Monitoring Ploughing Activities during Submarine Pipeline Construction on different Seabed Substrata

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Resumen

Tecnoambiente S.L ha realizado dos campañas de geofísica y una oceanográfica en 2009 y 2011 respectivamente con el propósito de la construcción del gasoducto submarino *offshore* como parte del sistema nacional de infraestructuras energéticas de España; *The Balearic Submarine Pipeline Project-Mallorca Landfall area* and *The Castor Project* respectivamente*.* Batimetrías de precisión, morfología del fondo marino y resultados estratigráficos a lo largo de la traza, garantizaron la seguridad y coste económico mediante el uso del arado subacuatico como parte del proceso de instalación del gasoducto mediante arrastre. En el área de estudio del aterraje de Mallorca, los sedimentos son tipo fangos y grabas (73.3 % densidad relativa; 0.2 mm tamaño de grano) y en particular la presencia de praderas marinas por encima de ellos, diferenciándose de los sedimentos encontrados en el área de estudio al sur del delta del Ebro, con sedimentos tipo limos y fangos muy finos (25 % densidad relativa; 0.07 mm tamaño de grano). En consecuencia, las diferencias en el tipo de sedimentos requirieron arar a 1.5 veces más despacio sobre sustratos gruesos que hacerlo sobre sustratos blandos.

Palabras clave
Plataforma del Ebro; Bahía de Palma; gasoducto submarino; ingeniería marítima; arado subacuático; sustrato fondo marino; sustrato grueso-blando; praderas marinas.

Abstract

Tecnoambiente S.L carried out two geophysical campaigns and oceanographic surveys in 2009 and 2011 for the purpose of the offshore gas pipeline construction as part of the national energetic infrastructures system of Spain; *The Balearic Submarine Pipeline Project-Mallorca Landfall area* and *The Castor Project* respectively. *A*ccurate bathymetry, seabed morphology and stratigraphy results along the pipeline, guaranteed the safety and economical cost using the submarine plough process as part of bottom-towed pipeline process. Into Mallorca Landfall study area, there are clay and gravel seabed subtrata (73.3 % relative density; 0.2 mm particle size) and particularly presence of sea grass above of them, which differs from the seabed substrata encountered south of delta Ebro study area with silty sand and very soft clay (25 % relative density; 0.07 mm particle size). Consequently, these different sediment typologies required to plough at 1.5 times slower over coarse substrates than do it over soft substrates.

Keywords
Ebro Shelf; Palma Bay; submarine pipeline; marine engineering; Submarine plough; seabed substrata; coarse-soft substrate; sea grass.

1. Introduction

The seabed substart analysed and compared came from two sources: ***The Castor Project*** (The *CP* in advance) it is a submarine natural gas storage facility located south of the Province of Castellón (Spain). The sink can hold 1.3 billion cubic meters of gas. The plant facilities take the gas from the general gas grid for storage in the submarine underground. In order to do this, the 74 % of the gas run under the sea bottom, which connects the Ignacio Pérez inland plant to the offshore platform located 22.4 km offshore (64 m depth). The technique used is known as Plough and Backfill of sea bottom.
On the other hand, ***The Balearic Submarine Pipeline Project-Mallorca landfall area***

(The BSPPM in advance). It has been operating since 2009 in which we mainly focused during the construction and reinstatement of the landfall in Mallorca Island (Balearic Islands, Spain), with a total length of 15.2 Km (-40 m depth). Here also, Plough and Backfill engineering technique (more detail on section 2) allowed that gas pipelines run under the sea bottom.

The main objective of this article is to compare the differences of sea bottom typologies and how they affected to the plough and backfill processes used during the construction of geotechnical and oceanographic surveys that TECNOAMBIENTE S.L developed between 2008 (Contract No.341911) and 2011(Contract No.617508) from an environmental point of view.
The first study area analysed is *CP*. The project itself is made up of an area of approximately 4440 ha (22.4 Km length x 2 Km wide) and is located in the western Mediterranean Sea, 21.6 Km from the coast, and face to Vinarós town (Castellón). It is also coincident with the Amposta's old oil field. In particular, our study area is the anchor corridor that connects the seashore to offshore platform. The exact limits of Industry's Ministry concession are from 40º31'17"N/0º31'43"E and 40º23'57"N/0º43'26"E at the north-eastern merge and from 40º30'26"N/0º30'51"E and 40º23'06"N/0º42'34"E at the south-western merge (Fig.1).

Fig.1 *The Castor Project* study area, face to Vinarós town (Castellón).

The second study area is the Mallorca landfall area of *BSPPM.* It is made up of an area of approximately 191 ha (4.7 Km length x 400 m wide) in the Palma de Mallorca Bay. More concretely, our study area is a section of the total anchor corridor that connects from seashore in Sant Joan de Déu (eastern of Palma Mallorca's Port) till -40 m deep towards Ibiza seashore (with a total of 146 Km). The exact limits of Industry's Ministry concession are from 39º32'51"N/02º41'29"E and 39º'32'19"N/02º42'24"E at the northern merge and from 39º29'31"N/02º39'01"E and 39º28'53"N/02º39'28"E at the southern merge (Fig.2).

Fig.2 *The Balearic Submarine Pipeline Project-Mallorca Landfall area-Mallorca* landfall study area, located right in the middle of Palma de Mallorca Bay.

The surveys where realized during July 2011 (in the case of The *CP*) and in March 2009 (in case of The BSPPM).
The objectives of each project were:

1) ***The Castor Project****:* The Lay Survey Activities had the following goals:
- Obtaining the accurate bathymetry, seabed morphology and stratigraphy along the pipeline / Fiber Optic Cable (FOC in advance) route and Anchor Corridor
- Identifying and determining the position of any significant obstructions (debris, obstacles etc.) along the pipeline route, which could interfere with the laying of the gas pipe / FOC
- Verifying that route was clear of all debris and obstructions within the proposed trenching depth to confirm the acceptance of the route profile.

The Geotechnical Activities had the following goals:
- Acquiring all the geotechnical conditions of the seabed along the route where the pipeline would be laid and post trenched.

2) ***The Balearic Submarine Pipeline Project-Mallorca Landfall area***: *Plan de Vigilancia Ambiental* (PVA in advance) had the following goal:

-Studying how pipe laying activities affected *Posidonia oceanica* meadows.

1.1 Spanish Natural Gas Background

The use of the energy resources is a fundamental element for the economic development of any social group. In this respect, there are many kinds of planning studies that have concluded that natural gas is the most significant viable energetic alternative capable of responding to the future growing energy demands in an industrialized society like Spain.

Nonetheless, Spain is especially vulnerable to the increaing prices and to issues caused by the Natural gas storage and dependence on energy resoureces (97 % by the natural gas case) coming from foreign countries. In 2012, Natural Gas represents 18.7 % of the final type energy consumption in Spain.

