code : 221)

This element is directly linked to the drainage network extraction and, once a distance to retained thalwegs has been computed (which is part of the necessary attributes used in classification), it can be determined using simple cutoff on this distance below the grid mesh. So {Dist_c < 10 m} will be the used criterion for the applied classification in all boxes. In the order of classification operations, it will be running (computing) as the last operation to overwrite all other previously determined classes and appearing as a continuous set of grid-cells.
Generally, the thalweg path also corresponds to a situation of negative residual bathymetry, indicating a trough. Nevertheless, in order to keep the thalweg continuity, such criterion of negative residual ({Zres < *0 m*}) initially applied together with the distance criterion was abandoned.

These thalwegs in the canyon areas have their upstream continuity in the Canyon heads areas - previously identified - with the corresponding classification code 211.
Else other thalwegs elements belong to interfluves, like secondary channels or juvenile canyons (which are not retained as main canyons), they can be also identified using a similar distance criterion. They will be recalled in the interfluves elements and receive the classification code 241. Thalwegs paths are represented in white on maps.
Proximity to the main thalwegs, which is also one of the available attributes linked to the classification, could be also interesting to be tested in habitat characterization.

Canyon beds

CMECS code Fmc(b)_c1*Fmc(b)_c2*; internal code: resp222 and 223

Within an approximately 10 to 500m proximity distance from these canyon thalwegs, we find the canyon beds. These are the relatively low slope areas contiguous to thalwegs. Two classes for these beds have been decided, based on the instant slope and for respectively [0 to 10°] and] 10 to 20°] slope classes. To correctly honor the slope break limit with the flanks, it is preferred to use the (*slope*_1) from filtered DTM rather than slope from the medium resolution DTM (*slope_150).* Considering typical canyon morphology in its beginning as the Odet canyon from Bob2 area, mapping of classes 221 to 223 is illustrated in Figure 14, for better visibility and understanding than in global view.

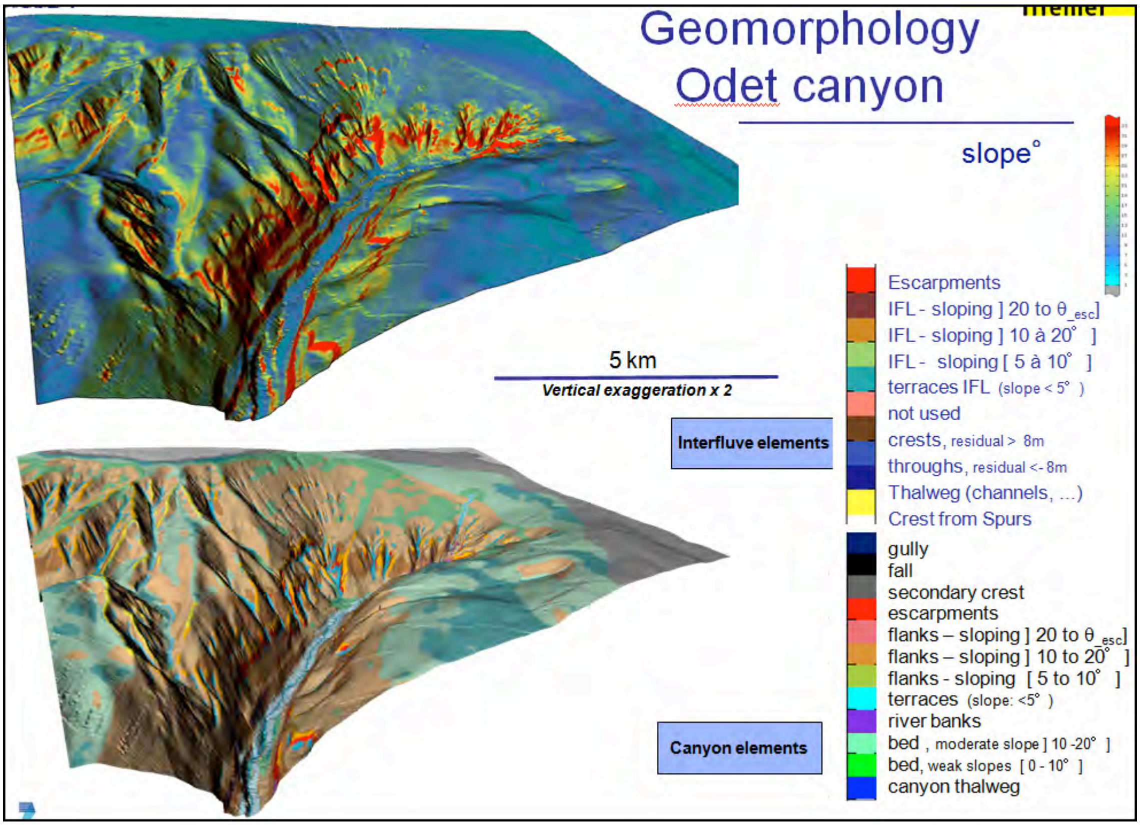

Figure 14 : BOB2 – Close-up and classification map Near Odet canyon heads

Using a variable function (of depth) for the distance threshold defining the beds

A further complexity has been introduced to take into account the fact that canyon beds are generally larger (often larger than the 500 m threshold) when reaching the base of continental slope and - equivalently- deeper part of canyons - below depths of ~ - 2500 m. Conversely the 500 m width threshold seems a bit too high when considering the beds upper the part of canyon. A predefined function that can be defined by linear transforms of depth (or trend depth to be smoother) can be used instead of the fixed 500m threshold on distance as given and shown in Figure 15. This was applied in the last revisions of classification (v2.4).

Using a variable function (of depth) for the distance threshold defining the beds

The formula used for the threshold was as:

(aux3) = distance max to thalweg for the canyon beds =
= 500 -300(3500+ Depth)/3000*
= ifelse (ge(Depth ,-500),200,aux3)

