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Submarine geomorphology and submarine landscapes of rocky platforms preceding Cliffs in Brittany (France)

Geomorfologia subacquea e paesaggi sottomarini delle piattaforme carbonatiche antistanti la Falesia in Bretagna (Francia)

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ABSTRACT – This paper presents a comparison between different types of submerged abrasion platforms and "plate forme à écueil" situated on the northern and southern coasts of Brittany (France). The aim of this comparison is to understand the spatial repartition of land forms in order to produce a tool for a later mapping of these submarine forms. The main sites for this comparison are St Malo in the North (with a 13m tidal range) and Belle Ile in the South (with a 8m tidal range), though many other sites have been explored during diving field work. The first part of this paper is an inventory of land forms at a definite scale, depending on the observation technique (air photos, dives). The observed forms are quite variable in size and frequency. Potholes are frequent; ridges and furrows are carved by differential erosion; submarine falls create field of blocks or submarine cones of clasts; ravine are infilled with coarse material or with sand. True erosional horizontal platforms, with a smooth surface are not quite common and are only observed on the North coast, close to the surface. We infer from this observation that true wave-cut abrasion platforms can only be localised close to the surface (in this case mean tide level) and are eroded or buried if they are submerged by more than a few meters of water. This implies that geomorphological heritages play a very important role, but in some locations only (REGNAULD & FOURNIER, 1991). The second part of this paper tries to explain the cause of the location of submarine land forms. If all forms, beside one, are found every where, they are not located without an order. Their spatial combination are very peculiar and reflect conditions of exposition, of sediment availability and of structural constraint. We try to present the spatial logic of the land form repartition. To achieve this understanding we have to determine which scale is efficient to explain which dynamics. This may lead to a better understanding of sedimentary movements. The last part of this paper presents a cartography of these submarine landscape. We include algal cover as an important element for the definition of this landscape. Some maps, at different scales, are shown and commented.

KEY WORDS: Submarine geomrphology, abrasion platform, landscape, Brittany.

RIASSUNTO – In questo lavoro vengono presentate le differenze tra vari tipi di piattaforme d'abrasione sommerse e la «plate-forme à écueil» situate nelle coste settentrionali e meridionali della Bretagna (Francia). Lo scopo è quello di comprendere la ripartizione spaziale delle forme del paesaggio per produrre successivamente una cartografia di queste morfologie sommerse.

I siti principali per questi paragoni tra forme diverse sono St. Malo a Nord (con 13 m di variazione di marea) e Belle Ile a Sud (con 8 m di variazione di marea), anche se durante il lavoro di rilevamento subacqueo sono state esplorate molte altre zone.

La prima parte di questo lavoro è un inventario di forme del paesaggio a scale definite, dipendenti dalle varie tecniche di osservazione (foto aeree, immersioni). Le forme osservate sono abbastanza vere sia per dimensioni che per frequenza. Sono frequenti le cavità d'erosione; creste e trincee sono scavate da erosione differenziale; frane sottomarine creano campi di blocchi rocciosi o conoidi sommersi di clasti; le gole sono riempite di materiale grossolano o di sabbia.

Vere e proprie piattaforme d'erosione orizzontali, con una superficie liscia, non sono molto comuni e si osservano solo sulla costa a Nord, vicino alla superficie. Da ciò deduciamo che le vere piattaforme d'abrasione marina erose dalle onde possono essere localizzate solo vicino alla superficie (in questo caso corrispondente al livello medio di marea) e sono erose o sepolte se sono sommerse da più di pochi metri d'acqua. Ciò implica che l'eredità geomorfologica gioca un ruolo molto importante, ma solo in alcune località (REGNAULD & FOURNIER, 1991).

Nella seconda parte di questo lavoro si cerca di spiegare le cause dell'ubicazione delle morfologie sommerse. Se tutte le forme, rispetto ad una, si trovano ovunque, esse non vengono localizzate senza un ordine: la loro combinazione spaziale è molto peculiare e riflette le condizioni di esposizione, di disponibilità di sedimenti, di caratteristiche strutturali. Per comprendere la logica spaziale della ripartizione delle morfologie occorre determinare quale sia la scala adatta per esprimere i diversi processi dinamici. Ciò può contribuire a spiegare meglio i movimenti dei sedimenti.

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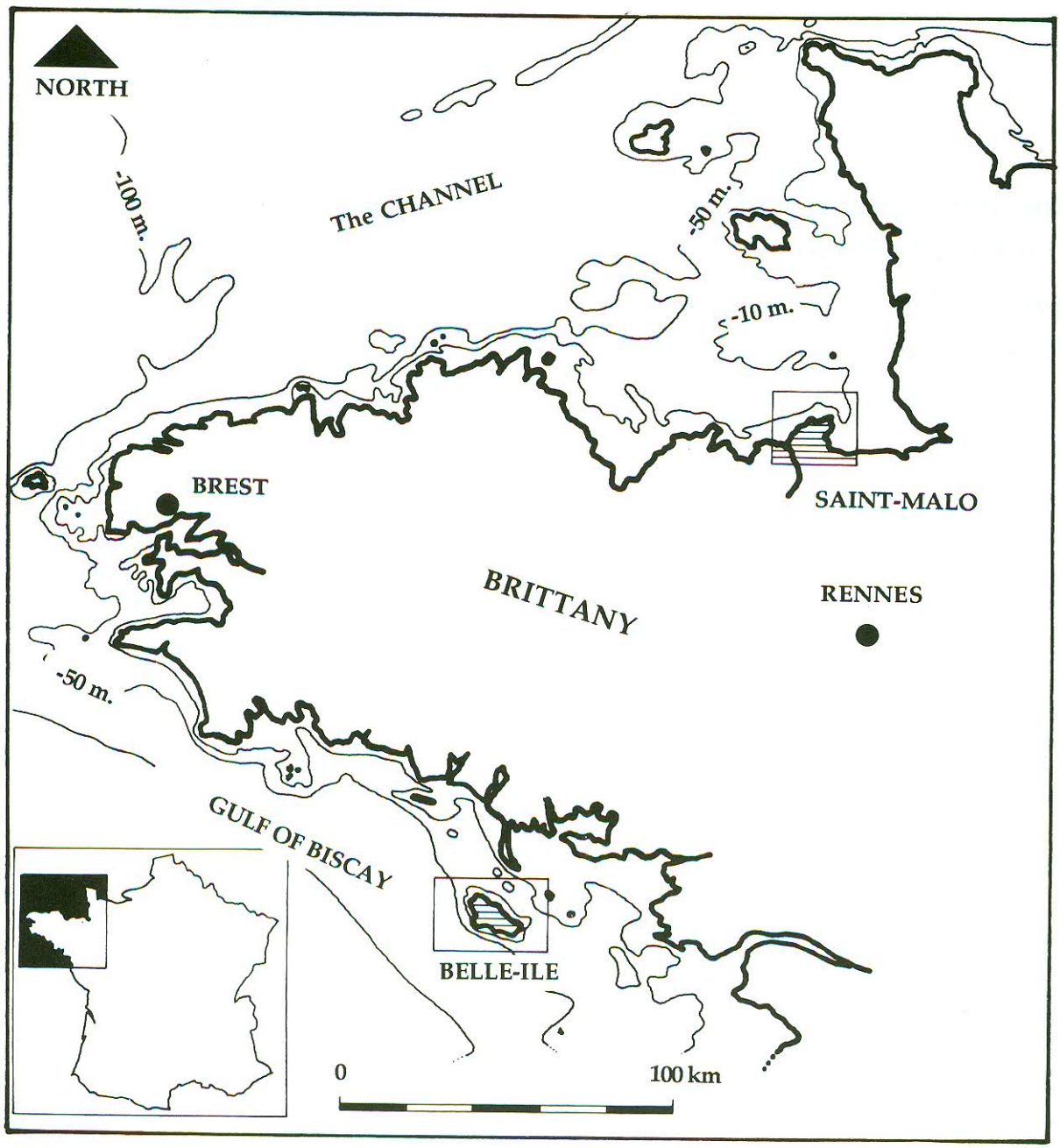