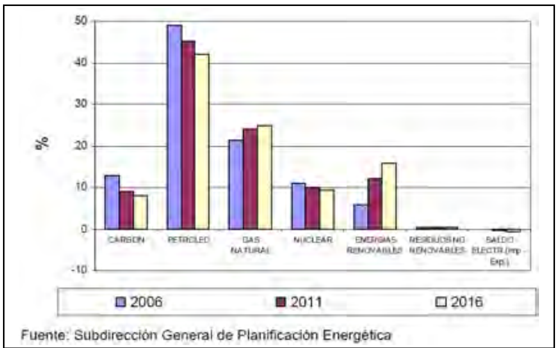
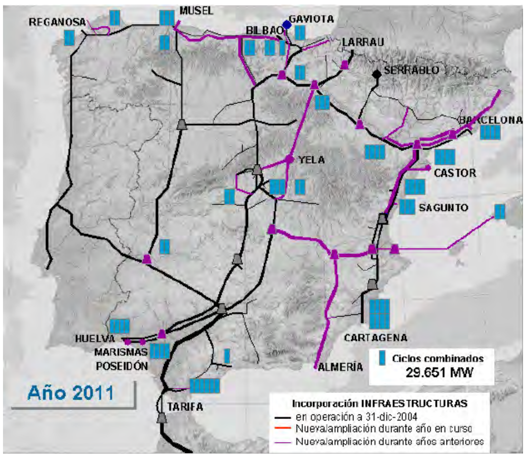


Fig.3 Primary energy consumption from 2006 to 2016 in Spain. Source: *Subdirección General de Planificación Energética. Ministerio de Indústria Turismo y Comercio.*

ENAGAS, as Technical Manager of the Gas System and the only transporter of the main primary network of natural gas in Spain, has also been the promoter of both study cases (*The Castor Project* and *The Balearic Submarine Pipeline Project-Mallorca Landfall area*) presented in this paper.



1.2 Similarities and differences between the two study areas

The CP and the *BSPPM* consisted in shallow water operations. These operations are generally defined as those where Pipeline Plough (PL3 in advance) is operated in water depths of less than 40 m. In these two study cases the majority of the pipeline route is at less than 40 m water depth. It is for this reason that special care was paid during all operations.

The similarities to use this plough engineering technique is because the objectives are similar: to avoid interferences with trawl gear pull-over and carry out combined loading, as the most remarkable fact by the BSPPM study case; and avoid to find out the artificial reefs structures (anti trawling fishing area) by the CP study area. Both cases are affected along the anchor corridor that lands with the seashore.

Due to the singulrity of this marine engineering activity developed in both study areas, we suggested analyse the results of both focusing the interest on the marine soil different.typologies.

1.3 Soil Type of the study cases

The margins of the Mediterranean Sea, and consequently their continental shelves are passive type (Maldonado, 1985). In our case, lift the front of the peninsula, mainly Catalonia and Valencia, passive margins can be considered classic, structured from holistic faults parallel to the margin (Nelson and Maldonado, 1990).

Fig.4 *Enagas' Gas Network. Source: Memoria Anual Enagás 2009.*

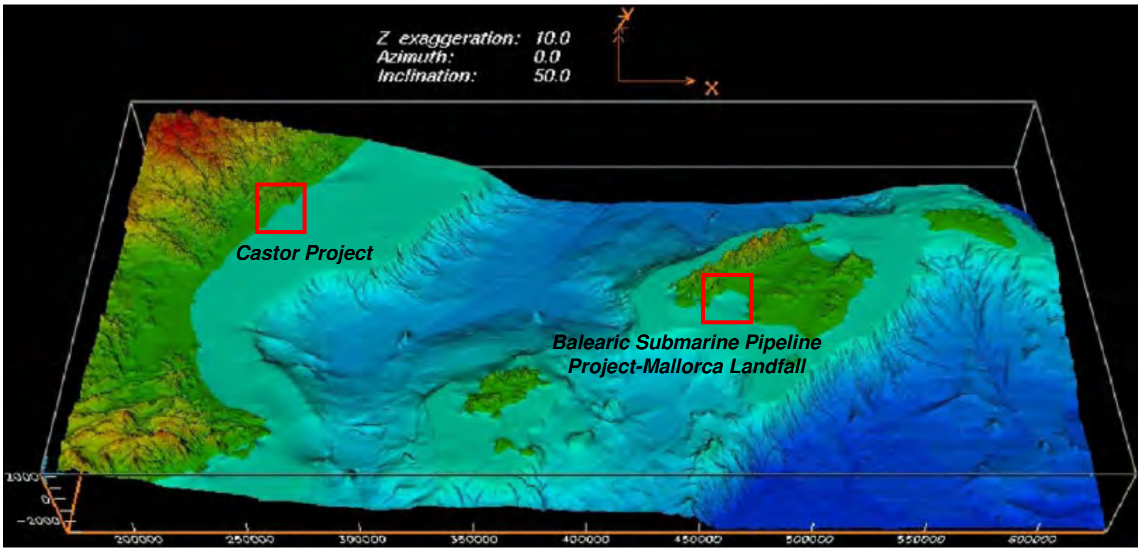


Fig.5 Bathy-topographic map of the Balearic Sea and Gulf of Valencia.(Posted by GRC Geoscience Marines, Fad. of Geology, Barcelona Univ. MBES & digital topography.(Earthvision©)). In red, study cases.

The Ebro Shelf

This is perhaps one of the best studied areas of the entire Spanish continental shelf. Scientific interest is due to the existence of significant natural resources that have conditioned intensive research carried out by the oil industry (Geological and Mining Institute of Spain (IGME) in 1986 (Nelson and Maldonado, 1990). The Spanish Mediterranean platform turns south at Tarragona width an average width of 15-20 km for a distance of 60 Km. This extension is kept until approximately the latitude south of Valencia, where it inflects again. Its remarkable extension must be attributed to sediment the River Ebro and its possible ancestors of the Miocene bottom; time begins to structure this continental margin.

In terms of evolutionary history, the margin is characterized by the interplay between thermal subsidences and fracturing, as well as eustatic changes that take place in a closed basin, modelled by establishing close connection at all times with the world's oceans. It is from the geometry and power margin deposits point of view that during the Pliocene progradation occurred most important Ebro margin, which gives its distinctive features and a great extension to the rest of Spanish banks of the Mediterranean (Dafiobeitia et al., 1990).

The Castor Project

As part of a geological/geophysical study, the soil conditions study is one of the most important. It's mandatory to clearly locate and identify which is the typology of the soil all along the future pipeline trench with the aim to minimize the engineering risks during construction and adapt all machinery to soil typologies.

According to MOPU-*Dirección General de Puertos y Costas* throughout Estudios Geológicos Marinos S.A consultancy (ESGEMAR S.A), the study area is composed by two (2) types of sediment: **Fine SAND** (0.250-0.125 mm) are generally present from -5 m till 18-20 m deep; and C**LAY** (<0.063mm) which are generally present from 18-20 m deep till the deepest part of our study area (-63 m deep, shown on Fig. 6)

According to Palanques et al. 1990, the study area is included in the prodelta zone of Ebro River, where the general structure of sediments (granulometric particules) is as follows: **CLAY and Very Fine SILT** (2 and 4 µm) as principal granulometric units. The inner platform located south of the delta, contains **Fine SILT** with a grain size between 10 and 20 µm (see Fig. 7).