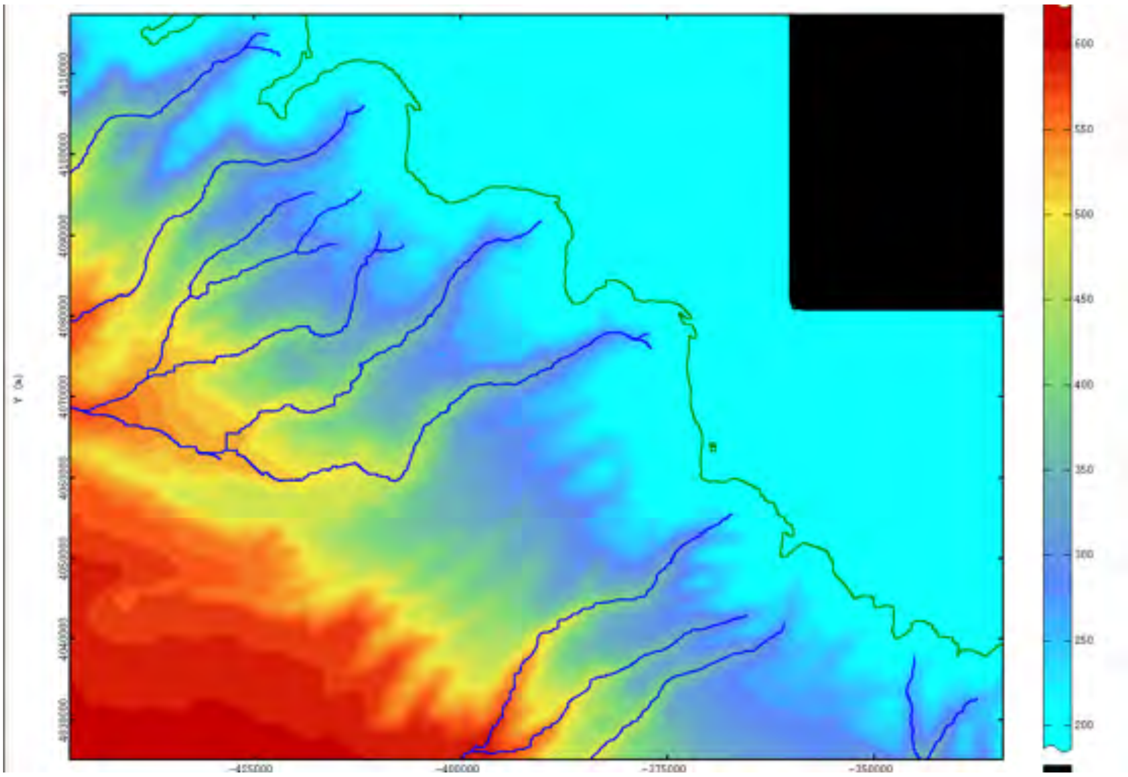

Figure 15 : BOB2 - Variable *« maximum distance to thalweg for the beds »*
(one can also use a constant as previous default = 500m)

In order to maintain «contiguous beds» (contiguous to thalweg), it is also necessary, after a first step, to discard (and hence reclassify in flanks or internal terraces) the «bed cells» that are disconnected to the main canyon thalweg. This is possible if they still have a relatively low slope (<20°) closer than 500m from thalwegs. However, when some first abrupt canyon edge (ie a close bank) disconnects them from the thalweg, this is done by using the connex component search algorithm applied to these classes.
Two other specific elements, presenting strong instant slopes, can be present nearby the canyon path or thalweg (at a maximum distance of 600 to 800 m), these are banks and falls. They will be further developed right after in the next paragraph.

Banks

Banks ("berges" CMECS code Fmc(b)_*; internal code: 224)

These are areas of strong local instant slope (*slope_1* variable): > 40 ° in Bob1 or 38° for the other Bob2 to Bob4 areas) and which remain close and sub-parallel to the thalweg.
The term *river bank* is often used for such steep limits of a river in fluvial and land geomorphology. It also marks a boundary in current regimes (at least when speaking of fluviatil flows, measurements and proofs are of course much difficult to obtain in the submarine domain) and erosion processes.

These banks can appear directly juxtaposed to the bed, or in between and one can find medium slope flanks start (with average slope in the 20° to 38° interval) that will be another class (228). In the case of a very narrow and incised canyon thalweg as in the start of canyon Blackmud, these banks can directly be along the thalweg itself (meaning an absence of bed, which must be understood at the DTM resolution - 15 m in the present case).

Then, within a 600m distance from the thalweg:

Falls

Falls ("chutes" CMECS code Fhc(f)_*; internal code:231)

Still with strong to very strong instant slopes and within a proximity distance from the canyon path (retained threshold = 600 m), one can find falls which have a semi circular shape as can be observed on the land surface morphologies of mountain areas or when a river or thalweg has incised and crosses a rather thick consistently hard geological layer resulting in waterfalls – the most famous being probably the Niagara falls. Without being as large these, the falls in the Bob continental slope have a typical 500m to 1km broad extension across the canyon path and the vertical drope (*waterfall height* if we were on terrestrial morphology) can be of ~50 m to a few hundred m. They are also the testimony of a regressive erosion process ie from downstream to uphill.
The most striking and developed falls (presenting also the higher drop) are encountered in several main canyons from the Bob1 area, with up to 3 main generations of falls encountered along the canyon paths.

Such falls also exist but with lower fall heights on Bob2, they are nearly absent (just one small occurrence) on Bob3 and totally inexistent in the Bob4 area which is much smoother.

The setup criterions to define initially a possible fall region are as following:

- local slope (HR : from filtered DTM) above 45° (& 50° for Bob1)
- distance to canyon's thalweg < 600m
- Zres > 0 (only the upper part of semi circular shape is considered)

For the distingo between the banks and the falls elements that can be steep also, one uses the fact that *fall* class is defined sequentially after. But this automatic criterion is not enough to correctly classify between these 2 sets and the subdivision Banks / Falls remains subject to interpretative supervision / modifications in order to reflect the parallel to canyon path (case of banks) or transverse and with semi-circular shape (case of falls) elements preliminarily identified as connected components.

Then finally, as some grid cells have not been identified in these thalwegs proximity, 3 classes will be classified as:

- flanks (general case) with 3 sub-classes according to the medium resolution instant slope (*slope_150*)

- escarpments for elements with strong slope (HR slope > 38 °) but located at a distance more than 600 m from the canyon thalweg and elements from gullied canyon heads or flanks
- gullies in which the decametric (15 to 25m) resolution enables to distinguish the Crests and Throughs - which will be detected by the residual bathymetry.

Intra-flank Terrace

Intra-flank Terrace ("terrasses" CMECS code Fmt_c1*; internal code: 225)
« terrasses « : zones à pentes faibles : pente < 5°

{cond : slope 150 < 5° AND not belonging to beds (~=> distc < 500m) }

These are elements presenting a low slope: < 5°, and actually we use the *slope_150* attribute for this class, which gives simpler classes outlines.
One can notice that such intra-slope terrace morphology is a rare and very specific situation in the flanks. The corresponding slope class is of course much more present and developed in the interfluves.

Canyon flanks

Reference: CMECS code Fmc (f) _c1* Fmc(b)_c3* ; internal code :resp. 226 to 228)

Other elements from the canyon flanks correspond to a set of 3 slope classes, with predefined cutoffs and generated automatically when other classes are not present.

228 = flanks with high slope] 20 - ~ 40°] *flancs - pentes élevées > 20°*
227 = flanks with medium slope] 10 – 20°] *moyennes*
226 = flanks with moderate slopes [5 – 10°] *modérées*

Together with the terrace areas, these represent the background classification (by default), when no specific element is determined. It can be generated also as a first initialization map for the classification.

Escarpment

Escarpment («escarpement» CMECS code Fhs_ c4*; internal code: 229)

Within the *high slope class,* elements with an instant slope (from local DTM: *slope_1* and not from the medium resolution slope as used for other classes setup) above a threshold will be retained as a new class: escarpments.

