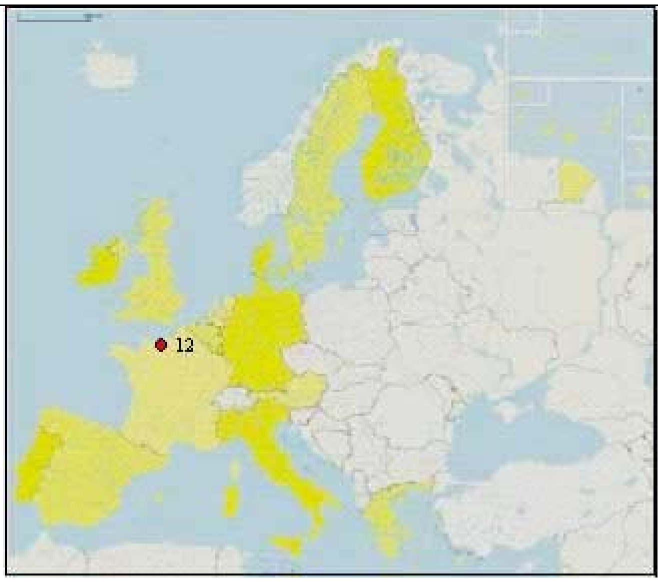
HAUTE-NORMANDIE
(FRANCE)



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1. GENERAL DESCRIPTION OF THE AREA

The Haute-Normandy and Picardy cliff coast extends from the Seine Bay (south) to the town of Ault-Onival (North, Picardy) along the French oriental Channel (Fig.1). The chalk cliffs are locally cut by deep valleys perpendicular to the coast. These valleys, protected by a pebble spits often against a stone packing, are lower than the water level of spring tides. Nevertheless, the inhabitants have chosen to settle their activities in these areas liable to flooding. Because of the altimetric characteristics of the low coasts and the progress of the cliff erosion, the Normandy and Picardy coast are of particular interest as far as analysis of natural hazard (storm surge and coastal erosion).

1.1 Physical process level

1.1.1 Classification

- General: Chalk cliffs and pebble beaches (Ablation coast)

1.1.2 Geology

Geologically, this area corresponds to the North-West termination of the Parisian Basin. The plateau of Haute-Normandy and Picardy, and consequently its cliff, is formed of Upper Cretaceous chalk (Cenomanian to Campanian) more or less rich in flints. Residual formations with flint and Quaternary loess are also deposited on this karstified chalk. Major tectonic deformations in NW-SE directions result in the outcrop of various layers from the Upper Cretaceous. It is well known that the majority of cliffs are formed by Senonian white chalk rich in flint (Coniacian, Santonian and locally Campanian). Nevertheless, this apparent homogeneity hides more complex details (Juignet 1974 ; Kennedy & Juignet 1974 ; Bromley & Ekdale 1986 ; Pomerol *et al*. 1987 ; Mortimore & Pomerol 1987 ; 1990 ; Juignet & Breton 1994 ; Laignel 1997). Coniacian chalk is present between Antifer and Saint-Valéry-en-Caux, and also between Dieppe and Le Tréport. Santonian chalk is found continuously only in the central part of the shore from Saint-Valéry-en-Caux to Puys. Campanian is present locally from Quiberville to Pourville. Turonian, chalk comprising clayish, greyish to whitish, with little or no flint, protrudes from Antifer to Etretat, from Fécamp to Eletot, and from Puys to Tréport where it reaches its maximum extension at Penly. Locally, at the Antifer and Etretat cliff feet, and at the east of Fécamp, Cenomanian chalk protrudes. These are heterogeneous, sometimes rich in detrital componants (clay and quartz) and can be glauconitic or nodular. A cover approximately 10 m thick of sandy, clayish sediment of palaeogene origin can be found at the cliff top at cap d'Ailly, Sotteville and at Bois de Cise (Bignot 1962; 1983). Because of their different structural characteristics favourable to weathering, the various ages of chalk layers correspond to different types of cliff morphology with contrasting rates of evolution

Sediment characteristics of the beaches are flint gravel (with a mixed flint shingles and sand inside the beaches). D_{50}= 6 cm (for flint pebble).

1.1.3 Morphology of the coast

The cliffs of the study area extend over 130 km of shoreline. The cliffs have an average height of 70 m. A wide shore platform (150-300 m) develops at their feet, covered on its landward margin by a thin shingle or pebble beach. These cliffs are cut by numerous dry and drained valleys perpendicular to the shoreline, and protected by a shingle beach that is often thick and between 30 and 100 m wide. These valleys represent the lowest points on the cliffs and the population are established in. Their altitude is no higher than the highest High Tide Level, which makes these zones very fragile during storms.