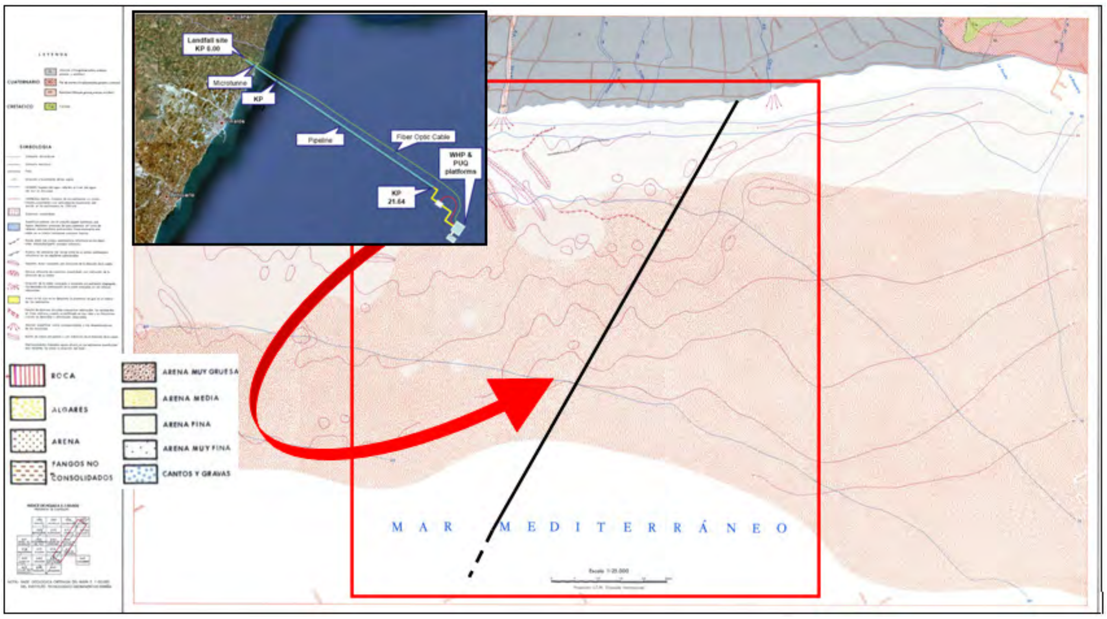


Fig.6 Bathymetry, Isopaques, soil type and littoral geology of Vinaròs (Castellón) seashore and surroundings. Source: ESGEMAR S.A consultancy (December 1988).

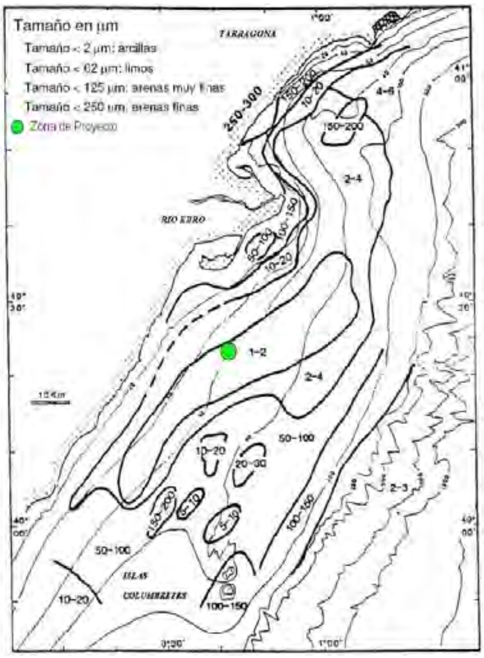


Fig. 7 Mean granulometric distribution (Palanques et al. 1990)

The grain size (conditioned by the distance with respect the coast: thicker closer to the shore and thinner further away) is crucial in determining the composition of organic matter, benthonic respiration, potential redox and even the heavy metal concentration in the study area.

The Balearic Promontory

The Balearic Islands - Menorca, Mallorca and Cabrera - and Pitiusas - Eivissa and Formentera – are located in the western-most part of the Mediterranean and are the emerged part of a large underwater, high promontory area known as the Balearic Islands. One of the main features of the promontory is that there are two different blocks in it: one of the blocks emerges northward with the islands of Mallorca and Menorca. A southward block protrudes creating the islands of Ibiza and Formentera.

The Balearic Promontory extends over 350 Km in a NE-SW direction and has a width of about 100 Km and a relative height of surrounding funds between 1000 and 2000 m (Acosta et al., 2002).

From the geological point of view, the Promontory is situated in the prolongation of the Betic system and is part of the Iberian Plate. The Valencia Furrow separates it from the rest of the Iberian Peninsula to the west, and the deep ocean basins of Provence and Algeria surround it. The Furrow of Valencia has a length of 400 Km and is oriented in a NE-SW direction, becoming wider and deeper to the northeast, where it reaches a depth of 2200 m.

The Provence Basin between Iberia (including the Balearic Promontory) and the European SO Corso-Sardinian block, has a triangular shape and a maximum depth of 2800 m. The Algerian Basin between Africa and Iberia, has a triangular shape and a maximum depth of 3000 m

The bark of the Balearic Promontory is continental although thin (with a maximum thickness of 25 Km). The bark of the Furrow of Valencia, also continental, is thinner than the Promontory (about 15 Km thick). The Balearic Promontory is subdivided into two blocks or platforms that rise above the surrounding seabed to depths of around 150 m, separated by the Mallorca channel which reaches depths exceeding 1000 m. The platform that surrounds the northern block, consisting of Menorca, allorca and Cabrera, is relatively close by their sides NW and NE (3 Km north of Mallorca) have relatively large for the SE and SW (35 Km SW of Cabrera). The boundaries or breaks in the platform are mostly steep and straight, highlighting the south-eastern boundary coinciding with the Emile Baudot Escarpment. The other side of the platform that surrounds the southern block consisting of Ibiza and Formentera is relatively wide in the west of the islands (25 Km west of Formentera) and about 10 km in other areas.

The Balearic Submarine Pipeline Project-Mallorca Landfall area

With the same objective, this study case in Palma de Mallorca Bay, is composed by four (4) types of sediment: **Very Fine SAND** (0.0625-0.125mm), **Medium SAND** (0.25-0.05 mm), **Very Coarse SAND** (1-2 mm) and the last and most characteristic substrata into the Balearic Island are the **Seagrasses** (MOPU- *Dirección General de Puertos y Costas.Demarcación de Costas de Baleares* throughout Instituto Español de Oceanografía). This last typologiy is made up of all superior plants (*Posidonia oceanica* in this particular case) forming meadows above the main substrate.So, the following Fig. 8 shows hypothetical distribution into the Palma de Mallorca Bay.

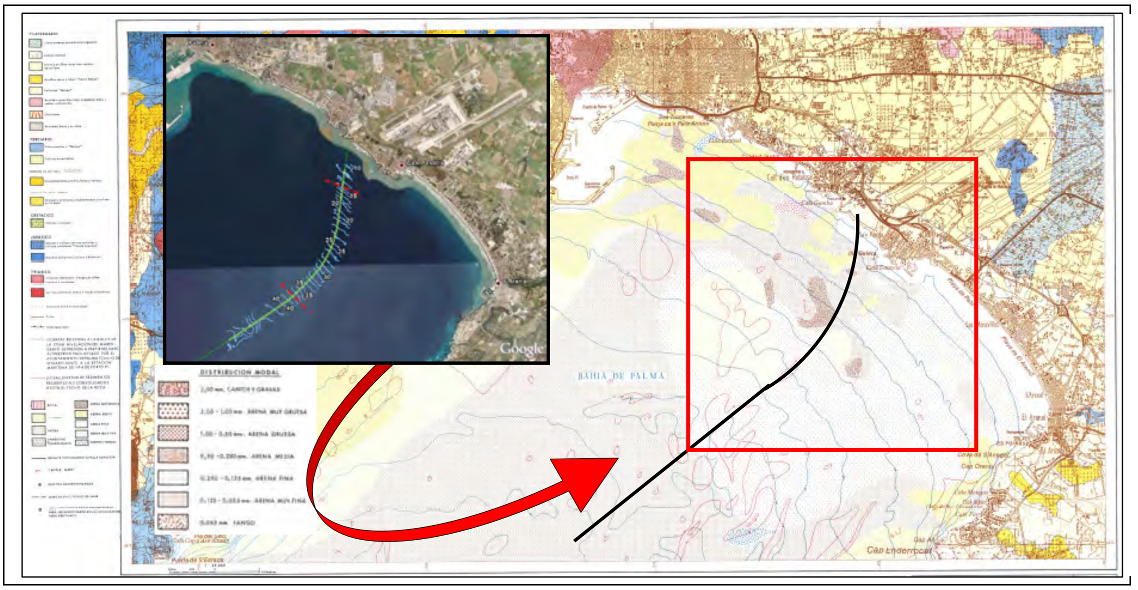


Fig. 8 Bathymetry, Isopaques, soil type and littoral geology of Palma de Mallorca Bay (Mallorca Landfall area). Source: Instituto Español de Oceanografía (July 1984).