This threshold has been chosen as 38° in all boxes (initially 40° for Bob1 but finally reset to 38° for global consistency). Therefore, considering this threshold one can say that a grid node belongs to 1 out the 3 specific classes:

- banks (canyon banks when close and parallel to thalweg)
- falls (specific semi circular shape across canyon path) – with often slopes above 45°
- *escarpments* for the other elements

Generally speaking, there should be also cleaning and morphological constraints on the escarpment elements which are generally rather thin. In fact this has not been done yet since non major problem or non consistent escarpment was noticed, due to preliminary DTMs filtering and consistency checks.
One can say that such a high cutoff value adopted (~ 40°) let when the DTM is consistent and of a good resolution appear components with geological and morphological continuity.

Besides, such high slopes can be also found locally in gullies areas, and therefore in order to make them appear specifically, 2 other classes based on residual bathymetry are designed.

Gullies crests and Gullies Throughs

Gullies crests («crêtes de ravines» CMECS code Fmg_ c2+*; internal code: 230)
Gullies Throughs («creux de ravine» CMECS code Fmg_ c2-*; internal code: 232)

These classes based on residual bathymetry are designed to reflect the crests and secondary thalwegs (mostly from order 1) from the side canyon gullies.

For this, in an initialization run, a cutoff *Zres > Xm* for crests and *Zres < - Xm* for secondary thalwegs is considered on (filtered) residual bathymetry from the 150m averaging radius. As it is in journal file, the cutoff is made as a preliminary constant variable (X) and can be tested / adjusted for the different regions.
The cutoff was taken with default value at X=9 m (applied in all boxes) and X=10m in Bob3 which gives slightly « better resolution » (thinner yet contiguous) in these crests and thalweg elements.

These elements, as other specific classes (banks: 224, falls: 231,) once predefined in an initialization run will be tested for their morphological consistency and isolated too small components can be removed and reclassified in a second run.

A more immediate « cleaning » and simplification option consists in keeping these specific elements only in the HR part of the DTM, meaning possible artifacts residuals seen in the rest of grid will not be taken into account. This was the retained option for the Bob2 and Bob3 boxes.

4.6 - Morphological elements present in the interfluves areas

For the recall, interfluves areas are, inside the continental slope, defined as the complementary from canyons and upper slope areas. They are by definition the external parts besides the canyon flanks.
Ten (10) classes have been defined so far in the **interfluves** areas. These classes are organized in the same way than for the canyons, but with less specific elements. The

list is the following with the associated CMECS code (green), internal reference code and initial setting condition based on attributes *{cond}*.

Notice that the conversion / association of a CMECS (green) code is not obvious since in the F [F = Flanks, continental slope, basin/island flanks (200-3,000 m)] Megahabitat type, the interfluves are not especially distinguished from canyons as group of geofeatures so this distinction is in fact more present in the (3rd character) meso- or macrohabitat types

c = canyon
d = deformed, tilted and folded bedrock
e = exposure, bedrock
f = flats, floors
g = gully, channel

The list of retained and proposed classes is as follows:

240 = Spur crest within interfluve *(crêt isolé d'éperon)*
241 = Thalweg

242 = Through (eg channel) - low residual *creux, à résiduelle <- 8m*
243 = Crest within interfluve - high residual *Crêt, à résiduelle > 8m*
(not a main Spur crest line)
(244 internal codes is not used for the moment)

245 = Terraces area in interfluves (slopes < 5°)
246 = Interfluves - moderate slopes [5 – 10°]
247 = Interfluves - medium slope] 10 - 20°]
248 = Interfluves – high slope > 20, but local HR slope < escarpment slope

249 = Escarpments (within interfluves)

240 = Spur crest within interfluves *(crêt isolé d'éperon)*

These elements are typical from the interfluves and probably also significantly specific habitats because they are specifically the frontiers (“crest lines”) between main drainage basins -or sub basins.

Their morphological signature corresponds to specific continuous lines of high residual bathymetry (medium scale: *Zres_150*).

A simple cutoff on residual bathymetry (eg Zres > 8m) would not be enough to identify and extract these elements since other grid cells (nearby channels, proximity secondary or minor gullies areas (still classified in interfluves) can have the same property.

Hence we have added two conditions for spur crest class definition:

- there should be no (or very few) surrounding cells with negative residuals , condition which is performed using a proportion variable for residual

bathymetries below a -3 m cutoff (variable *prop_resNEG*)
- the elements must have a linear continuity and significant size

Therefore, after a first initialization run

{cond : Zres _150 ≥ 8 m AND prop_resNEG < 5% }

The resulting components of this class are scrutinized and some declassified.

Another simpler algorithm we used lately (June 2011) consist in checking that the high residual components are indeed in the vicinity of a local maximum depth in the MNT for a large window exploration size .

249 = Escarpments (within interfluves)

{cond: local HR slope ≥ escarpment slope }. Yet the slope cutoff has been kept same than in the canyon areas: 38° for Bob2 to Bob4 and 40° for the Bob4 area).

These are generally absent from the interfluve, unless the case of a (transverse to canyon direction) lateral prolongation of an escarpment present in the canyon area. Last figure of internal code (9) and color: in red, are kept similar.

241 = Thalweg (within interfluve)

These secondary thalwegs are from much lower incisions than the canyons (else the area would have been classified as canyon area), but can correspond to either juvenile or non active older canyon, or to channels in the interfluves.

So they can be extracted as part from the secondary drainage network. In practice the variable *distc_o2*: distance to thalwegs of order >= 2 all over the DTM (excepted possibly removed artifacts branches) is used, still with cutoff <10m on this distance, to extract this class.

242 = Through (eg along channel) - low residual *creux, à résiduelle <- 8m*
243 = Crest within interfluve – high residual *crêt d'interfluves (hors éperons)*

The crests and throughs in the interfluves have the same logical meaning than in the canyon areas, meaning that they are based on organized (or contiguous) residual bathymetry above (crests) or below (throughs) a cut off. In practice and due to much less incised nature of interfluves, these features should occur much less frequently. Also the cutoff is chosen below to the corresponding one in the canyon areas (eg 8m for canyon areas, vs. 6m for interfluve areas as we used generally).

In the case of crests, they would correspond to local crests other than the main Spur crests.

The other cells, unless specific elements described before (channel thalwegs, Spur Crests and areas with specifically high or low residual bathymetries: local crests or local throughs) will be classified according to the medium resolution slope variable (*slope_150*), which gives 4 classes as equivalents in the canyon areas:

248 = Interfluves – high slope > 20°, but local HR slope < escarpment slope
247 = Interfluves - medium slope] 10 - 20°]
246 = Interfluves - moderate slopes [5 – 10°]
245 = Terraces area in interfluves (slopes < 5°) which by definition are predominant

The last two classes will correspond to the predominant morphology in the interfluves.