Fig. 1 – The two coasts of Britany are submitted to very different hydrodynamic conditions. A wave exposed coast in the South, with a moderate tide (2 to 7 m.) is opposed to a wave sheltered North coast, with a very high tidal range (up to 13,8 m.). Two exemples of submarine landscapes are discussed in this paper, the western approaches of Belle Ile for the southern coast, the region of St Malo for the northern coast.

La parte finale del lavoro presenta una cartografia dei paesaggi sottomarini. Abbiamo incluso anche le coperture algali, che riteniamo un elemento importante per la definizione del paesaggio. Vengono infine mostrate e commentate alcune mappe, di scale diverse.

1. – INTRODUCTION

At the western end of France, Brittany is a 250 km long peninsula exposed to the Channel on its northern coast and to the Atlantic (Gulf of Biscay) on its southern coast. On these two shorelines the hydrodynamic conditions are very dissimilar (figure 1). The southern part of Brittany is a wave exposed coast and the tidal range is not very important (from 2 to 7 m according to the tide coefficient). The northern coast does not receive high waves but is submitted to the world's second highest tidal range, 13,8 m in Cancale just East of St Malo.

These differences are mainly caused by the tectonic setting of the region. The gulf of Biscay is

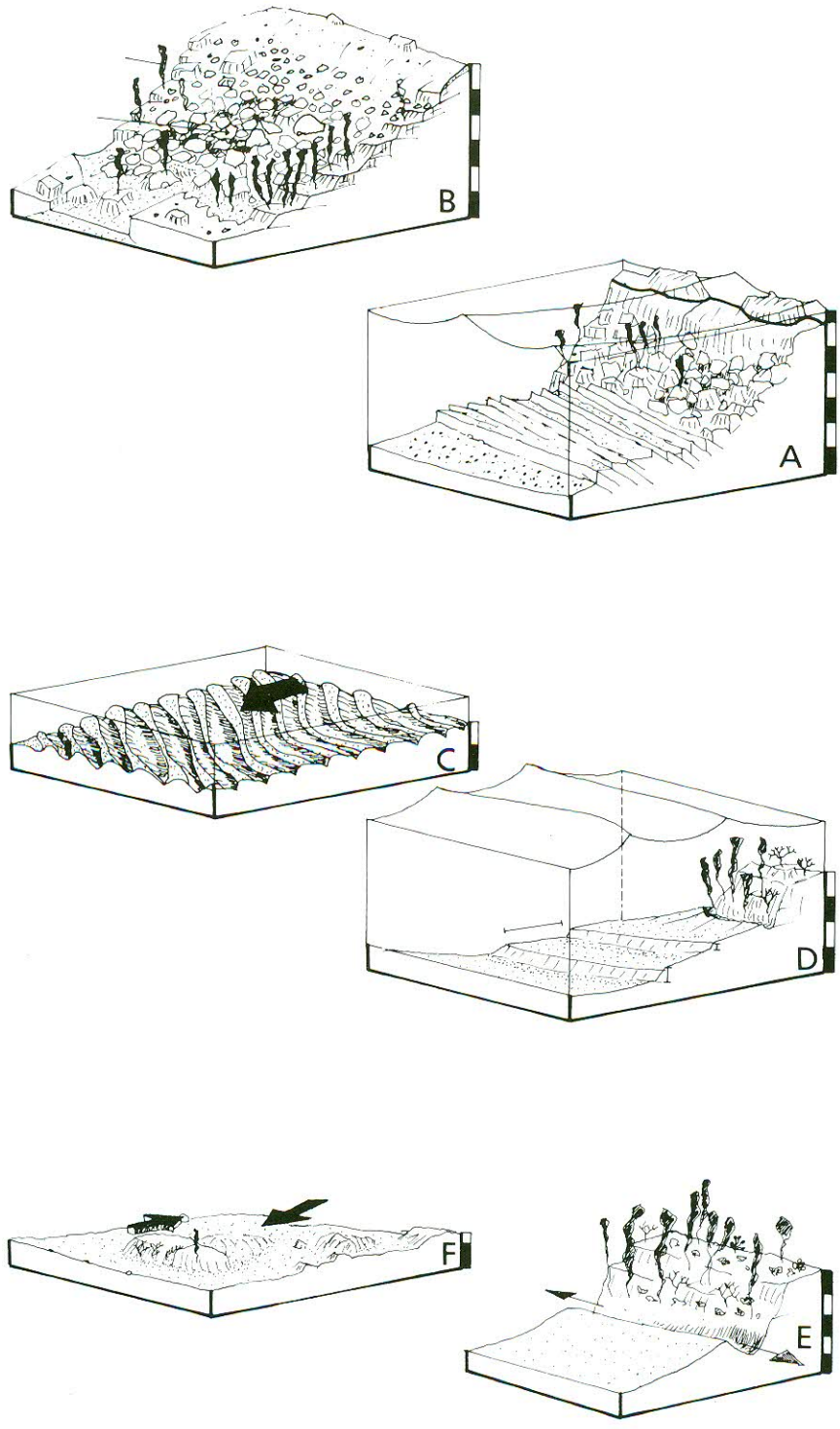

Fig. 2 – Diagrammatic blocks of local forms, observed during dives (located on figures 6 and 7).
As visibility is reduced the visual appreciation of landscapes is limited to some square meters.
Local forms only may be observed and they just give an information on geomorphic processes, but do not allow quantification.
- A: In situ rocky outcrop, structural form; .- B: debris fall and rock mantled slope, with *Haliotis sp.* and *Maia sqinado*; -
C: sandy sea floor with ripples. The complexity of the wave pattern in this area gives them a very changing form, which cannot be described by usual models; - D: an exemple of strange sand ripples, probably due to waves, tide and relected waves on the sea cliff; -
E: contact of sand and boulders, with moats; -
F: mobile thin sheet of sand covering a abrasion platform, tidal dune with *Crepidula fornicata, Pecten communis.*

a true passive margin: its rifted structure (Albian) and differential uplift (Albian to Eocene) have created many horst-like islands, parallel to the continent, such as Belle Ile, Groix, Les Glénans. These islands are close to the shelf break and are exposed to high oceanic waves. In Belle Ile the amount of spray is high enough to allow the growth of *Halimione portulacoïdes* 32 m above sea level. Average wave conditions are above 1,5 m and storm waves are able to move 9 tons blocks for 13 meters.

The Channel is an epicontinental sea, with an continental crust, no important tectonics and shallow depth : the 20 m isobath is 5 to 25 miles offshore. Thought diffracted waves may be important, their average height is under 0,8 m in many exposed locations (Pointe du Grouin, East of St Malo). The main hydrodynamic agent is tide which is amplified by the shallow depth and the geographical configuration of the Channel (funnel like shape). Tidal current are varying between 0,1 and 3,5 knots and may exced 7 knots in narrow straights locally called "Raz" (Raz de Sein, Raz Blanchard).

Thus Brittany possesses two very different spectacular coast lines. They have been populated by fishermen since the middle of Holocene and many ancient dwelling sites are now submerged. They survive throught legends and in the Celtic culture of the region. Brittany is also an attractive landscape for foreigners (this term includes people from the rest of France and further apart). The growth of touristic activities, and especially yachting, has created many problems for local fishing harbours that E.U. policy for fisheries has not totally solved.