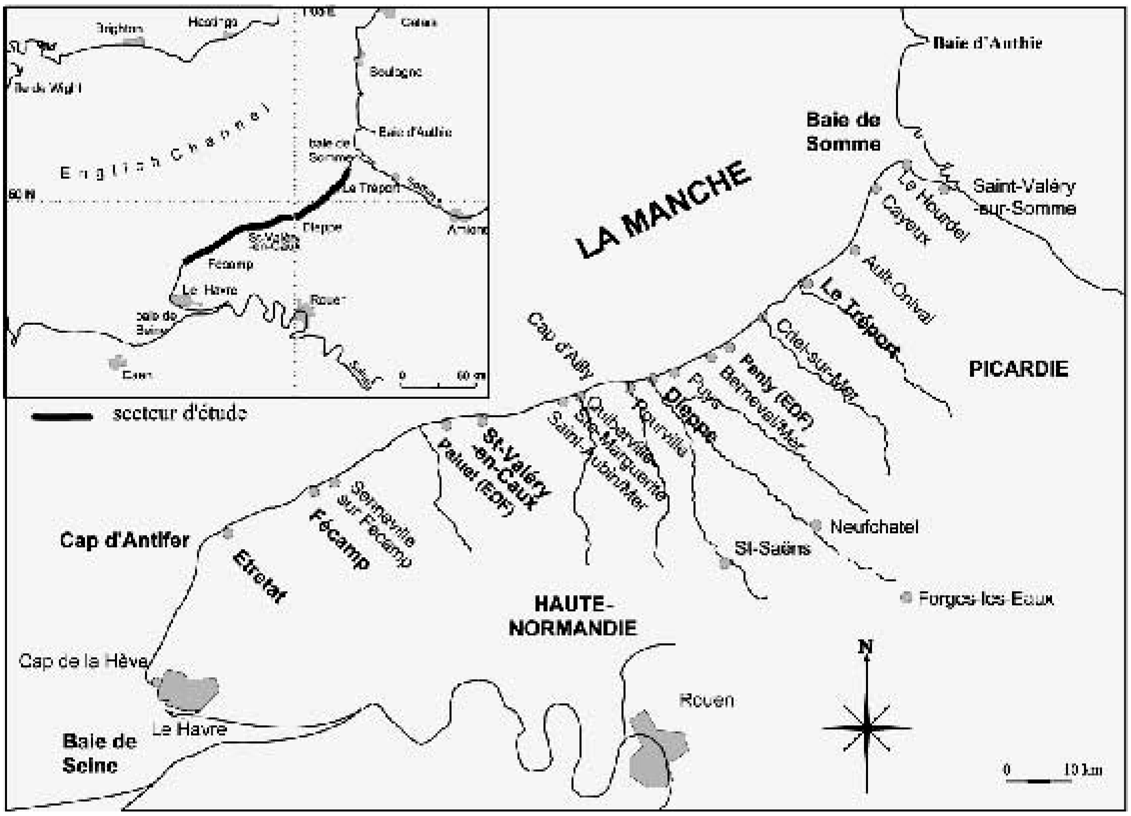

Fig. 1 : Location map

1.1.4 Physical processes

The evolution of the Haute-Normandy and Picardy cliff coast is influenced by the combination of marine and continental processes. Nevertheless, the pebble beaches are under the impact of the action of the hydrodynamic conditions especially, the wave (Table 1). Because of the oblique direction of the coastline (NE-SW), the Normandy and Picardy is very hightly exposed to the western storms. Then, the transport of the pebbles is dominated by a longshore drift. The direction of the dominant longshore is SW-NE (Fig. 2).

Table 1 : Significative wave height (Hs) for several sites of the Normandy Coast. (Allen & Delannoy, 1990).

Location	Le Havre	Antifer	Paluel	Dieppe	Penly
Annual height (meter)	3.5	4.1	4.1	4.3	3.8
Decennial height (meter)	4.6	5.7	4.9	5.7	4.7