These “non specific elements” cover more than 50% of the interfluve area for instance in Bob2 and correctly describe the more gentle morphology inside the interfluves. Yet it would be possible also to split differently the region, using lower slope classes, but the visual effect and colors transition with canyon areas appeared somewhat confusing and we finally preferred to stay consistent in the slope based classes for both regions (interfluves and canyon areas). In the same principle the color classes’ are kept close.

5. Summary of main morphological aspects on the 4 BOB areas

5.1 - Qualitative morphological aspects on the 4 BOB areas

Bay of Biscay is constituted of 130 canyons distributed into 8 large drainage basins (Bourillet, 2003) from the South West of Ireland to the French/Spanish border.
In terms of relative coverage the following global statistics per each of the four zones were initially summarized in Table 3.

Bob1 and Bob2 boxes areas concern respectively the Northern and central part of «Amorican margin» of the Bay of Biscay, they cover ~6 000 km² each with respectively 2930 and 3250 km² of informed DTM when considering the initial high resolution data (the rest being merged with regional model). Both present a succession of spurs and broad canyons, but organization and morphologies are different in several aspects: Interfluves and spurs are less developed – or in other words canyons closer one to the other - in the Bob1 area than for Bob2. This can be related as main factor to the proximity of the Western Channel Approaches and active strong currents during the glacial stagesBob3 (southern Amorican margin) and Bob4 (Aquitan margin) areas concern the southern part of the Bay of Biscay and they cover respectively ~ 600 km² & 7000 km² with 726 and 972 km² of high resolution data. Narrow and steep canyons characterize the area Bob3. The Rochebonne, Aiguillon and Ars canyons present an incised morphology but more gentle than those in areas Bob1 and Bob2 (Figures 18 and 19).

The higher density of canyons when counting them following the shelf break from North to South in a given area is also stronger in the BOB3 area as for BOB1 and this can also be reflected when comparing the overall % of the interfluves (lower there) classified areas within the continental slope.

One of the most striking feature concerns the highest escarpments and falls that are encountered along and across canyons, these are mainly inside the Bob1 area, with up to 3 main generations of falls encountered along the canyon paths, (Bourillet & al., 2010; Veslin, 2010). They are really visible on Black Mud Canyon (and Lampaul Canyon) as we can see on the graph below.

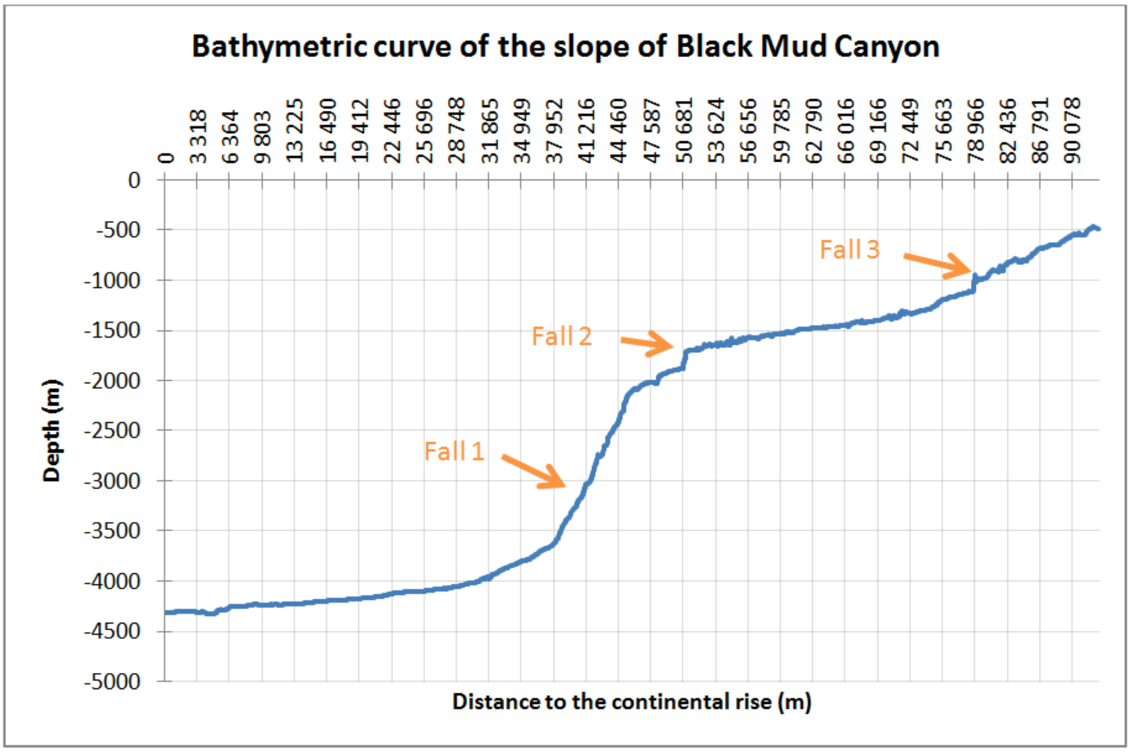

Figure 16: Bathymetric profile of Black Mud canyon

Such falls also exists but with lower falls heights on Bob2, they are nearly absent (just one small occurrence) on Bob3 and totally inexistent in the Bob4 area which is much smoother.

Flanks are constant, with sediment and gullies. Thalwegs are continuous with gentle banks. A major difference between Bob1 and Bob2 areas is the absence of flat and escarpment, or steep banks and falls, favorable to coral settlement.

One can note also that the canyons become straighter more we go in the South and some are more convex than another like the Canyon of Cap-Ferret.