This set of elements may explain that the "marine landscape" has arisen as an important topic for reflexion. The definition of rules for coastal management implies the definition of rules for submarine areas. This is not only a supply of sediment for beaches or of fish for industries, but it is also a landscape, in the most complete meaning of the word. The first appraoches of this concept were build by archeologists who have produced evidences for patrimonial values of submerged megaliths since the 50's (GIOT & MORZADEC, 1993; LE ROUX, 1993). Then diving and yachting schools have pushed in the same direction, not without questionable ulterior motive. Since the beginning of the 90's artists (land artists: Dinahet in THAERON & ABGRALL 1993, working in the sea) have found a new interest into this notion of submarine landscape (TIBERGHIEN, 1993). This work is part of a general project of the "Ecole Regionale des Beaux Arts de Rennes" about littoral landscapes. A first part presents a collection of observed submarine land forms. Then a definition of a landscape is built in order to understand the spatial distribution of these forms. Two maps are also proposed, as a base for future works.

2. – SUBMARINE LANDSCAPES IN BRITTANY: A COLLECTION OF LOCAL GEOMORPHIC FEATURES

From the point of view of a geomorphologist a submarine landscape is a land form, which may be observed at different scales, according to the choosen technique. The following land forms were observed during dives, at various depth. As the average visibility is under 3 meters, these forms are all small and occupy an area of 2 to 10 square meters. The depth are measured below the hydrographic 0. In France the maps are drawn with two different systems. On the main land the 0 level is the "average sea level in Marseille" and is called Nivellement Général de la France. It is used by the Institut Géographique National. At sea the 0 is the lowest possible theoretical tide and is called the hydrographic 0, used by the Service Hydrographique et Océanographique de la Marine. The two "0" are represented when a confusion is possible.

2.1. – FORMS DEVELOPPED IN A ROCKY BASEMENT

Most of the coast of the St Malo region is made of migmatites and gneiss. In Belle Ile the cliffs are made of metamorphic rocks (with intercalated siltstones) of volcanic origin. So the submarine part of the cliffs is cut into hard basement and many specific forms may be observed. They can be classed into two main categories: in situ rocky outcrops and boulders fields.

– Basement exposures are frequent. One case is presented on the diagrammatic block of figure (2, A)

– Waves and storms destroy the basement which produces many clasts and boulders. Their accumulation builds rock mantled slopes as on the (B) diagram of figure (2).

2.2. – FORMS DEVELOPPED ON SEDIMENT

Sandy sea beds are not considered as interesting landscapes, mainly because there is nothing to see close to the bottom. The nepheloid layer may reduce the visibility to 0,5 m or even less. Our observations were made in the vicinity of rocky slopes, in the center of bays. Two main types of rip-

ples are occuring. The most frequent is a regular ondulation of the sea floor, with waves length between 0,7 and 1,8 m. All tentatives to link the observed wave length with the measured waves have been ineffective: no model is able to describe these forms (figure 2, C).

An original example of sandy forms have been found in the eastern approaches of the Meinga close to St Malo. They are described on figure (2), diagram (D) and are located at the foot of a submarine cliff. Their direction is not that of the tidal currents, neither that of the waves. They correspond to a láminar flow (tide current) and a state of balance between tide, incomming waves and reflected waves.