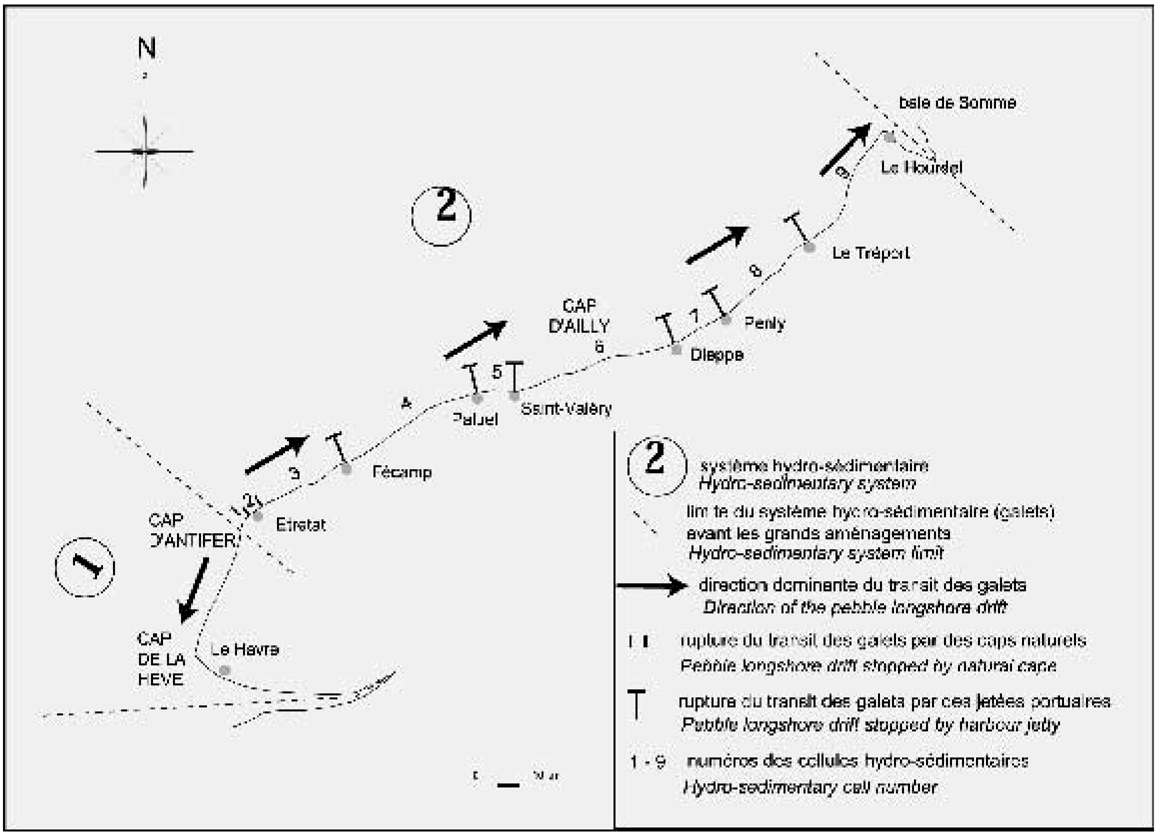

Fig. 2 : Direction of the longshore transport and the hydro-sedimentary cells (Costa, 1997).

This Longshore transport is strongly influenced by man's actions (pears, jetties, extraction) modifying the volume and the progression of the protective pebble beaches. Because of the shapes of the Channel sea-floor and the coasts, the studied area is subject to macrotidal tides creating alternative currents parallel to the coastline (Fig.3). These currents carried only mud and coarse grained. The dominant direction is to the NE.

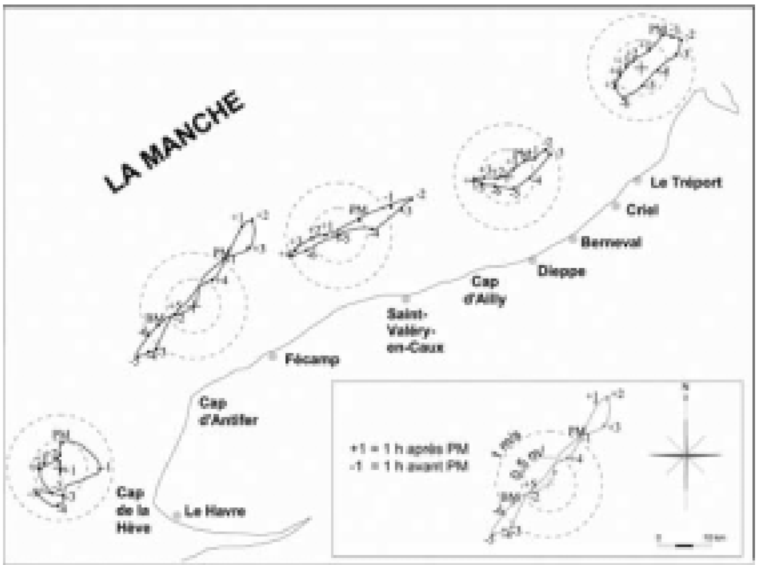

Fig. 3 : direction of the tide currents along the Haute-Normandy coast (SHOM, 1968).

1.1.5 Erosion

The cliffs can only fall back, and their retreat nourishes the pebble beaches with flints. The annual average speed of retreat on the whole coast is about twenty centimeters a year. Nevertheless, this result is not good because, it's an average. In fact, the Haute-Normandy and Picardy chalk cliff speed erosion knows a very important spatial variation (cf. part 2.1). This is due to the lithologic characteristics, and especially, the different outcrops of chalk (Fig 4 and 5).

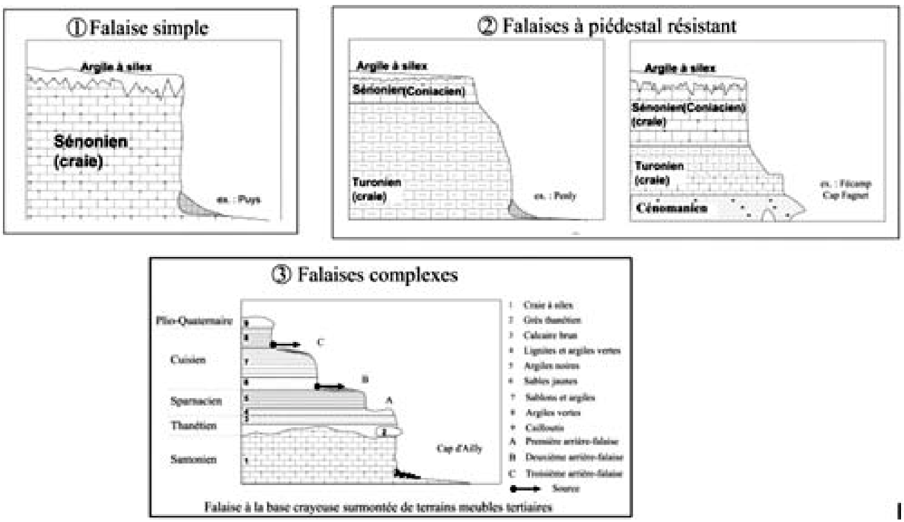

Fig. 4 : Typologie of the different morphologies of Haute-Normandy and Picardy cliffs (Costa, 1997).