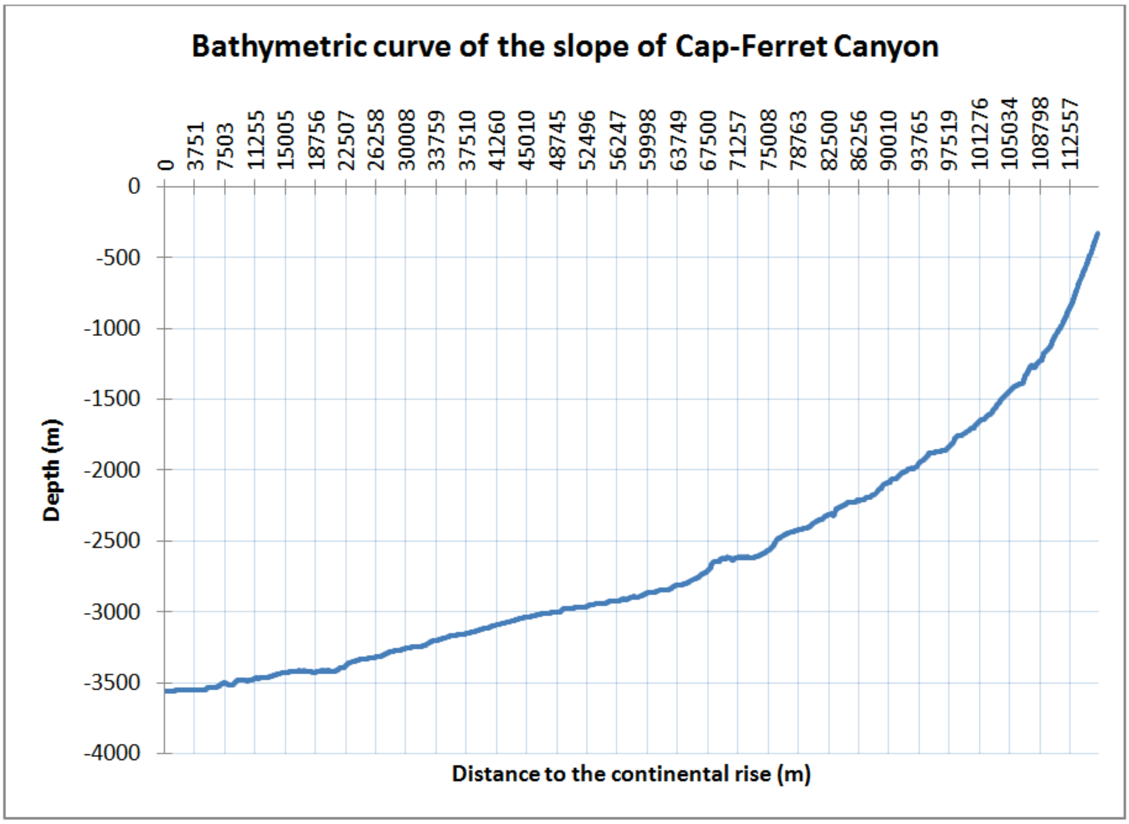

Figure 17: Convex type profile of Cap-Ferret canyon

Arcachon canyon in the Bob4 area presents a quite different morphology with a broader canyon thalweg and very gentle flanks, and neither gully nor escarpment. It looks like a channel-levee system. This canyon is the longest in all the Bay of Biscay following by the canyon of Cap-Ferret and the one of Blavet. Note that we have significantly increased the extension of the area for taking into account the Southern upstream and northern junction with the cap Ferret canyon.

All these informations will be used to create a map with Isatis for each area. 2 examples will be presented below for BOB 1 and BOB 2.