2.3. – Contact between rocks and sand bodies

Tidal banks are moving all year long within unknown limits. They erode the foot of the rocks and are able to carve some submarine notch. In most of the case of an isolated rock is surrounded by a moat, as on figure (2, E). Wide areas are also covered by a thin (0,1 to 0,6 m) layer of sand. In this case some scattered rocks only are visible and they interrupt the tidal currents on the sea floor. They produce a tidal dune (figure 2, diagram F).

All these forms are small and none of them may be considered as a landscape. They give informations about sedimentary processes but they do not allow to establish quantitative models. An other scale of approach is needed, for geomorphology and, maybe, for landscape also.

3. – SUBMARINE LANDSCAPES ARE LOCATED ACCORDING TO DEPTH, EXPOSURE AND GEOLOGICAL STRUCTURE.

The landscape is defined as a combination of land forms. A certain surface of sea floor is needed to understand the input and output of sediments, the rate of abrasion, the mobility of the forms. For these reasons it is important to understand how the local forms are located, how they fit together into a wider geomorphological unit at medium scale. The small forms are located according to three determinations: depth, exposition to waves in relation to structural constraint, intensity of the tidal currents.

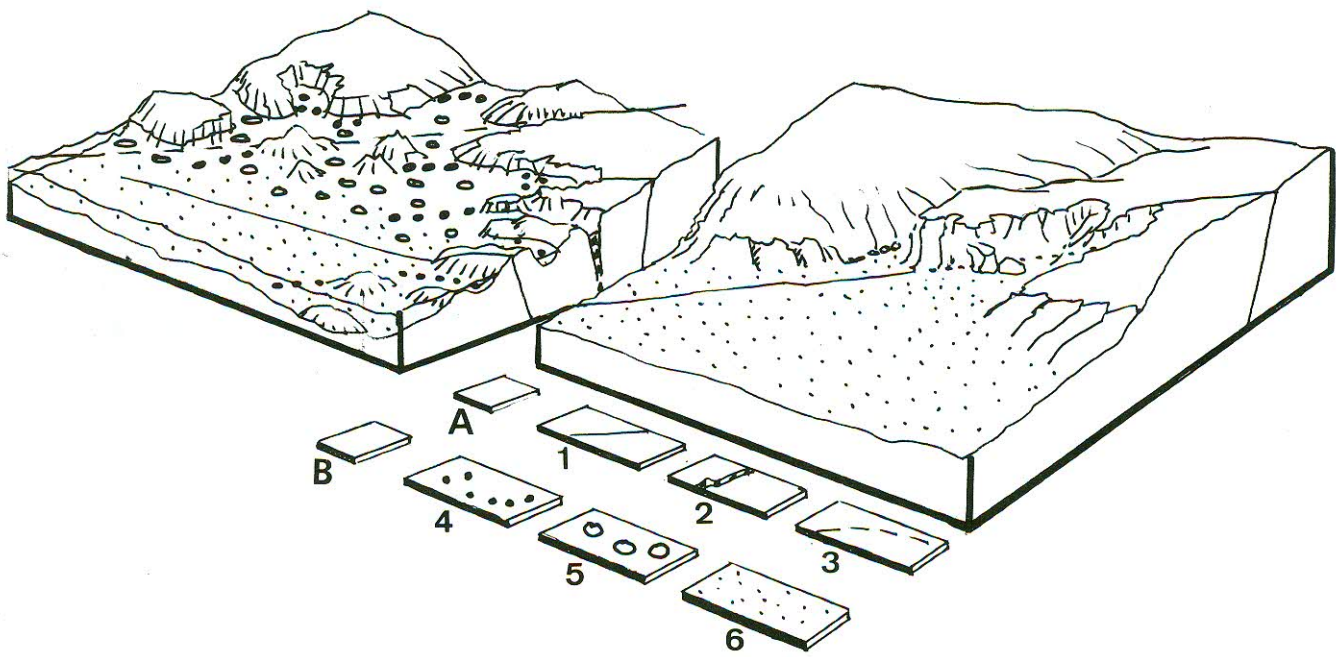

Fig. 3 – At medium scale the local forms combine into peculiar geomorphic unit.
This diagrammatic bloc represents the different layers of forms on the exposed coast of Belle Ile, in two sites: Domois and Le Pouldon. The first site is a submerged valley, a "ria", the second a fault scarp. A: structural pattern: - 1: fault; - 2: dyke; - 3: possible fault line. B: Submarine morphology: - 4: mobile pebble accumulation, submarine spit, ridges; - 5: rocky platform, with boulders and sand patches; - 6: sea floor with very thin sediment cover and rocky outcrops.
Each drawing is 1 square Km wide.

3.1. – Variation of landscape according to depth

The diagrammatic block of figure 3 shows two aspects of the repartition of the forms on the western coast of Belle-Ile.

The northern site is Domois and the southern site is Le Pouldon. The expected succession of submarine land forms is that of captions 4 to 6: mobile boulders and clast on the infra tidal zone, wave cut abrasion platform just below (– 1 to – 3 m), then a low gradient slope with scattered boulders moved by storms and abrasion forms. Some sediment patches are also present. In Domois these forms are disposed on an ancient topography, a Wurmian river submerged at the Holocene. This a ria and paleo forms (the river) do not change anything to the localisation of today submarine forms. In le Pouldon a fault scarp (Audren & Plaine, 1986) creates a high slope (24 m) and the deep landscapes are able to extend very close to the coast. Paleo form (the fault line) plays then an important role for the present distribution of landscapes. The importance of inherited forms is a delicate problem. In the neighbouring island of Groix, one part of the Island has been classed as a "geological museum" because it displays many different outcrops on a reduced surface. This could also be done for the display of geomorphic forms.

3.2. – Variation of landscape according to exposition

The Pointe du Meinga is a 1 km peninsula close to St Malo which displays an exposed western coast and a sheltered estern coast. This site is interesting because waves are never very high and they can build shapes by the repetition of slow processes. In Belle Ile the opposition between the sheltered and the exposed submarine landscape is just an opposition between a rocky platform destroyed by storms and a sand bank. In St Malo many interesting elements may be noticed and the effect of extreme events (storms) do not recover slow processes.