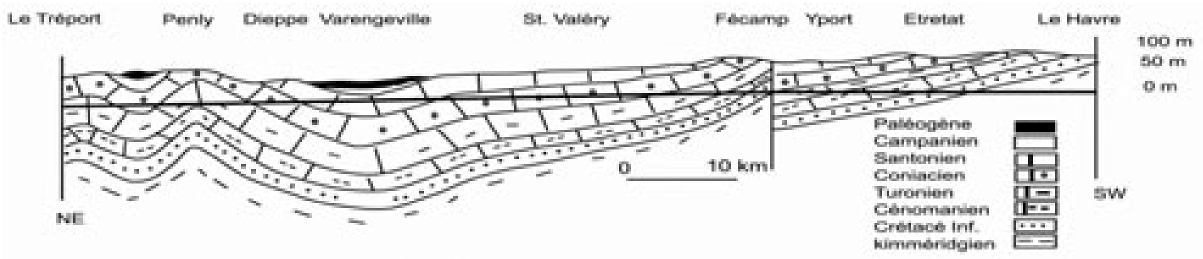

Fig. 5 : geological section of the Haute-Normandy coast (Costa, 1997).

Erosion Cause

Even if this evolution of the cliff erosion is well understood, quantification of the rates and of the processes involved remains a problem. These difficulties are due to the discontinuous of the cliff erosion rhythm. The erosion is continuous, but the retreat occurs discontinuously, at various rates, according to different agents and processes (continental and marine) in time and space.

The coastal erosion management in Haute-Normandy and Picardy has been performed through construction of rigid defences in times of crisis which have a limited lifetime, a localised effect, and are often disruptive for the pebble longshore drift. An increase of the rockfall frequency appears at the immediate down of transversal sea defences (harbour jetties or major groynes), showing the impact of these obstacles on the pebble longshore drift. This sediment budget modification produces an increase of the hydrodynamic conditions which are favourable to the cliff retreat.

More, during the previous century, 50% of the total volume of pebble (3 millions m^3) between Antifer and Le Tréport) has been extract. These extractions are forbidden since 1972 on the beaches. The cliff erosion is normal, but it’s increased come from a natural depletion of the sedimentary budget inherited from post ice-age and even intensified by man’s action (quarrying and defensive engineering).

1.2 Socio-economic aspects

1.2.1 Population rate

The Haute-Normandy population is 1 239 138 (INSEE, 1999). The average population rate is 145 inhabitants/km² (place 4 in France) (Fig. 6). The more important density area is near the big town (Le Havre, Rouen), along the coast, and especially on the valley (200 to 500 inhabitants/km²).

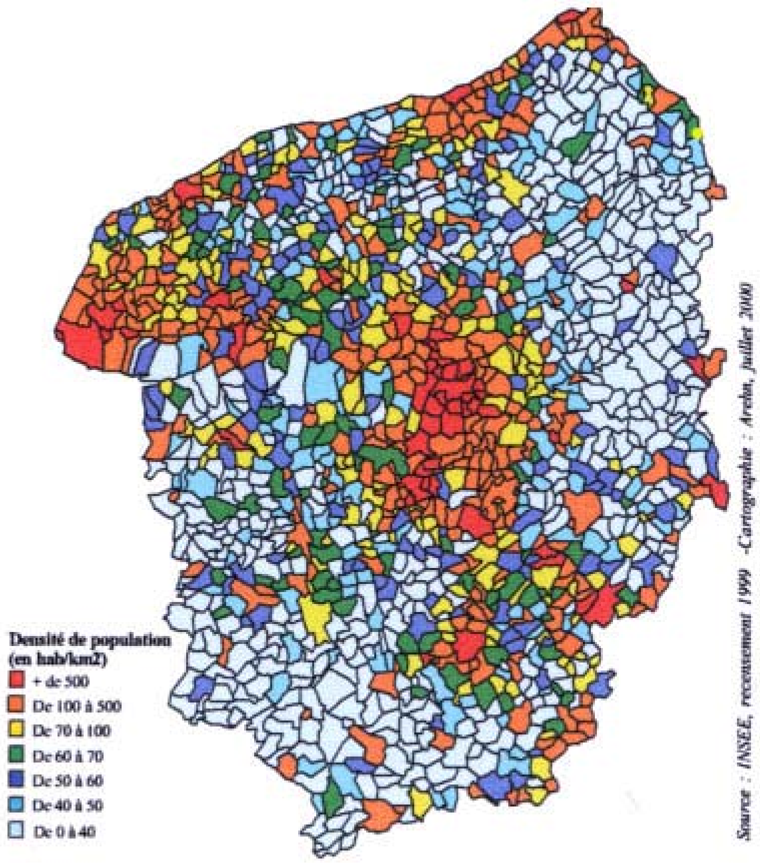

Fig. 6 : Density population map of the Haute-Normandie (INSEE, 1999).