1.4. Marine Engineering of Plough

The plough activity is part of the bottom-towed pipeline of marine engineering. Before ploughing, this method of fabrication whereby the pipeline assembly process, that is, the welding, inspection, joint-coating, and anode installation process is done on-board derrick/lay barge vessel, immediately prior to the pipeline going into the water. The assembled pipe is then towed to its designated position. The pipe is towed near the seafloor along a route that has already been pre-surveyed in order to identify any potential hazards. This method of installation is particularly well suited to pipe-in-pipe flowline assemblies. The only limitation of this technique is that exist an important risk if the pipe contacts with a subsea obstruction when it is laid down. Such damage could result in potentially catastrophic consequences if the integrity of the outer pipe, resulting in the exposure of future gas to the subsea environment.

Plough, by definition, is the act to turning up an area of the sea bottom forcibly with a plough. So, in this paper, the marine engineering employed consists in using the world's biggest submarine pipeline plough, PL3 (design of Engineering Business's company). The subsea plough was used to lower the pipeline below the seabed level using the PL3 ensures that the pipeline will remain stable in its position throughout its lifetime (50 years).

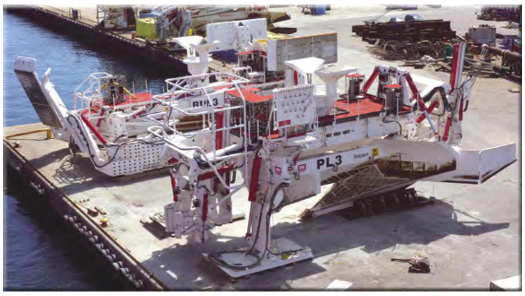


Fig.9 Image above, PL3 plough unit and behind it, a BPL3 (backfill) unit.

Subsea ploughs work much the same way as their land-based farming equivalents, except for that a subsea plough passes the pipeline through a pair of roller boxes in the body of the plough whilst the seabed is dug up as the plough advances. The PL3 plough raises the pipeline into its roller boxes using hydraulic grabs, and is then deployed, tended and towed by the survey vessels.

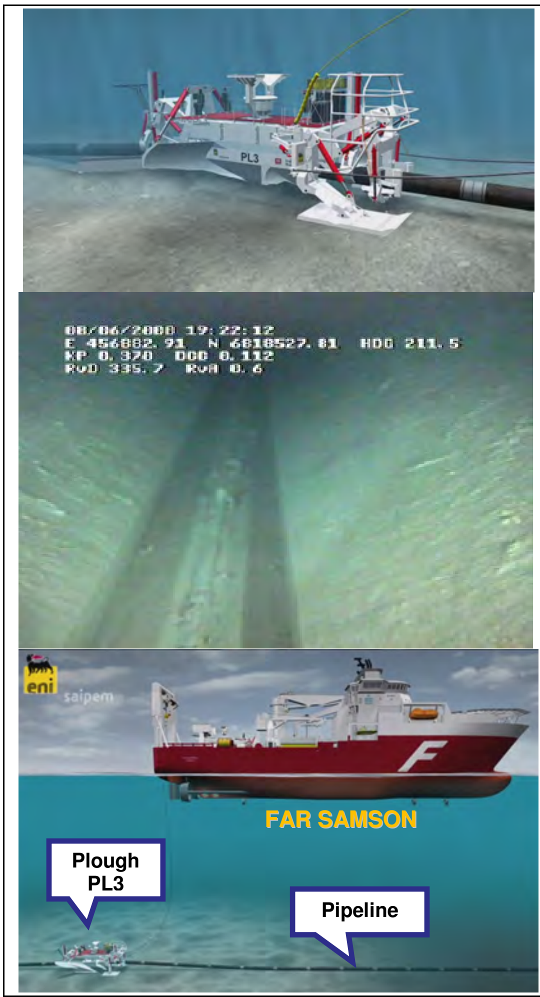


Fig.10 Part of the animation showing the process of how the PL3 places pipelines onto the sea bottom.

The PL3 multi-pass pipeline plough, which was designed for 350 t continuous bollard pull, it weighs approximately 200 tonnes and is 22 m long. It is capable of achieving a trench depth of 2.5m in a range of soil types and is designed to operate in water depths of up to 1000 m. The pipeline plough is capable of handling pipes between 75 mm and 1550 mm diameter.

Plough Survey Vessels

SSV (Subsea Support Vessel) "Far Samson" was used during the *CP* ploughing activities and finished during 2009 and the multipurpose offshore support DP vessel Far Sovereign was used during the *BSPPM* plough. Both of them were the supplier vessels that towed the PL3 & Backfill Plough (BPL3 in advance), creating a trench of a pre-determined length, depth and width into which the pipeline was laid as the plough progressed.

Classification:
DNV +1A1, supply vessel basic, tug, clean design, E0, SF, DYNPOS, AUTRO, COMF-V(3)-C(3), HELDK-SH, NAUT OSV A, Ice 1B (hull only)

Dimensions:
Length: 121.5 m
Breadth: 26 m
Depth: 10.5 m
Draft: 7.0 m
Gross tonnage: 12,000 t

Tonnage capacities:
Ballast water: 4,000 cu.m
Production water/fresh water: 3,000 cu.m
Fresh water: 1,200 cu.m
Fuel oil: 3,500 cu.m
Fresh water watermist tank: 60 cu.m
Deck cargo: 2,000 t
Main deck closed area, 10 t/sq.m: 430 sq.m
Main deck/winch deck aft, 10 t/sq.m: 720 sq.m
A-deck, 15 t/sq.m: 1,450 sq.m
ROV hangar, A-deck, 10 t/sq.m: 200 sq.m

Accommodation:
100 persons in 61 cabins

Fig.11 SSV "Far Samson" used during The Castor Project pipelaying.

Classification:
DNV +1A1 Tug Supply Vessel, SF, EQ, Ice C, OIL REC, Fi-Fi I Fi-Fi II, DYNPOS AUTR, TMON

Dimensions:
Length overall: 85.2 m
Breadth moulded: 20.5 m
Depth moulded: 9.50 m
Gross tonnage: 4,400 t
Main deck area: 680 sq.m

Main propulsion:
2 x main propellers 7,940 kW each
Thrusters: 2 x Sidethrusters aft 883 kW each
1 x Sidethruster fwd 1,200 kW – 1 x Azimuth fwd 1,620 kW
Bollard pull: 280 t

Dynamic positioning:
DYNPOS AUTR NMD Class II - ERN 99/99/99

Lifting facilities:
"A" – Frame 270 t SWL Stern "A" – Frame
1 x main crane 100 t double fall @ 10 m radius
1 x aft crane starboard 10 t single fall @ 12 m radius
2 x auxiliary cranes 6 t single fall @ 8 – 15 m radius

Pipe trenching equipment:
PL2 advanced pipeline plough – BPL2 pipeline backfill plough

Crew facilities:
Accommodation up to 63 people

Helideck:
Suitable for Super Puma AS332

Fig.12 The multipurpose offshore support DP vessel "Far Sovereign" used during The *Balearic Submarine Pipeline. Project-Mallorca Landfall area* pipelaying.