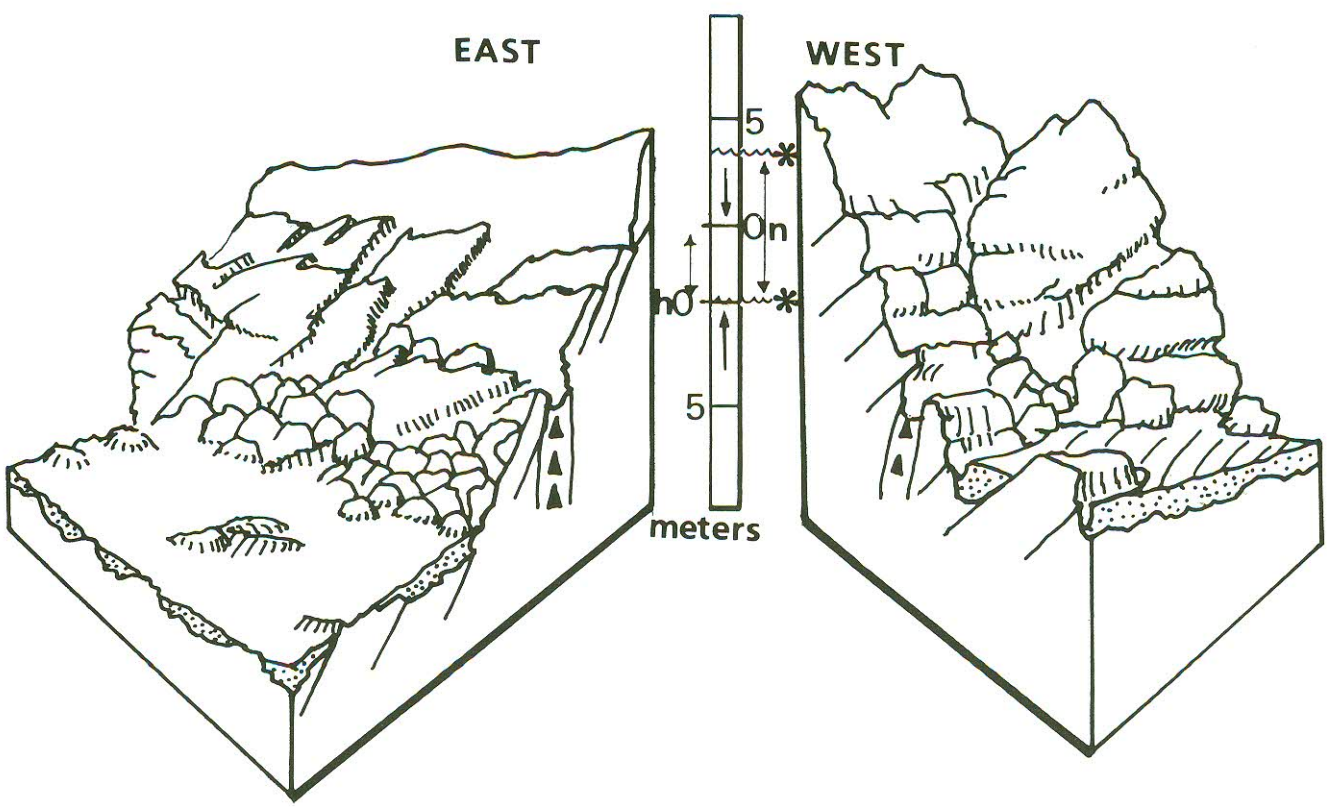

Fig. 4 – Local form may be located according to the exposition to waves. These two diagrams show the opposition between the exposed and the sheltered parts of the Meinga close to St Malo. The structural disposition of migmatites plays also an important role. Stars indicate the tidal range in spring tides and the two arrows shows the difference (7,45 m.) between NGF 0 and Hydrographic 0.