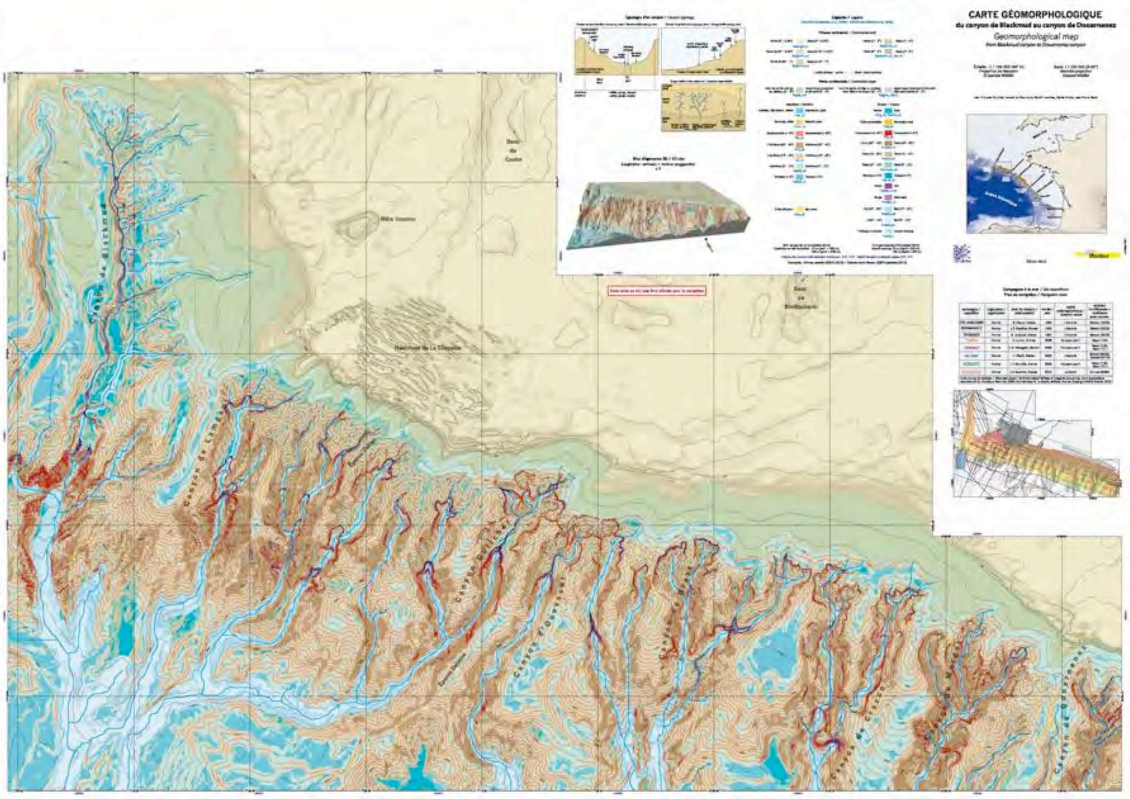

Figure 18: Geomorphologic map of BOB 1

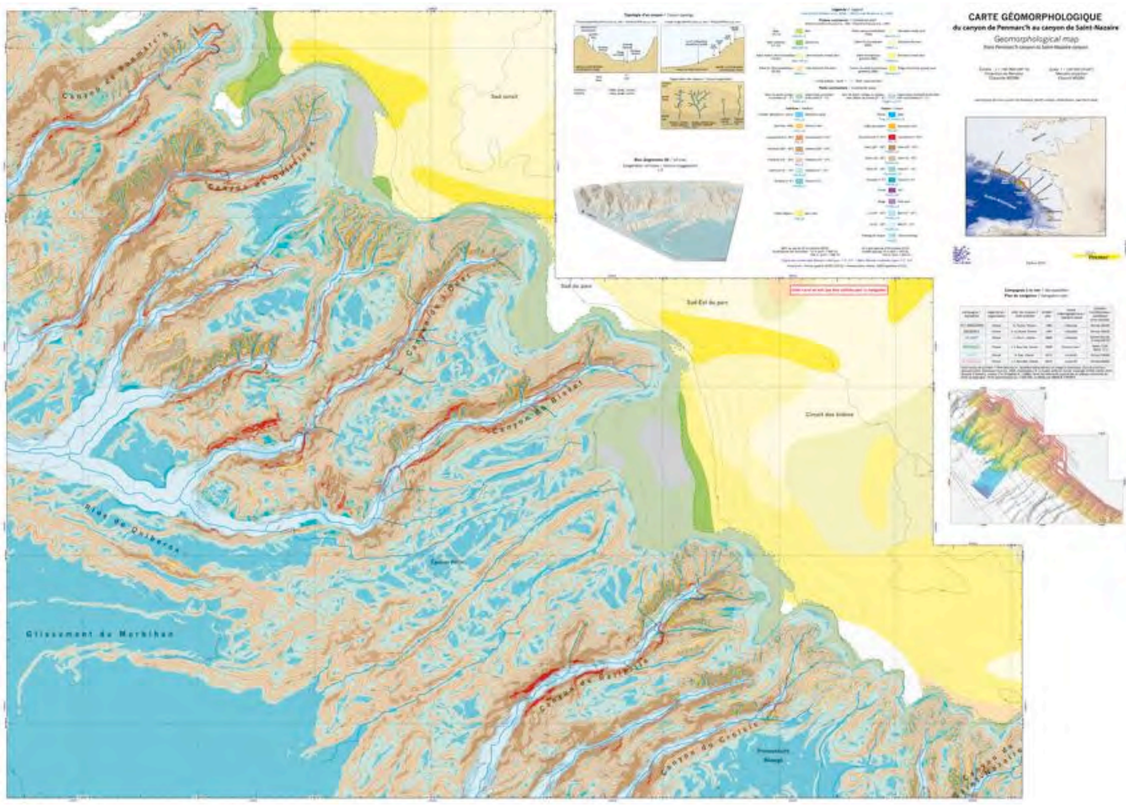

Figure 19: Geomorphologic map of BOB 2

We can go further in the analysis of the seabed with the study of HD videos with the software Adélie © Ifremer. The investigation was focused on the canyon of Lampaul. The analysis of the seabed geology of the Bay of Biscay shows that the falls are mainly constituted of basaltic (Figure 20) and calcareous rocks (for the others). Most of them are kind of turbiditic rocks (Figure 21).

Figure 20: Basaltic rock constituting the Lampaul canyon's fall

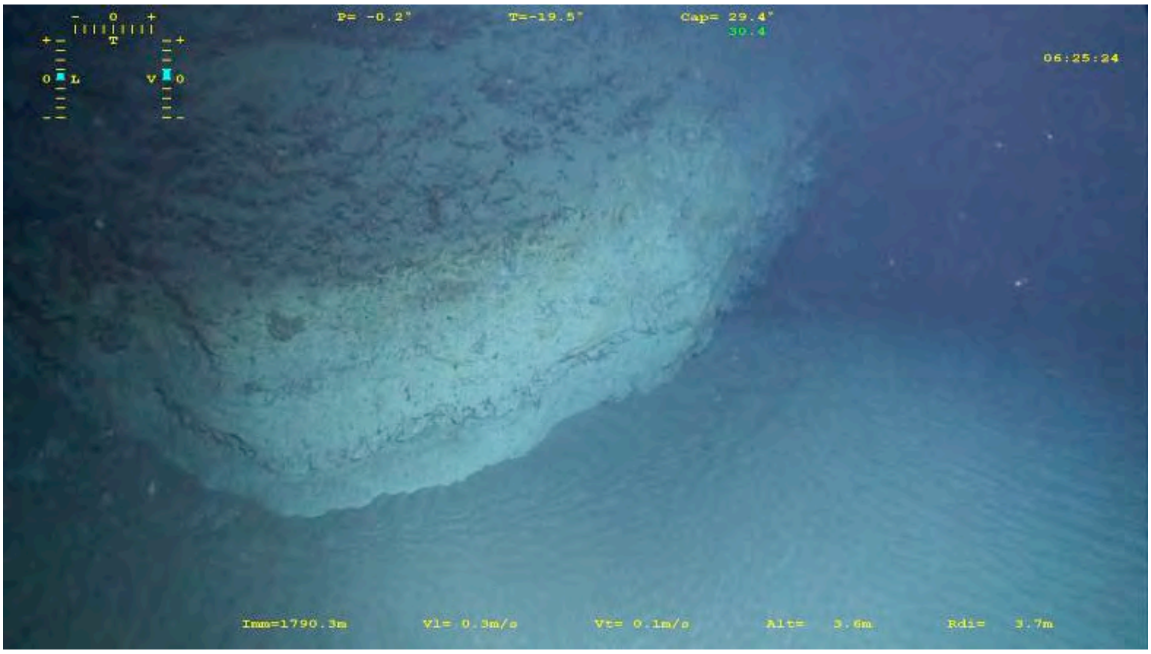

Figure 21: Turbiditic carbonate rock from the Lampaul canyon's fall

On the seabed, some different kind of ripples can be seen: most of them are lingoides type and straight type (Figure 22). They are visible within the thalwegs and on the stairs of the flanks (Figure 23). We can find also parallel ripples and sinuous ones.

Figure 22: Bottom of thalweg with debris and linguoides and straights ripples

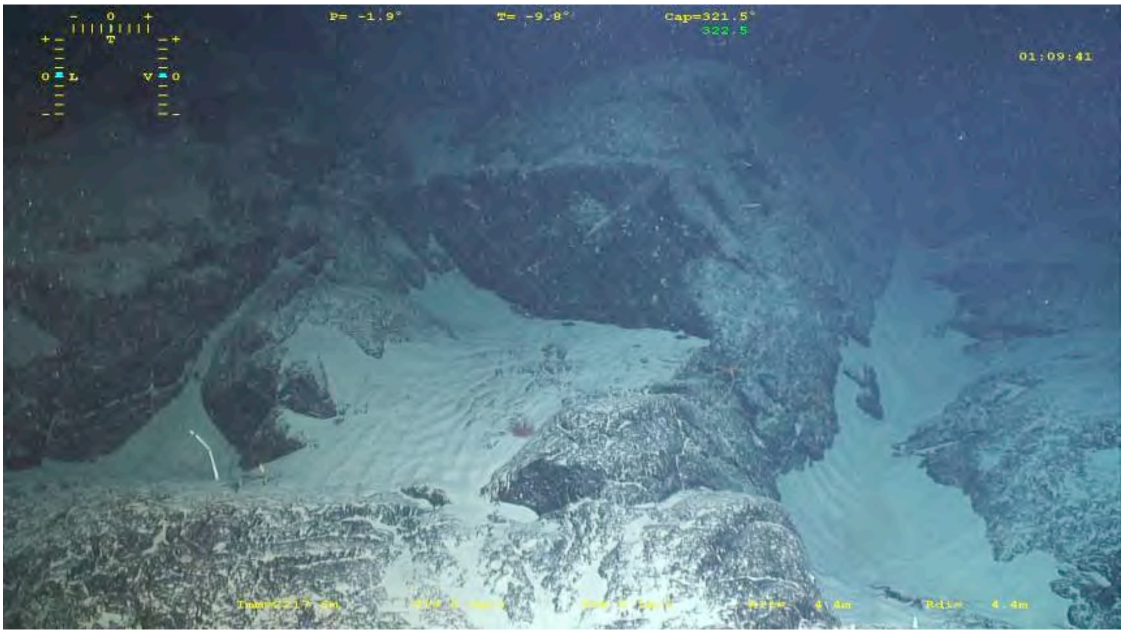

Figure 23: Linguoides ripples inside the stairs of flanks

5.2 - Quantitative morphological aspects on the 4 BOB areas

It is interesting to analyze the results of these classification in a comparative way, for instance in comparing the different covered areas and percentages for the main areas (as interfluves vs. Canyon areas). See table 3 below