After the completion of the first pass, an intermediate survey was conducted prior to the second pass in order to assess that area is in "as trenched" condition of the pipeline. Then the backfilling operation was done by the BPL3 unit. The operation consisted of refilling the excavated hole with the material that had been dug out of it. The BPL3 is designed for 150 t maximum bollard pull and because its front skids run outside the trench, it is also aimed at reducing the risk of damages to the trenched pipline. As a result, it has been designed to fold onto itself for launch and recovery, much like a spider.

The "Far Samson"/"Far Sovereign" performed the low pass. The BPL3 runs through the trench produced by the trenching plough and is capable of following and returning spoil to a pre-formed trench between 0.5 m and 2.0 m in depth.

So, by the case of plough operability and following the pipe-laying activities, pipelines were ploughed to a target depth of 1.5m below of pipe. Then, upon completion of trenching operations and as soon as was practicable the two offshore submarine pipelines, they were mechanically backfilled to achieve a minimum 0.5 m top of pipe.
In the event that soil conditions or operational parameters required the use of additional tugs, these could be connected to the bow of the vessel demonstrating the possibility of using an extra plough (mechanical power applicable) in case that hard substrate sea bottom were to appear in the study area.
Adjustable cradles were connected to the main chassis at the front and rear of the plough with pivoting hydraulic linkages. On these cradles were rolling carriages, to support the pipe during ploughing operations and the loading of equipment used to raise and lower the pipe to and from the seabed. The skids, towing and steering equipment were located at the front of the main chassis while the lifting, control and instrumentation systems and power pack were are located on top of the chassis.
So, for the case of plough operability, some buoyancy tanks were installed on PL3 and BPL3 due to the soft soil conditions. PL3 also had 1.5m keel extensions fitted to it in order to increase bearing capacity in the soft soils.
The first pass for the entire length of the route was performed with the mouldboards lowered to allow for the completion of a second pass where required. Following completion of the first pass, an intermediate survey took place in order to determine the achieved depth of lowering of the pipeline. Following completion of the second pass, an as-trenched survey was performed.
The pipeline was trenched in the empty condition and backfilled in the flooded condition following commissioning process.
There were no crossings units along the pipeline route and a 2nd pass was performed locating the routing wrecks up bends of 2000 m radii wide.

The Balearic Submarine Pipeline Project-Mallorca Landfall area

As was mentioned in the Introduction of this paper, the PVA developed by Tecnoambiente S.L intended studying of the *Posidonia oceanica* meadows affected by pipe laying activities (Fig. 19). In this particular study case, the surveillance performed was carried out over a period (2010-2012) after the completion of activities, with one campaign each year (during the winter). In detail, the campaign was done by professional divers at same time with scientific knowledge about sea grass meadows.

2. Material

The Castor Project

- SBP (Sub Bottom Profiling): here the model used was K-Chirp 3310: (Klein Associates Inc.)
  Pulses ranging from 2 to 8 Khz. It detects type soils from 5 to 50 m depending on the conditions of the subsoil, with an operational resolution of up to 15 cm. Therefore, soils can be detected in sufficient detail; thicknesses of sediments not consolidated (sands, gravels, mires ...) paleochanels, buried reefs, accumulations of shallow gas, gas manifestations,etc.
- SSS (Side Scan Sonar): here the model used was 3000(Klein Associates Inc.).

Pulses ranging from 100 to 500 Khz. It detects type soils till 600 m.

- MBES (Broadband MultiBeam Echo Sounder): here the model used was R2Sonic 2024. Selectable frequency range of 200 kHz to 400 kHz. Selectable opening angle, from 10° to 160°, using all 256 beams.
- Vibrocorer samples. The model used was the Rossfelder P-3 which obtains samples of the seabed terrain through a core trusted by vibrate-percussion in the soil.
- Bottom Grab Samplers. The model used was Van Been grab, a lightweight sampler designed to take large samples in soft bottoms terrain.

During this survey, carried out from July 3rd to 17th, 2011, the surveyor vessel "Isla de Alborán" was built in 1988 as a fishing boat for use in the Mediterranean catch encircled by the "Astilleros Lehimosa" Vinaroz (Castellón). In 1999, a series of improvements were made on the vessel and similarity in 2005, further reforms were carried out to adapt to constantly changing sector.
The methodology (according to schedule) allowed for two days of mobilization people, the vessel and equipment; two days of vibrocorers sampling, extracting 15 samples with a minimum of 3.5 m corer corresponding to the geological campaign; four days of equipment calibration and validation for the geophysical survey; four complete days of required data acquisitions (24 hours, over a 4440 ha surveyed area); and finally two extra days for the demobilization of the campaign.

The Balearic Submarine Pipeline Project-Mallorca Landfall area

- Bottom Grab Samplers. The model used was the Van Been grab, a lightweight sampler designed to take large samples from soft bottoms terrain.
- Analysis of the benthonic parameters of the *Posidonia oceanica* meadows.
- Quantitative study of the benthic macrofauna.
- Underwater cameras and diving activities.

During this survey, carried out from Mach 5th to 14th, 2009, two different vessels were used during operational sampling: the "Burbujita" and the "Mirafons".
The methodology (according to schedule) allowed for one day of mobilizing people, the vessels, and equipment; two days of diving for macrofauna sampling; and finally one final day for the demobilisation of the campaign.

3. Results

A description of the surficial substrata of the seabed is considered essential in generating ecologically relevant seabed types, as the type of substratum has a strong influence on the nature of the biological comunities it supports.
In this particular study, we define the word soil as the entire unconsolidated earthen material that overlies and excludes bedrock. It is composed of loosely-bound mineral grains of various sizes and shapes. Due to its nature of being loosely bound, it contains many voids of varying sizes. These voids may contain air, water, organic matter, or different combinations of these materials. Therefore, an engineer must be concerned not only with the sizes of the particles but also with the voids between them and particularly what these voids enclose (water, air, or organic materials).
Soil formation is a continuous process and is still in action today. The great number of original rocks, the variety of soil-forming forces, and the length of time that these forces have acted all produce many different soils. At a particular area are usually several

layers (strata), one above the other, each composed of a different kind of soil. Strata may be a fraction of a centimeter or many meters thick.

A soil's physical properties (grain size, particle shape, gradation, density. specific gravity, moisture, consistency and organic soil) help determine the marine engineering characteristics by construction process. The discussion of the physical properties of soil focuses on the soil particles themselves. Physical characteristics of soil particles include size and shape. The proportions of different-sized particles determine an aggregate's gradation.

Soils are divided into groups based on the size of the particle grains in the soil mass. Common practice is to distinguish the sizes by using sieves. A sieve is a screen attached across the end of a shallow, cylindrical frame. The screen permits smaller particles to fall through and retains the larger particles on the sieve. Sieves with screen openings of different sizes (the largest on the top and the smallest at the bottom) separate the soil into particle groups based on size. The amount remaining on each sieve is measured and described as a percentage by weight of the entire sample. Soil seldom exists separately as sand, gravel, or any other single component in nature. It is usually a mixture with varying proportions of different-sized particles. Each component contributes to the mixture's characteristics. The accurate completion of the sieve-analysis test will produce the percent of gravel, sand, and fines of the material. The most accurate process fort his test method is to wash the material over the sieves; this will give a more accurate percent of fines.

The standard grain-size- analysis test determines the relative proportions of different grain sizes as they are distributed among certain size ranges, which are referred to as particle-size or grain-size distribution.