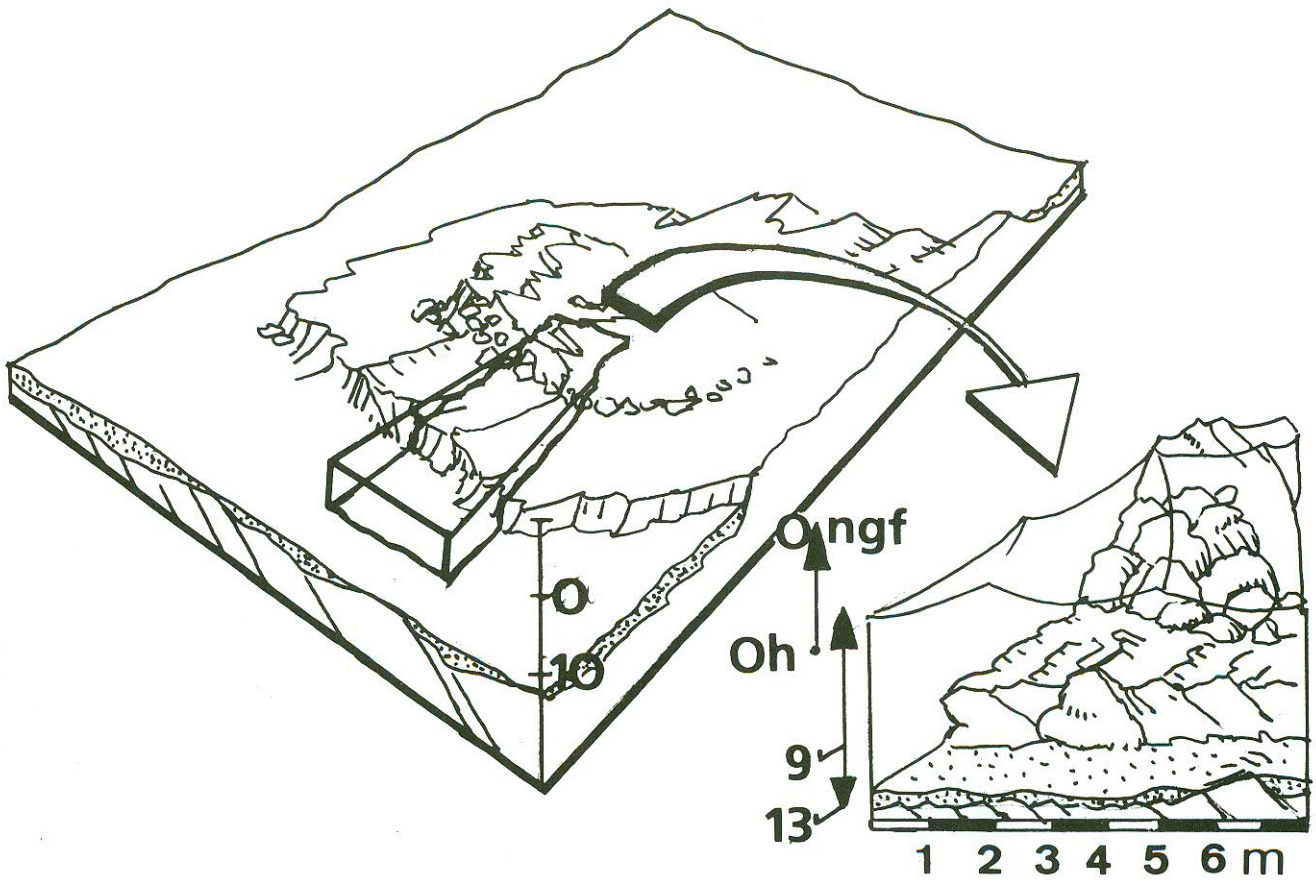

Fig. 5 – A very specific landscape may be found in straights of the northern coast, where tidal current vary between 0,3 and 3,5 knots. These sites are not well known because they are difficult to reach and dangerous for small ships. They are not exploited by fishermen and are playing the role of natural reserves. The abrasion platform at -9 m. may be a paleo sea level, as it has been proposed by Battistini and Guilcher for the coast of western Brittany. Still, confirmation is needed.

Figure 4 presents the main points of this opposition. The western site (exposed) is under a constant sand accumulation and at a 6 m depth no rocks are ever sediment free. In the eastern site this same case begins at 9 m The exposed coast is washed of any small clast and displays only in situ rocks. Structural joints are clearly visible. The submarine landscape is a continuation of the intertidal landscape, with sea weeds. The sheltered coast offers a great distinction between the intertidal and the infra tidal zones. The former is charachterized by structural planes and the latter is entirely recovered by boulders, rocks, clasts, gravels and sandy patches. It is an ideal biotope for many expensive sea animals, such as *Haliotis sp.*, *Pagurus sp.*, *and Maia sp.*, at least during spring time. For these reasons, and because it is a sheltered place submarine hunting has nearly exterminated these animals.These landscapes are being more and more destroyed.

3.3. – Variation of landscape with the tidal currents

The sea floor is, obviously, changing all day long with the tidal current pattern. This point is not very well understood at this step of the field work. At this stage we can only characterize portions of sea floor were tide is the main erosive and constructive agent. Diagrammatic block of figure 5 is a representation of a strait, Les Tintiaux where tidal current were measured: 0,2 m/s at low tide, more than 2 m/s at half tide, with coefficient of 107 and 114. Even on low tide, current does exists, but was not measured.

At this scale of observation the landscape is an ordered distribution of local forms. The order which determine this setting is the result of external geomorphic agents as waves and tide, applied onto a structural basement. This is by no way different from what is observed on the shore or inland. To point out the specificity of submarine landscape other elements have to be stressed.

4. – CARTOGRAPHY OF SUBMARINE LANDSCAPES: SOME CONTRIBUTIONS OF GEOMORPHOLOGY.

The concept of submarine landscape belongs to many people and geomorphologists are only one part of them. The notion of "geomorphological wealth", originally developped in Italy, then in France by Lautridou may be one good approach to include the shape of the sea floor inside of the general idea of marine landscape. A geomorphological wealth is a combination of land forms, situated in a definite place and offering both a representative sample of regional features and an original combination of them. This idea is the guide for the following maps.

4.1. – CRITERIA FOR THE DEFINITION OF A SUBMARINE LANDSCAPE

A landscape is supposed to extend on a large surface. This dimension may vary, but is always far greater than the observed extension of submarine landscape in Brittany, where visibility is so reduced. A first point to notice is that, in our region, the landscape is a concept, not a scenery. Starting from this fact, we may built the definition of a submarine