Table 3: Summary of the Continental Slope characteristics (in percentage and km²)

	BOB 1	BOB 2	BOB 3	BOB 4
Upper Slope area (%)	13%	6%	2%	2,7%
km²	693	377	26	120
Canyon area (%)	47%	34%	71%	48%
km²	2690	836	1111	2137
Interfluve area (%)	38%	60%	26%	50%
km²	2057	1470	405	2217
Total Continental slope	5 440	6 782	1 542	4474

This table is quite interesting because we can see well the percentage of both parts of the continental slope. Thus, BOB 1 and BOB 3 are the areas which are the most important in canyons and at contrario the interfluves surface is the lowest. However the Upper slope percentage is different for these 2 sectors because it is wide for BOB 1 (the biggest) and it is the lowest for BOB 3 due to a really low continental shelf/canyon distance.

BOB 2 is the total opposite as the interfluves area is bigger than the canyon area. It includes few canyons with wide interfluves.

BOB 4 has its percentage between interfluves and canyon which is almost equal with a very low upper slope. This canyon presents two distinct sectors: the Northern part with Cap-Ferret Canyon similar to the BOB 3 morphology; the Southern one with one single canyon “Arcachon” and very gentle continental slope.

This can be done also then for each specified morphological class as in the canyon areas or for the interfluves.

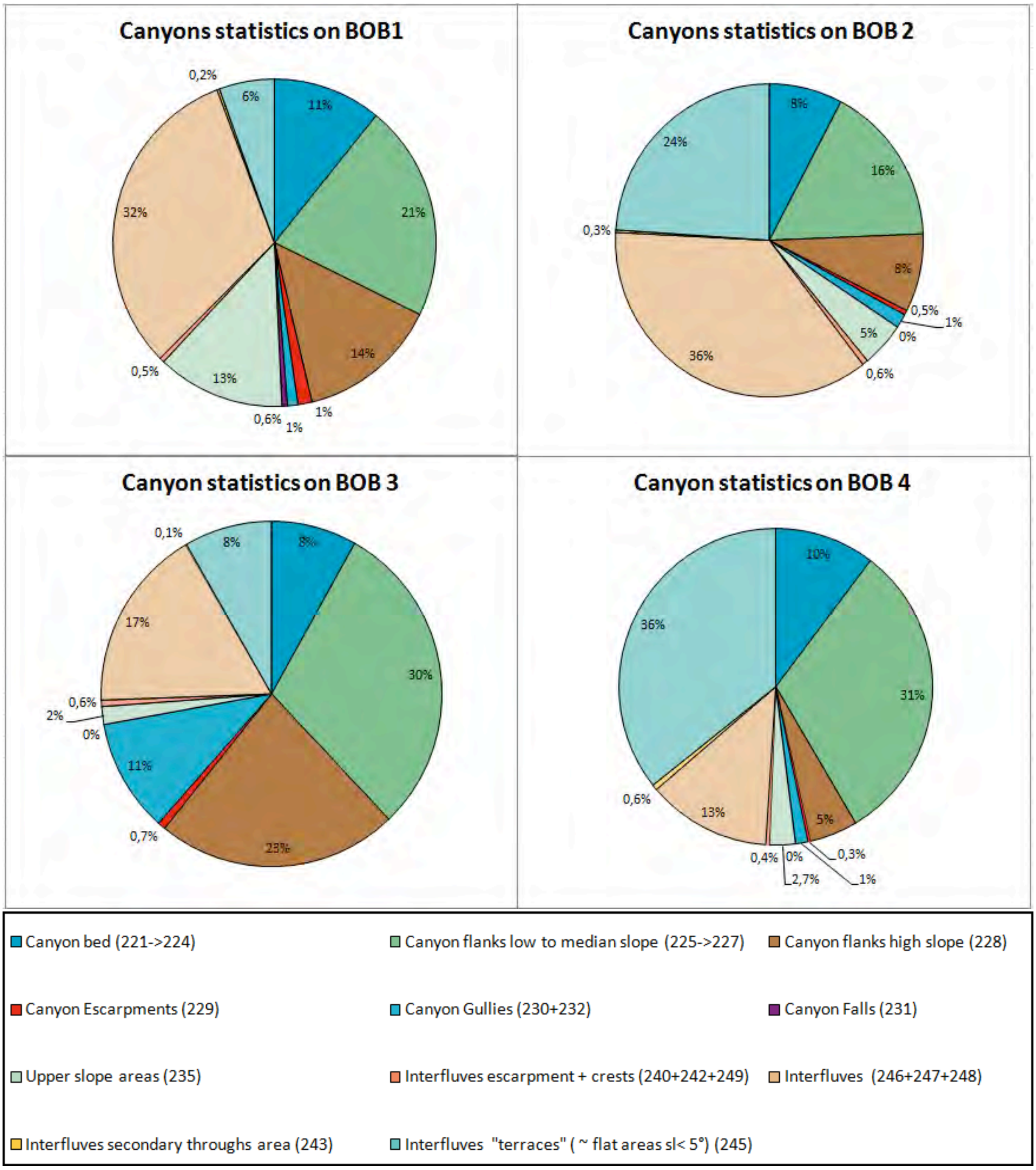

Figure 24 : Frequency (%) per morphological class in the 4 boxes for the canyon areas and for the interfluves areas

Some comments about the Figure 24:

In BOB 1: a wide upper slope area contiguous to the shelf is observed meaning a continuous shelf/slope transition. Canyons and interfluves are well balanced. The canyons' part is equally distributed between bed, flank and high slope; escarpments are present. Falls are notable features of this area. The interfluve section is characterized by medium slopes.

In BOB 2: interfluves are predominant firstly with the medium slopes class and secondly with the terraces class. Canyons are wider but few which explains the really low percentage of bed and flanks. Escarpments are still present but in a lower percentage and falls have already disappeared.

In BOB 3: Canyons (thalwegs + flanks) are dominant. Gullies are quite developed in this area and escarpments are still visible.

In BOB 4: Low slopes interfluves and terraces are predominant and canyons' section is dominated by low to medium sloping flanks. Falls and escarpments have almost disappeared.

5.3- Links of classification with corals (CWC) settlements

Coral rubble and small mounds

Large carbonate mounds similar to Belgica or Arc mounds in the Irish Porcupine seabight have not been found throughout Bay of Biscay, but some regions of the upper slope include small mounds. These have been found mainly in the Bob2 area and discovered using the high resolution (10 or 5m) backscatter and DTM models. These will have been identified as a specific meso-habitat and classification item.