The Castor Project

From the results obtained during the **vibrocore campaign** and geophysical survey, we identified into the study area two (2) essential types of soil in the study area: **Silty SAND** and **Very Soft CLAY** summarized into Table 1 according to the Kilometer Point (KP in advance) range we are considering.

In this case, a mixture occurs, so the primary name is the predomnant fraction, in perecnt by weight, and the minor fraction is used as an adjective (for instance. Silty Sand). When the objective is achieve uniformity in estimating the consistency of soil (Terzaghi Clasification; Table 1a) based on unconfined compressive strength be used as a tentative standard (for instance, soft: 0.25 to 0.50 Tons /Sq Ft).

Table 1a) The *Castor Project* KP ranges with two Soil type encountered according to Terzaghi Clasification in terms of consistency (Unified Soil Classification System-ASTM Designation D-2217-85. Field Manual: 5-472 NAVFAC MO330 AFJMAN 32-1221(I), Materials testing. Appendix B); Table 1b) Same The *Castor Project* KP ranges with relative density (D_r) and Grain diameter at 10 percent passin (D_{10}) results.

a)

Zone	KP Range (km)	Section Length (m)	Soil Type
1	1.1 – 5.5	4,400	Silty SAND
2	5.5 – 7.5	2,000	Very Soft CLAY
3	7.5 – 9.5	2,000	Silty SAND
4	9.5 – 21.6	12,100	Very Soft CLAY

b)

Zone	D_r (%)	D_{10} (mm)	Undrained Shear Strength (kPa)
1	30	0.07	-
2	-	-	7
3	20	0.07	-
4	-	-	7

The structure of the aggregat of soil particles may be dense (closely packed) or loose (lacking compactness). A dense structure provides interlocking of particles with smaller grains filling the voids between the larger particles. When each particle is closely suttounded by other particles, the grain-to-grain contacts are increased, the tendency for displacement of individual grains under a load is lessened, and the soil is capable of supporting heavier loads. Coarse materials that are well-graded usually are dense and have strength and stability under a load.

Table 2 Density of the soil at The *CP.*

Parameter	Value
Minimum Soil Density	1930 kg/m^3
Average Soil Density	2930 kg/m^3
Soil Angle of Internal Friction	25.0 Degrees

The submarine gas pipline route presented into near shore (KP 0.420) occasional area of rock outcrop and coarse sediments. In these cases, ploughing activitiy was substituyed for the dredging technic. Consequently, this shallow area is not considered in the analysis.

According to **biological features (flora)** observed during underwater filming all along the trench (from -6 m till 62 m depth) just into the near shore , there were: scattered bushes of sea geass *Cymodocea nodosa* (-8m depth with one meter wide) and *Caulerpa prolifera* at sandy and isolated cases of very low densities.

By the other hand, according to **biological features (fauna)** where abundance (relative representation of a specie); richness (number of different species in a collection of individuals); biomass (plant matter)or diversity (variety of species) provide a useful (and more broadly applicable) description of the macrobenthic community representing the effects of ploughing activities in this study is of Vinarós. These indexes facilitate the understanding of complex benthic data, summarizing a considerable amount of ecological information into a single representative value.

The results of this study indicate that for the species of the benthic macrofauna (basically polychaetes (71 %); Crustacea (14 %) and Bivalvia (11 %) others (4 %), in the area affected by the ploughing activity, their recruitment took place with a lower intensity (in a factor of time) respects to a normal condition (Tecnoambiente, 2012).

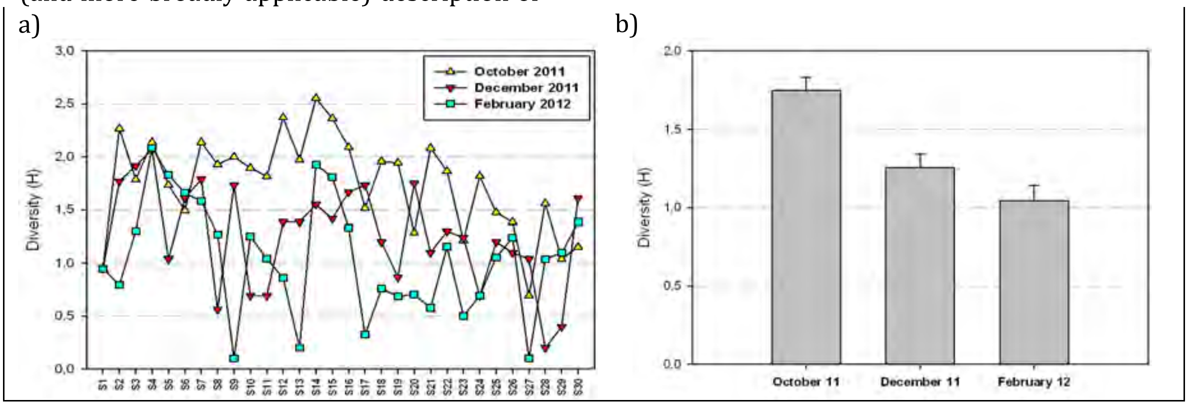


Fig.13a) Shannon index (H) by station and periods of plouging activities at The *CP*; b) Diversity (mean sampling values joined by periods) during plouging activities at The *CP*.

Shannon-Wiener Index is a diversity measure came from information theory and measures the order (or disorder) observed within a particular system. In ecological studies, this order is characterized by the number of individuals observed for each subspecies in the sample plot (zone on our site). It has also been called the Shannon index and the Shannon-Weaver index.

Similar to the Simpson index, the first step is to calculate P_i for each category subspecies. You then multiply this number by the log of the number. While you may use any base, the natural log is commonly used. The index is computed from the negative sum of these numbers. In other word, the Shannon-Wiener index is defined as:

$$H = -\text{sum}\ (P_i \log [P_i])$$

The substrate determines to a large extent the presence or absence of a particular benthic species and modifies the effect of disturbance on the benthic community (Greene et al. 1995, Auster & Langton 1999). So, analysis indicates the presence in the study area of a typical macrobenthic community of disturbed areas with a relatively simple ecological structure (low-medium diversity, presence of a small number of taxonomic groups, presence of opportunistic species with cycle's very short life) (Tecnoambiente, 2012).

Observed fluctuations during activities of ploughing, the ecological parameters can be ascribed to the strong disturbance of the macrobenthic community in this area, with significant variations of the substrate characteristics, which determine the alternating phases of recovery to phases of regression. The presence of these phases of regression and recovery is due to the instability of the macrobenthic community that reflects the instability of the sediment due to the proper plough activities itshelf. It is therefore expected that this phase lasts until it has reached the substrate stability (Tecnoambiente, 2012).

On the other hand in the present study exists an effect due to the time of the year, (sampling time) that has not been possible to separate from the ploughing effect. The structural parameters of macrobenthic community (diversity, richness, density, etc.) of the western Mediterranean, during autumn - winter reach the lowest values, due to low temperature and low nutrient availability. In normal conditions abundance and biomass of structured macroinfaunal assemblages at sublittoral zone of the studied area showed clear seasonal trends. Abundance and biomass rose sharply during spring, followed by a striking decline through summer and lower values during autumn and winter. This seasonal pattern is common throughout the western.

Fig.14 Images of silty SAND and very soft CLAY substrata of the Castor Project seabed.

The results obtained during **batihymetric profile survey** of The *CP* along the route, are summarized into Table XX. Basically varies in depth from -64 m Water Depth (WD in advance) at KP 22.4 to – 1.3 m WD at KP 0.115 (MSL of Alicante).