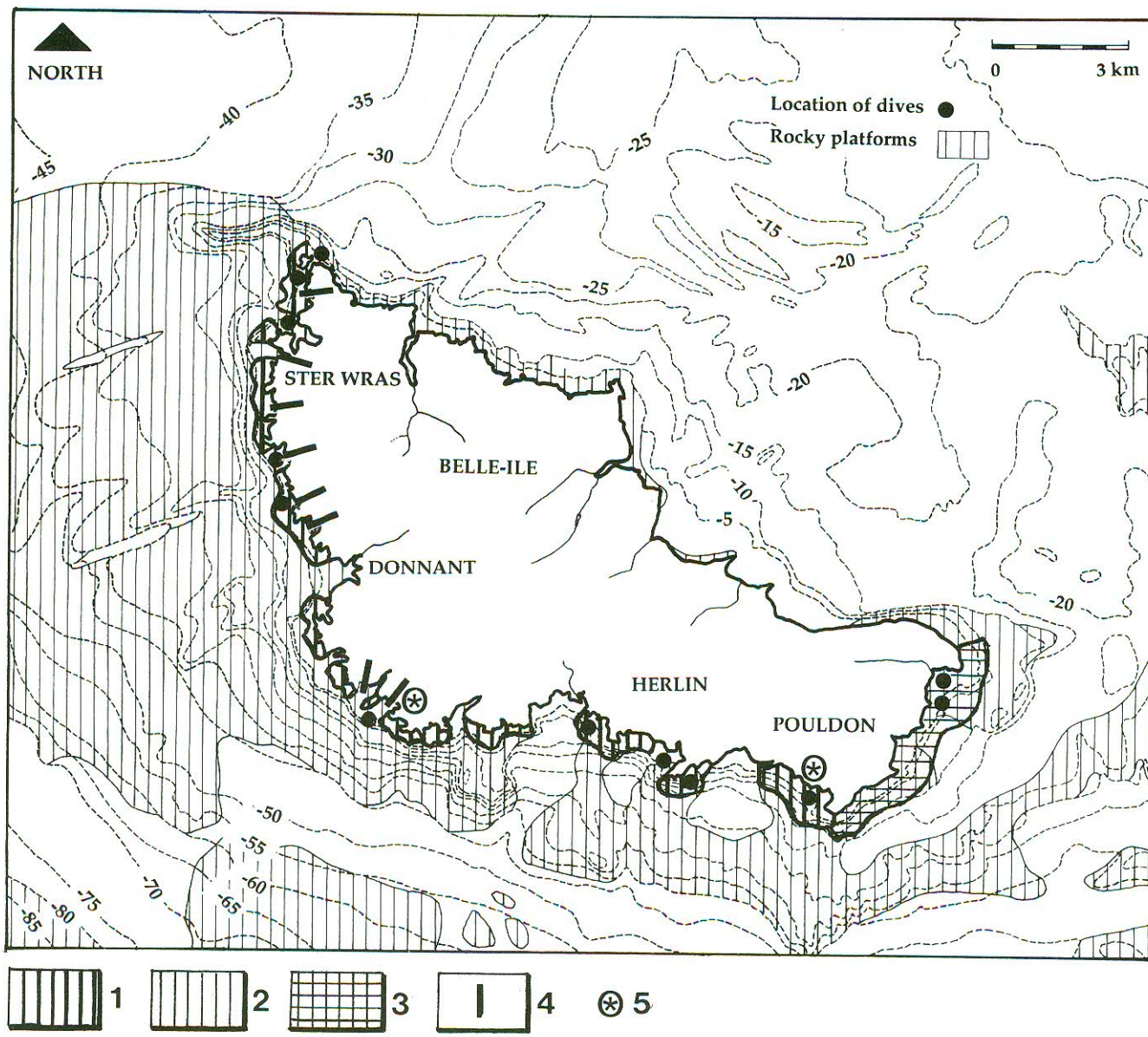

Fig. 6 – Medium scale map of submarine landscapes in Belle Ile, partially adapted from Vanney, 1977: - 1: retreating rocky shore line, with sea stacks, debris flows and ravines. - 2: wave dominated abrasion processes and forms. Isolated boulders , sediment free rock platforms. - 3: current dominated transport processes and forms, scattered clasts, furrows, ripple on rocky basement. - 4: local exchange of debris between the submarine ravines and the coast. - 5: location of figure 3 diagrams.

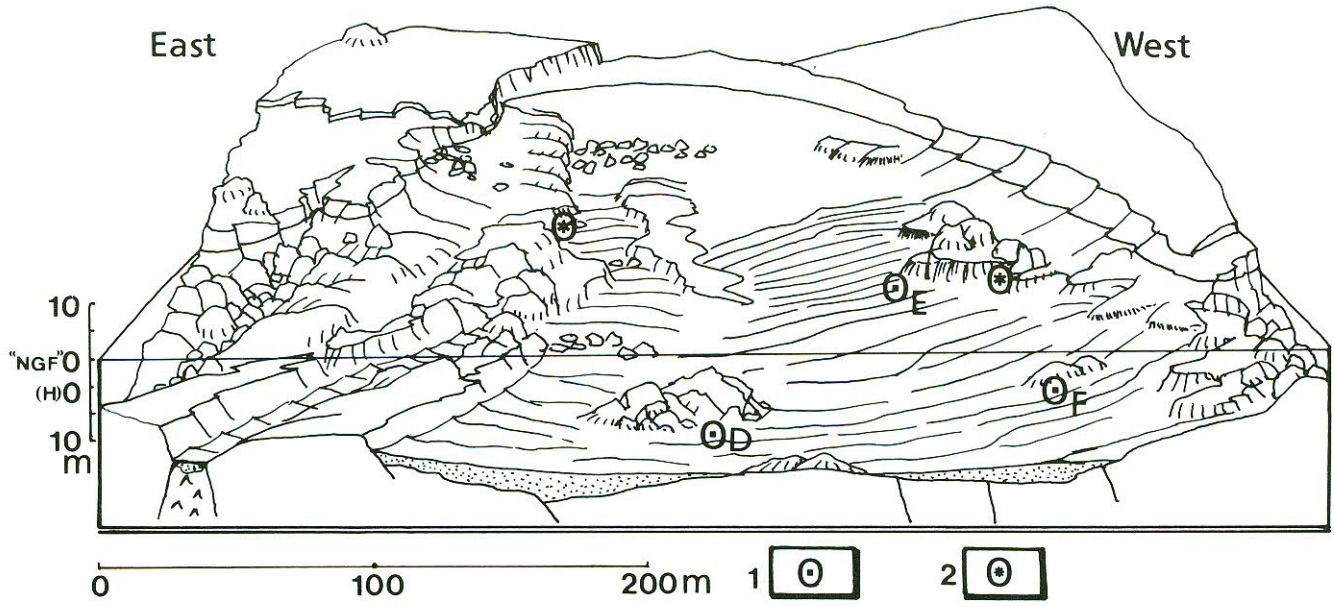

Fig. 7 – Physiography of a bay close to Le Verger. The different diagrams of figures 2, 4 and 5 are replaced in situ in order to show the spatial distribution of local forms and landscape at a smaller scale. - 1: local form with the same number as the in the figure 2 ; - 2: landscape, as represented on figure 4 and 5.

landscape out of reflexion and not out of sight. Three requirements are important.

Spatial homogeneity: the extension of a landscape is meaningfull if the landscape maintains a certain homogeneity. Other wise we change from one landscape to an other. Qualitative definition of homogeneity is difficult. A quantitative approach is easier. It would be based on the following parameters:

– Topography, such as slope, platform, tilted plateau... Plane areas have to stay in a definite variation of depth (1 to 3 m), sloping areas have to stay in a definite variation of gradient (1° to 10°).

– Occurency of local forms: the same forms are found every where and their functional combination is not variant. A fractal approach on a DEM would easily demonstrate this point (REGNAULD *et alii*, 1993) but we have no accurate DEM at this scale at the moment.

Temporal variability: sediment are moving with each direction of tidal current. Every six hours a new distribution of ripples is possible. This temporal variability may be considered as an intra tidal variability. This term would mean the same for tide as intra annual variability (as opposed to inter annual variability for climate). As tide is one of the main geomorphic agent it would be questionable to separate its effects into categories such as "low tide landscape" or "high tide landscape". The submarine landscape should then include a temporal variability, presenting different apparences according to the evolution of the tide. We have one landscape and many views of it, making it, once more, necessary to separate the notion of sight from the notion of landscape.

Regional occurency: a landscape should be an appropriate representation of the region. This may be controlled out of field test. In the same tide and wave conditions, the same landscapes should be found, within one single structural area. In Belle Ile this would mean that all rias are more or less equivalent, which is the fact. In St Malo, every exposed coast of a bay should be quite comparable with an other.