1.2.2 Major functions of the coastal zone

- **Tourism and recreation**: a primary indicator of the extent of tourism in the Haute-Normandy region is the number of the frequentation (night in hotel, camping ….). For 1999 this is 12 millions nights.
- **Urbanisation (safety of people and investments):** the safety for flooding of urban areas in Haute-Normandy is not calculated. When we are the conjunction of a Northwest storm (58 km/h) and an average high spring tide a lot of valleys know storm surge. It's in these valleys that is located all economic activities. More, exist 2 electronuclear stations along the coast (PALUEL and PENLY).

Near the coast, a large part of the Haute-Normandy plateau is employed by agriculture activity (especially, cereals and pasture).

Fig. 7: Little town on a valley(Pourville sur mer), and engineering measures (groynes and rip rap).

2. PROBLEM DESCRIPTION

2.1 Description of eroding sites

The photo-interpretation analysis of oblique aerial photography from the French National Geographic Institute between 1947 and 1990 (7 missions; National Geographic Institute) provided information on the cliff retreat, the location of rockfalls and the mean volume of rockfalls (Costa, 1997). This study shows that we can distinguish 2 sectors having a distinctive regressive evolution (Fig. 8). One of these sectors, comprising two intervals between Etretat and Saint-Valéry-en-Caux, then between Berneval and Le Tréport, is affected by a smaller retreat rate (0.14 to 0.17 $m.y^{-1}$), and is characterised by rare but massive rockfalls (mean return period over 25 years ; mean retreat per event typically over 8 m). On the other hand, the area between Saint-Valéry-en-Caux and Berneval is affected by a more rapid rate of retreat of 0.20 to 0.51 $m.y^{-1}$, and is characterised by more frequent but less massive rockfalls (mean return period of about 15 years ; mean retreat per event about 6 m) (Costa 1997).

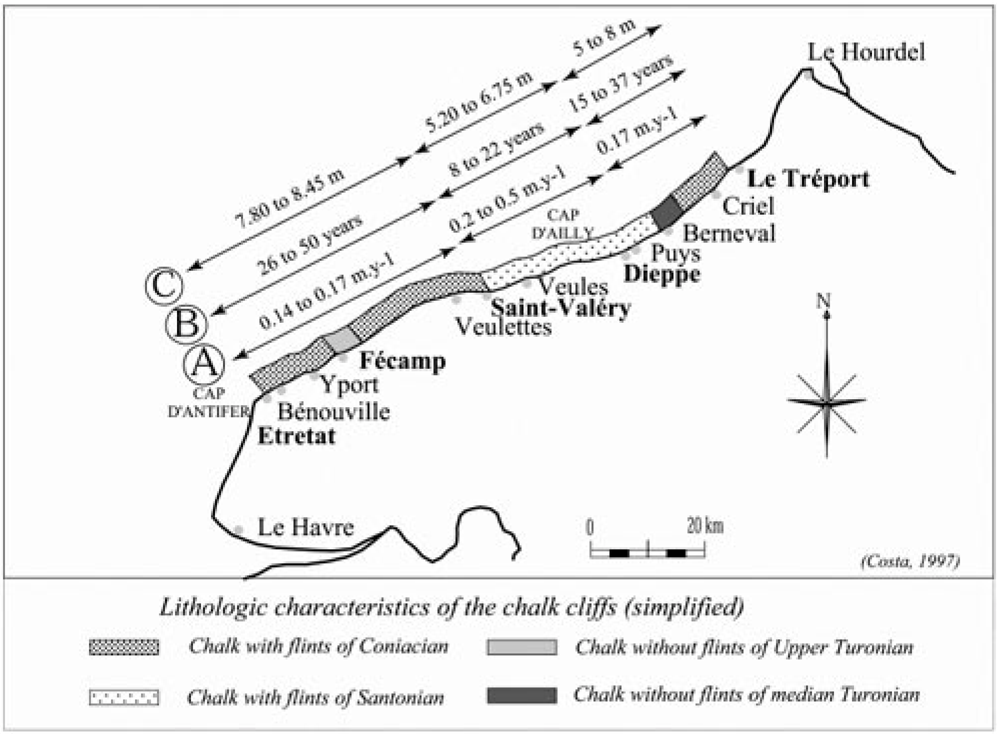

Fig. 8: Spatial location of the average chalk cliff retreat rate (A), the average repeat period of cliff falls (B), and the average per fall, in relation to the cliff toe stratigraphylithologic structure (C), per area between 1947 and 1995 (Costa, 1997).