Table 3. Gas Pipeline route gradients

Section	Initial KP	Depth (m)	Final KP	Depth (m)	∇ Mean Gradient		∇ Maximum Gradients Up Hill	∇ Maximum Gradients Down Hill
1	0.114	-1.3	0.450	-7.9	Slope	-1.13°	2.39°	-4.76°
					Gradient	-1 : 51	1 : 24	-1 : 12
2	0.450	-7.9	2.154	-14.6	Slope	-1.13° to -0.06°	0.00°	-1.43°
					Gradient	1:-51 to 1:-955	∞	-1 : 40
3	2.154	-14.6	6.198	-18.9	Slope	-0.06°	0.95°	-0.95°
					Gradient	-1 : 955	1 : 60	-1 : 60
4	6.198	-18.9	11.202	-29.3	Slope	-0.06° to -0.18°	0.48°	-0.48°
					Gradient	1:-955 to 1:-318	1 : 119	-1 : 119
5	11.202	-29.3	17.502	-49.4	Slope	-0.18°	0.48°	-0.95°
					Gradient	-1 : 318	1 : 119	-1 : 60
6	17.502	-49.4	21.842	-59.9	Slope	-0.18° to -0.13°	0.52°	-0.95°
					Gradient	1:-318 to 1:-441	1 : 110	-1 : 60

Positive sign for gradients and slope means Up Hill, negative sign means Down Hill, in ascending KP direction.

The results obtained during **Sub-Bottom Profile survey**; here it's summarized the results obtained:

As it is observed in Fig. 15a), presented the minor thicknesses of not consolidated sediment present in the shallowest zone of the corridor there managing to be detected the beginning of a rocky outcrop at KP 0.420.

From this point moving in direction away from shore, the trend of the sedimentary powers is increasing coming to -4 and -5 m about the KP 1.000 and reaching -10 m in the proximities of the KP 4.500, always with small lateral variations.

The KP 4.500 point is where the increase of the thicknesses of sediments not consolidated was detected coming from values of -15 m in the surroundings and reached them -17 m, near the KP 6.000. This KP represents also the point where, suddenly the isopaque goes from -17 m (6 or 7m) and immediately afterwards is established in the latter values up to the KP 8.500 from which it begins a soft increase of the thicknesses reaching 10 m.

The following change detected happens approximately in the KP 10.800 where values change from -10 m to -16 m, with maximums of -20 m in the part NEE. This change kept approximately 500 m herein after geting to the KP 11.300 where we return to thick of 6 and 7 m that are kept up to the KP 12.000.

The KP 12.000 is the point where the change we have observed repeats itself again. This time, however, thicknesses superior reach upwards of 20 m at KP 10.800 m.

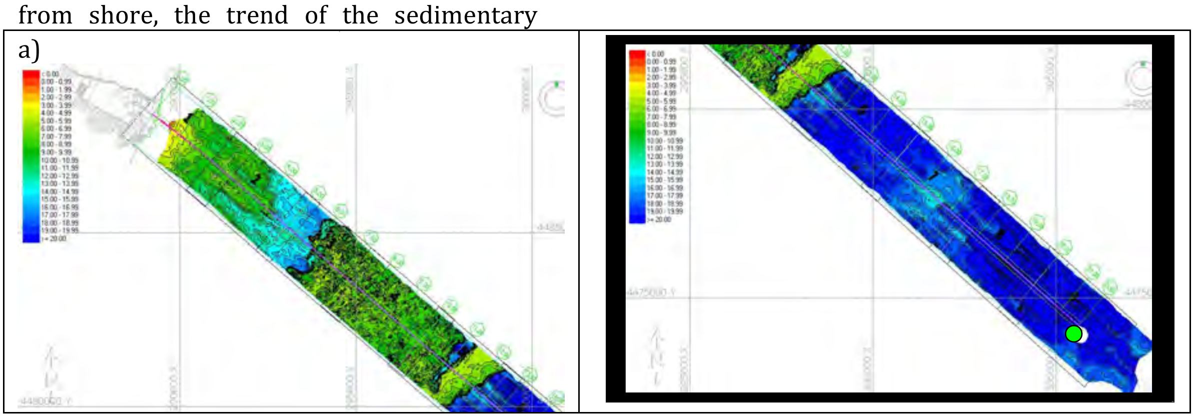


Fig. 13a) Isopaques for the area located near shore; b) Isopaques for the area located Offshore.

In Fig. 13b), which comes from the KP 12.000 until the end of our study, the zone presents thicknesses detected almost always superior to 19 m managing to reach -30 m of not consolidated sediment.
The exception of the whole this zone located between the KP 15.500 and the KP 17.500 as well as in the end SSE of the corridor where minimal thick detected approaches 13 m.

Stratigraphy description of the pipeline route

The survey area falls within the inshore section of continental shelf within the sub littoral zone. Continental shelves are typically associated with fast sedimentation rates of on between 15- 40cm/1000yrs. Sands are limited to the high impact surf zone and become increasingly fine and pelagic in deeper low energy waters offshore.

Holocene Deposits:

-The <u>Surface Unit</u> represents the current depositional regimes at work. Fine sands in the intertidal zone, grading to clay in an Offshore direction.

- <u>Unit 1</u> represents migrating Ebro River/Delta channel deposits, and is expected to be predominantly CLAY. The base of this unit cuts uncomfortably into underlying <u>Unit 2</u>.

Table 4. Geological Units summary

Profile Name	Geological Period	Description
Surface Unit A	Holocene	Silty SAND with Shells.
Surface Unit B	Holocene	Clayey SILT with Shells
Unit 1	Holocene	Sandy SILT
Unit 2	Holocene	Interbedded Stiff CLAY and Sand
Unit 3	Pleistocene	Clayey SAND
Unit 4	Pleistocene	Stiff Clays
Unit 5	Miocene	Conglomerate

Pleistocene Deposits:

-<u>Unit 3</u> and <u>Unit 4</u> represent remnant intertidal channel deposits within the sequence indicating rise in sea-level and subsequent coastline regression, (possibly associated with the end of the last maximum glacial period). These units are partially eroded, unconformably onlapped by overlying Unit 2 and pinch out in a shoreward direction. They may be the source of the biogenic gas present in the sequence.

Miocene Deposits:

-<u>Unit 5</u> is a conglomerate of varying lithification and cementation, located at depth where ploughing are not affected by.

We have used Fig. 14-16 below to illustrate and present the seismic general features profile of the Central Line where Units are represented except Unit 5 becasue SBP doesn't reach those depths.
We have divided the line into 4 parts of approximately 6 km each in order to present it in a practical way. The image presented may have graphical deficiencies, but on the whole, it permits us to observe and to clearly present the principal characteristics along the whole central line of the corridor therefore permitting us to hereby all the geophysical and physical phenomena that the sedimentary sequence in question presents.

In the first section, AB (Fig. 14), the most remarkable observation is the rocky outcrop present at the beginning in the proximities of the KP 0.420. From this point, the rocky horizon dives into the subsoil and doing of wall for the sediment not consolidated of the zone.

Fig. 14 Section AB of the geophysical profile of the Central line where every section is georeferenced by means of the KP that correspond to each of them.

This section also presents a surface of erosion that has given place to a sedimentary landfill in the proximities of the KP 5.000.
Regarding the materials that compose the sedimentary present units and according to its geophysical answers (extent of reflectivity and organization of the internal reflectors) shallow zones go of sands with a chaotic organization in consequence of the regime hydrodynamics present and as we move away from the coast there is more presence of thins. Treating itself about sequence sedimentary transgressive about the holocene, all the Units were presenting similar bosses regarding the negative particle size distribution from the coast towards sea to inside and from wall to I roof always with the reference of the level of the sea of its geological time.