Indeed, recent 2009 & 2010 surveys have show evidences of small mound areas, very localized near the shelf break and upstream from main canyons heads such as Guilvinec or Odet Canyons. These are highlighted from high resolution multibeam echosounder data providing bathymetric and backscatter or reflectivity models.
Typicallyy, these mounds occur at -180 to -500 m depth, with extensions of 50 to 150 m and relative elevations to the average seabed bottom ranging from 1 to 7m (de Chambrure et al, 2010).

CMECS literature (Madden et al, 2008) describes some typical corals environments that we can refer to as they have been encountered at various locations in the Bay of Biscay upper slope and continental slope. These are namely:

- *Reef Rubble* **-** Dead, unstable coral pieces. This habitat often occurs landward of well-developed reef formations in the reef crest or back reef zone. In the case of Bay of Biscay, these were found on or nearby small mounds that are present at the vicinity of some canyon heads as Guilvinec and Odet canyons (these have been mentioned as specific morphological class in the upper slope).

- *Deep Coral Reef* **-** Non-photosynthetic coral formed in deep waters averaging 70-1000 m. Deep-water coral reefs typically consist of thickets of live coral atop unconsolidated sediment and coral rubble, usually on an underlying rock base structure. Deep reefs are found in strong currents or upwelling zones. In the case of Bay of Biscay, these have been found on some canyon flanks; they are also rather limited in extensions (Figures 25 and 26)

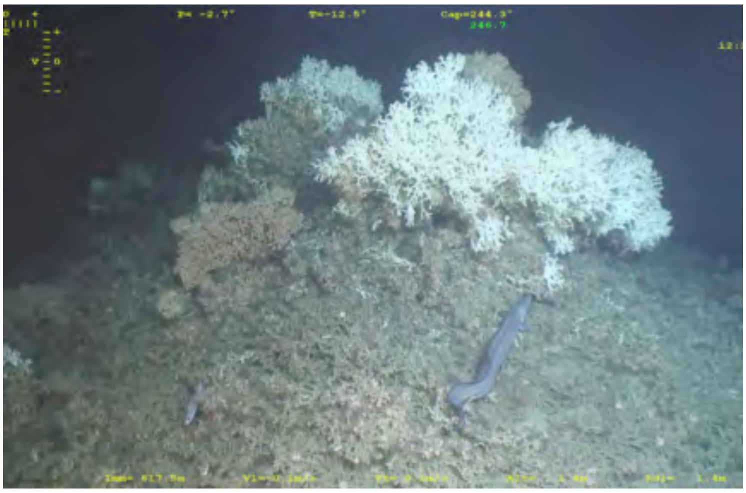

Figure 25: Living CW coral reef

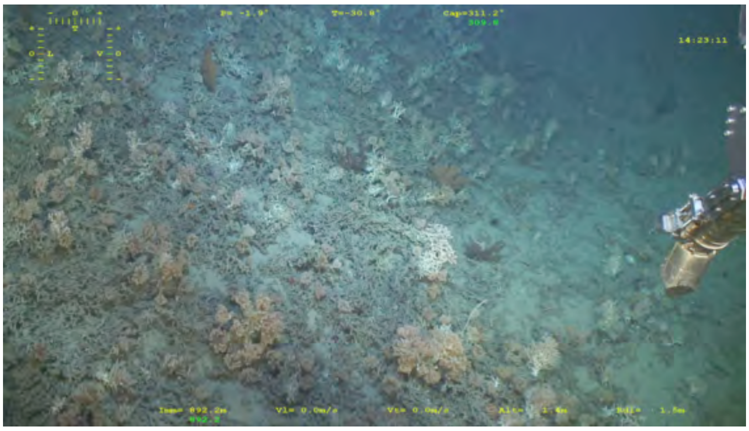

Figure 26: Colonized CW coral reef

- *Scattered Coral/Rock* - Scattered rocks or small, isolated coral heads that are too small to be delineated individually (*i.e.*, smaller than individual patch reef). They can represent continuous occurrences on some canyon flanks as was observed during scampi dive # 7 during the Bobgeo cruise (Figures 27 and 28)

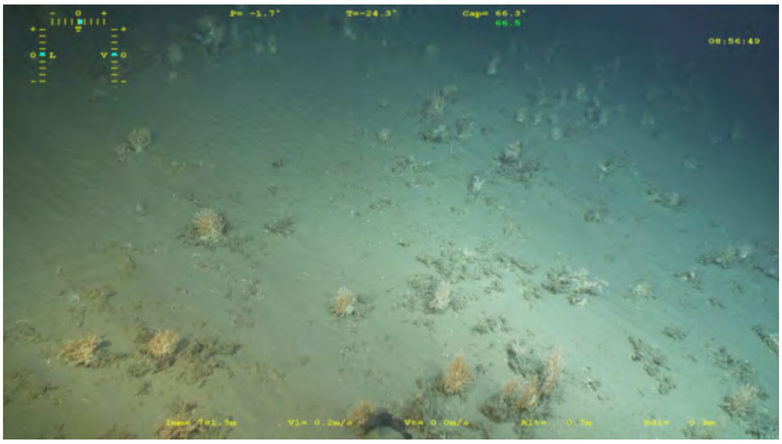

Figure 27: Packed-framework CWC on mud

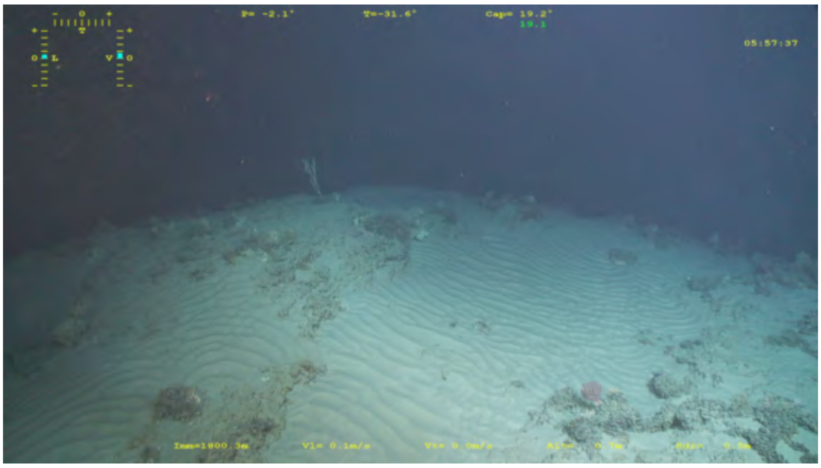

Figure 28: Mixed CWC on sand substrate

- *Coral Garden* **-** Aquatic beds dominated by non-reef forming soft corals, sponges or other sedentary or attached macro-invertebrates. Scattered hard corals may be present, but not dominant. Sea grass covers less than 10%.

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