Biological parameters must also be considered. Field work is being performed on this subject, following the observation methodology of GIRARD *et alii*, 1987.

4.2. – CARTOGRAPHY

On the coast lines many works have focused on the appropriate scale of time and of distance for each problem (SHERMAN & BAUER, 1993). In the submarine zone the need for different scales is equally obvious and two maps are presented, in relation with preexisting works on these site (figure 8).

The map of Belle Ile (figure 6) is intended to complete the map already published in REGNAULD *et alii*, (1993). The opposition between the two coast is outstanding (VANNEY, 1977). The southern coast is dominated by currents which flow parallel to the shore. Most of the forms may be explained by the depth at which they are located. Infra tidal zone differs from deep areas. Large sedimentary bodies are uncommun.

The map of St Malo may be considered as a zoom, in comparison with the figure 6. The localisation of local forms is shown on the diagramm of figure 7, which is a representation of a small bay, Anse du Petit Port. On this same drawing the blocks of figure 4 and 5 are also located. A mapping of landscape may, then, be considered as an interpolation between the explored sites. The only problem is that this interpolation relays on qualitative interpretations. What we know of local conditions allows us to propose an extension for each kind of landscapes. Thought, no air photo, nor Spot image may permit a true field control. Surface surveying, with a boat is difficult; impossible for an oceanographic vessel, hazardous with a small fishing boat, possible when the weather is fine, with a Zodiac. Most of these areas are poorly known and a better knowledge of these very specific sedimentary regions would probably be very interesting in order to build accurate models of near shore processes.

5. – CONCLUSION

Our approach of the concept of submarine landscape relies on a geomorphological monitoring of forms. Extension (interpolation) between the different diving sites is attempted, using qualitative methods. The landscape is more or less a wide sedimentary unit and differenciations are made according to the relative importance of sediment and rocky outcrops. Local forms (tidal dunes, rock falls) are a good indicator of sedimentary dynamics. The main limits of this works are the absence of precise soundings (and DEM) and the poor knowledge of sediment mobility.

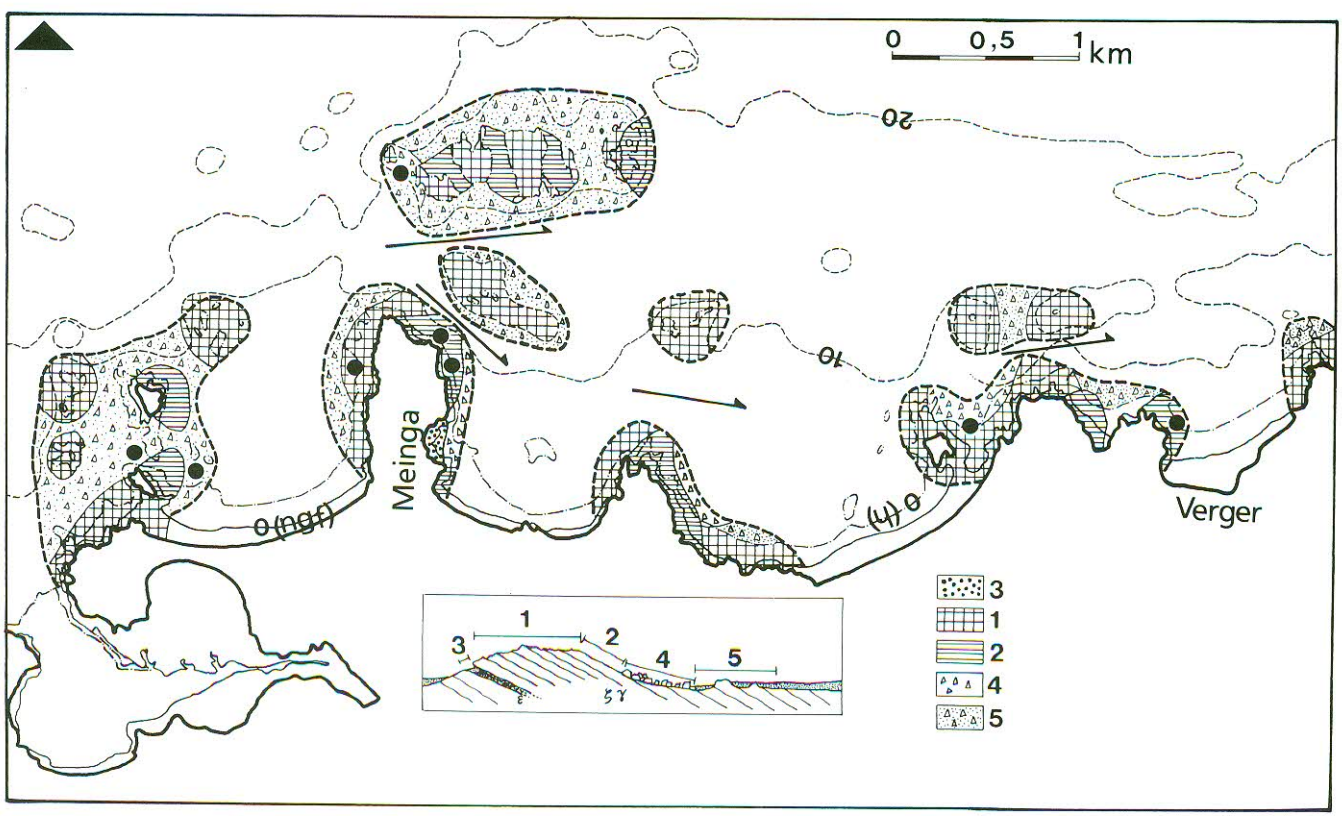

Fig. 8 – Local scale map of submarine landscapes in the region of St Malo. Sandy sea floor is not mapped. Almost all the landscapes mapped on this figure would belong to the n° 3 caption of figure 6, at medium scale. - 1: abrasion platform with chaos of small blocs and small sediment patches on the lee side of blocks - 2: structural slope with many blocs (over 1 m.) and debris flows. - 3: abrasion platform with excavated veins and fault lines, with sand intrusions moving inside. - 4: scattered blocks on a sedimentary body, tidal dunes, moats and riples. - 5: rocky outcrop interrupting the continuity of a thin sedimentary layer.

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