The photogrammetric analysis confirms and quantifies the observations obtained by photo-interpretation (Costa, 2000). The mean retreat rate of the entire shoreline under study is about 6 m between 1966 and 1995, that is to say 0.21 $m.y^{-1}$ (Fig. 9). Nevertheless, this figure is somewhat meaningless because of the very high spatial variability of cliff retreat in Normandy and Picardy. The analysis of the retreat per hydro-sedimentary cell and sub-cell enables three distinctive areas to be distinguished : (i) an area of low retreat rate (0.8 to 0.13 $m.y^{-1}$) between Antifer and Fécamp, (ii) an area of moderate retreat rate (about 0.19

m.y[-1]) between Fécamp and Saint-Valéry-en-Caux, and between Dieppe and Le Tréport, (iii) an area with fast retreat (0.21 to 0.28 $m.y^{-1}$) between Saint-Valéry-en-Caux and Dieppe. This division into sectors is identical to the division found through photo-interpretation.

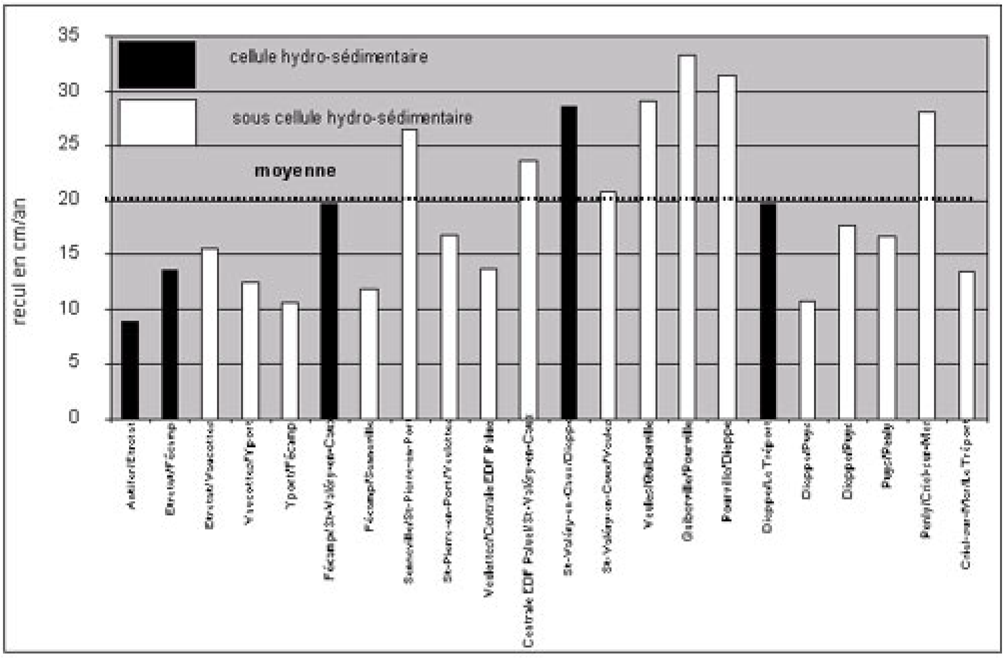

Fig.9: Haute-Normandy cliff erosion by hydrosedimentary cells between 1966 and 1995 (Costa, 2000 in CPIBP).

Nevertheless, important variations may exist within a sector. These sharp variations are linked with the influence of cliff falls or anthropogenic obstacles (harbour jetties or major groynes) that disrupt the shingle transit (from the South-West to the North-East).

2.2 Impacts

Erosion along the Haute-Normandy coast causes a higher risk for urban area put on the cliff, near the coastline. Nevertheless, only some sites are affected by erosion like Criel, Quiberville, or Saint Pierre en Port (Fig.10).

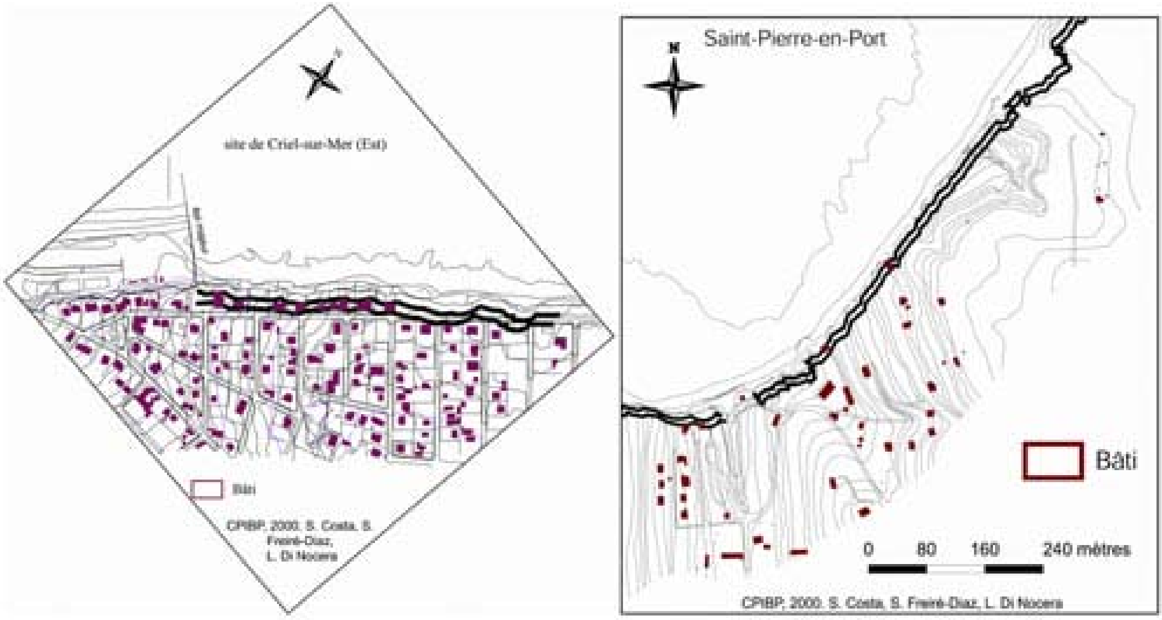

Fig. 10: examples of coastline estimation position (for 50 and 100 years) and the houses menaced (Costa, 2000 in CPIBP).

3. SOLUTIONS / MEASURES

3.1 Policy options

The adopted policy option is do nothing for the cliff erosion and hold the line for the pebble beaches. Nevertheless, since 1995, with the "Barnier low" it's possible to move the inhabitant menaced. The first case is Criel (Figure 11), where 7 families had been expropriated. In 2003, again 7 houses must be given up.

Fig. 11: Site of Criel. The aim here has been to built a groyne which stopped the pebbles which were protected the foot of the cliff of the sea erosion.

3.2 Strategy

The engineering options are both soft (nourishment of pebble beach, but it's exceptional) and hard (groynes, Figure 12a). The strategy is now to work as much as possible with natural processes.

A by pass experience of pebble flints is imagined near each Haute-Normandy harbour pears (Figure 12b).

3.3 Measures

The inventory of the different engineering structures is not realised. Nevertheless, these are only on the beaches (groynes and Rip Rap)

Fig.12a & 12b: Hard protection on photo A (Pourville) and soft (B) (extraction of the pebble on the harbour and put it on the beaches (Saint-Valéry en Caux).

3.3.1 Costs

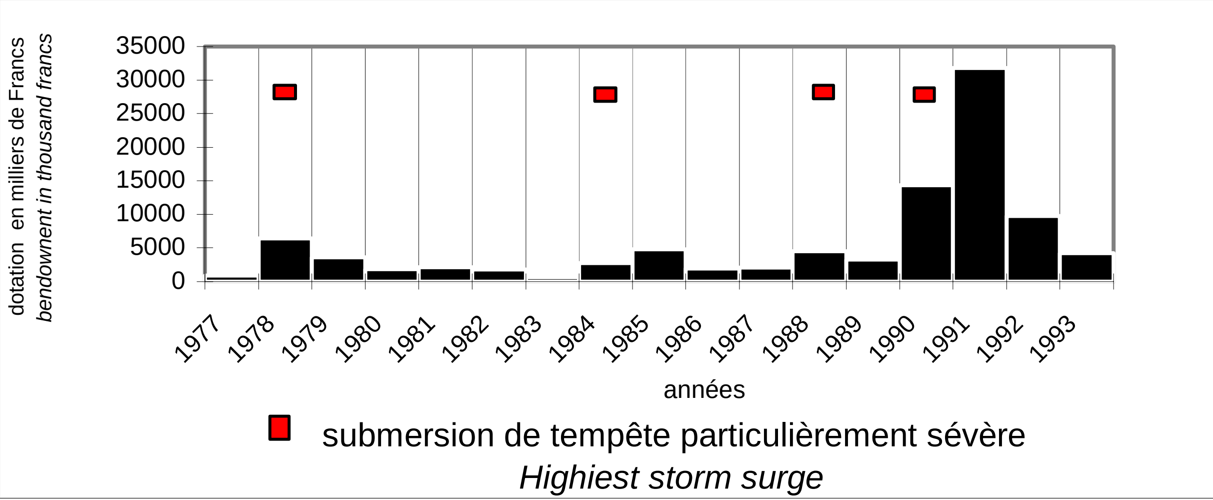

Fig. 13: Annual costs for the Haute-Normandy coastal management (Costa, 1997).

The expenses for the Haute-Normandy erosion and storm surges problems are very important (Fig. 13). As shows the figure 9, the expenses are realised during or after the catastrophes. It's a post-crisis management. Nevertheless, since few years this kind of management is not really used.

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

Structural erosion did not stop and it's better for the beaches which protect the urbanized valley. In fact, the chalk cliff retreats is important for the beaches sedimentary budget equilibrium. The annual production of flints (coming to the cliff erosion, Table 2) is the one contribution of the actual budget.

The Normandy and Picardy erosion coastal management, based on restrictive administrative division and not according to the scale of the natural phenomena, was summed up to a rigid and confined coastal defence policies replying to a crisis periods. Recently, this noting has incited the territorial institutions of the two districts (Haute-Normandy and Picardy) to think about a global and partenarial treatment of the coastal erosion. This was initiated within the framework of the "Contract de Plan Interrégional du Bassin Parisien (CPIBP)" and continued by an Interreg II programme: "Beach Erosion of the Rives-Manche".Becaused of the fiability, spatial and temporal representativity problems of the previous studies, the first step of this interregional co-operation was to establish a reliable and homogeneous quantification and follow method of the coastal dynamics.

Table 2 : Annual production of pebble flints coming of the chalk cliff erosion (Costa & Delahaye, in BERM, 2002).

Nom des cellules	Chalk falled volume between 1966 and 1995	cliff flint content (%)	coast line (km)	flint volume gave by cliff erosion between 1995 and 1966 (en m3)	Volume de galets produit entre 1966 et 1995 (en m3)	Volume potentiel de galets produit par an (en m3)	Volume de galets produit au km linéaire (en m3)
Cap d'Antifer/Etretat	**674 941**	**14**	**4 123.00**	**94 492**	**56 695**	**1 955**	**474**
Etretat/Fécamp	**3 992 919**	**11.2**	**14 424.81**	**447 207**	**268 324**	**9 253**	**641**
Etretat/Vaucottes	2 602 448	12.2	7 937.10	317 499	190 499	6 569	828
Vaucottes/Yport	267 049	10.7	1 293.53	28 574	17 145	591	457
Yport/Fécamp	1 103 402	10	5 194.17	110 340	66 204	2 283	440
Fécamp/Saint-Valéry-en-Caux	**9 274 008**	**10.1**	**27 614.89**	**936 675**	**562 005**	**19 379**	**702**
Fécamp/Senneville-sur-Fécamp	890 435	9.4	3 322.76	83 701	50 221	1 732	521
Senneville-sur-Fécamp/St-Pierre-en-Port	4 174 969	8.7	6 970.03	363 222	217 933	7 515	1078
Saint-Pierre-en-Port/Veulettes-sur-Mer	2 868 060	9	8 831.27	258 125	154 875	5 341	605
Veulettes-sur-Mer/Centrale EDF de Paluel	680 547	10.5	2 867.79	71 457	42 874	1 478	516
Centrale EDF de Paluel/St-Valéry-en-Caux	2 922 691	10.9	5 623.03	318 573	191 144	6 591	1172
Saint-Valéry-en-Caux/Dieppe	**10 743 201**	**9.2**	**28 060.18**	**988 374**	**593 025**	**20 449**	**729**
Saint-Valéry-en-Caux/Veules-les-Roses	2 337 869	11.6	6 696.49	271 193	162 716	5 611	838
Veules-les-Roses/Quiberville	3 429 919	8.8	9 144.37	301 833	181 100	6 245	683
Quiberville/Pourville	3 346 063	8	8 450.36	267 685	160 611	5 538	655
Pourville/Dieppe	2 242 387	8.3	3 768.96	186 118	111 671	3 851	1022
Dieppe/Le Tréport	**9 470 987**	**6.1**	**24 046.19**	**577 730**	**346 638**	**11 953**	**497**
Dieppe/Puys	284 387		2 627.90				0
Dieppe/Puys	242 972	8.6	1 361.19	20 896	12 537	432	318
Puys/Penly	3 361 818	6.2	9 592.24	208 433	125 060	4 312	450
Penly/Criel-sur-Mer	4 829 854	5	7 662.82	241 493	144 896	4 996	652
Criel-sur-Mer/Le Tréport	1 375 652	5.2	5 429.94	71 534	42 920	1 480	273
Antifer/Le Tréport	**34 156 055**		**98 269**	**3 044 478**	**1 826 687**	**62 989**	**716**

The technique we chose is the photogrammetric analysis by numeric means by vertical aerial views of the National Geographic Institute (analysis between 1966 and 1995). This technique gives accurate planimetric and altimetric values (± 0,40 m) which establish a reference level, a zero point of the coastline position and of the pebbles volumes along the cliffs between Antifer and the baie de Somme. The renewal of this technique or the comparison of these results to the previous data, produced surimposable information layers, giving a geographic information bank This bank allows a diachronic study of the coastal dynamics and forms a tool helping decision for the interregional coastal management.

The second step of this cooperation is the establishment of an interregional coastal observatory which must concentrate the past and actual information and will propose the future cooperation management.

The lesson learnt is that structural erosion cannot be stopped with hard constructions (impact of the groynes and harbour jetties modified the pebbles longshore drift and increased, locally, the cliff retreat.). In this situation, where there is only few houses, the politics are understood that the solution is the expropriation (7 houses in Criel sur mer).

4.2 Effects in neigbouring countries

this new management (cooperation at the scale of the natural phenomenon) will allow to limited the modification of the spatial pebbles repartition. More it's imagined to use "by pass" technical after each harbour jetty? This will reduce conflicts between townships, counties, or district.

4.3 Conclusions

- Nourishments will be a solution for reduce the sedimentary crisis of the pebble beaches. Nevertheless, this solution is again a project.
- Constructions have stopped local erosion of the coastline, but constructions always need maintenance, and modify locally the dynamics.

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