The section BC (Fig. 15) have an acoustic blanking becasue the response that takes place when there is almost total absorption of the emitted sign produce a total masking of the seismic record. The cause in our study case is the accumulation of gas in the sediments. The response of the top limit of this type of accumulation is marked by the presence of a reflector (generally flat geometry) that in detail gives a diffuse reflection.

Fig. 15. Section BC of the geophysical profile of the Central line where every section is georeferenced by means of the KP that correspond to each of them.

The acoustics columns sometimes manage to reach the surface of the sea bed giving place to what there is called as PockMark that show generally a vertical section in the shape of "U" on the surface of the bottom almost 8 m x 5 m in flyview and almost 2 m of depth

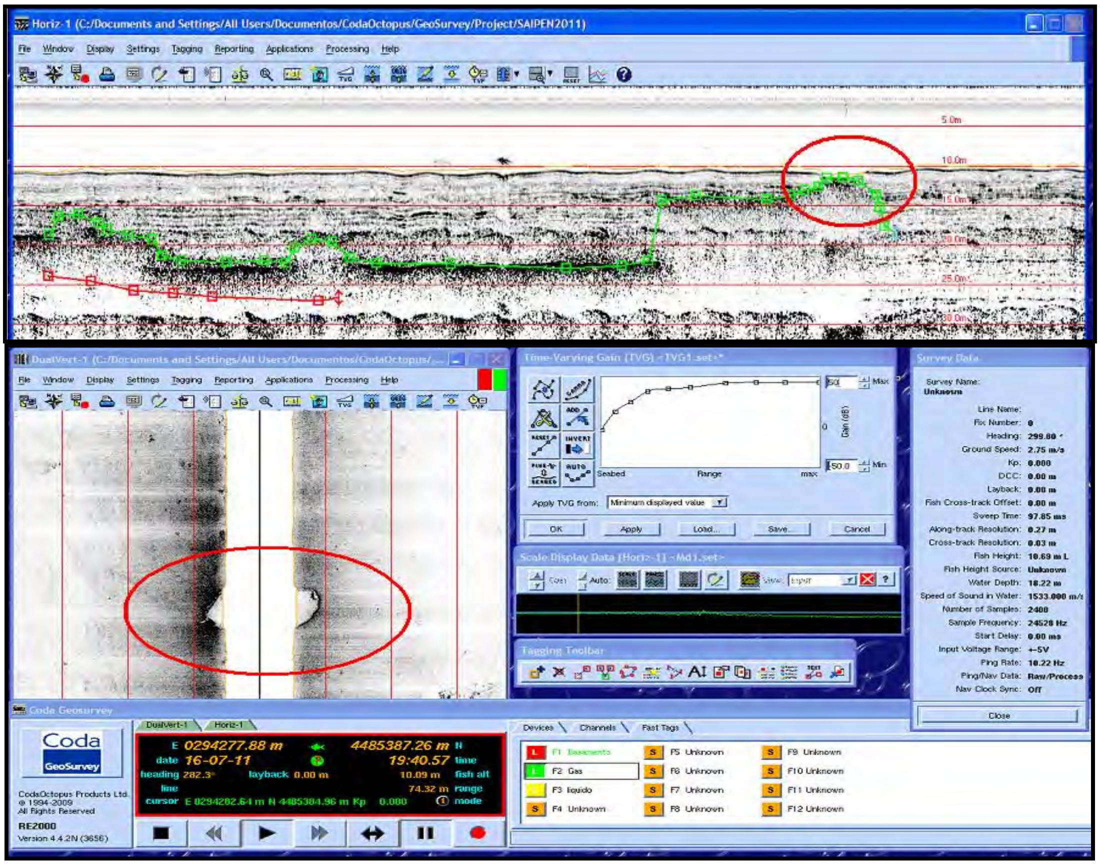


Fig. 16 Record SBP and SSS where the detection of a pockmark is observed where the present gas in the sediment reaches the marine surface.

In the following two sections CD and DE (Fig. 16) due to decreasing penetration of the signal, reaching 30 m, it's a great indicative where the materials are in general thin or very thin. All the Units in both sections present internal definite good reflectors proved from changes of densities inside the same Unit.
The Unit 4 that its ceiling presents in some zones surfaces of erosion.

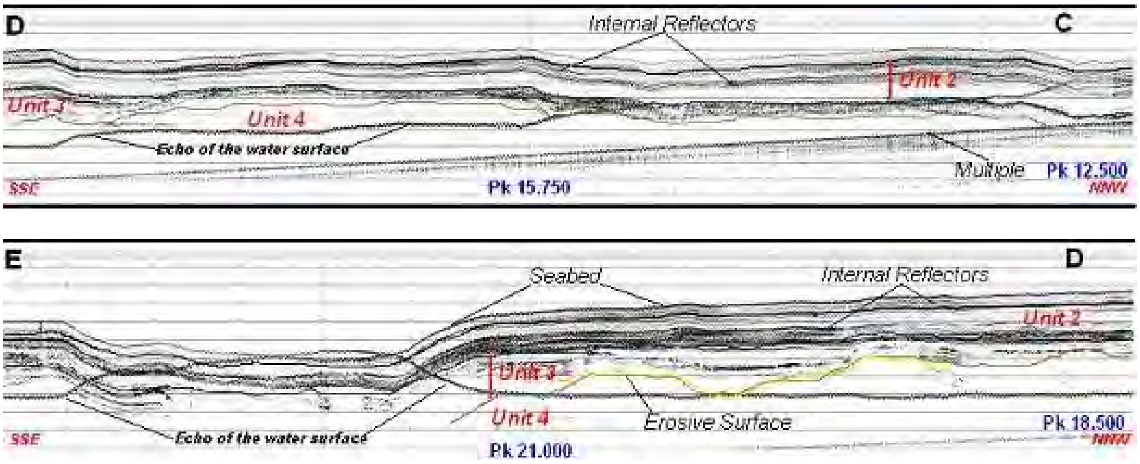


Fig. 16 Section CD and DE of the geophysical profile of the Central line where every section is georeferenced by means of the KP that correspond to each of them.

The Balearic Submarine Pipeline Project-Mallorca landfall area

The Mallorca landfall area is composed for several typologies of material but the most relevant is called Biogenic morphology of mix character. It's resulting from a several biological and geological combined processes.
The dense populations of macrofits, act as traps that catch the sediment. They determine a particular morphology that remains defined by reliefs similar to the bars in the shape of mounds of certain entity. Though also they are in flat surfaces, in the shape of submarine meadows of variable dimensions, depending on his different degree of development. They develop parallel to the shore profile, as consequence of the narrow existing relation between the development of the benthonic species and the gradient of depth. From the 35 m of deep, and therefore the associate morphology, they begin to be more dispersed and of minor growth (Palomino, et al. 2009).

From the results obtained during Environmental Surveillance Plan, we identified into the study area six (6) types of soil substrata: unconsolidates as **SAND, CLAY** and **GRAVEL** and as consolidates, **Conglomerate, Cobbles** and **Calcarenite** summarized into Table 5 according to the KP range we are considering.

Observing into Fig.17 and Table 5, the sediment typologies have a distribution much more disperse or chaotic making this ploughing service very exceptional and dangerous. Our particular interest is about the presence of meadows of ***Posidonia ocanica*** above the soil type making this survey singular and environmentally difficult

There are few geological studies carried out in the Bay of Palma and De Buen (1916) considered general aspects of the sediments at the bay, Diaz del Rio and King (1987) studied the structural and neotectonic and Diaz del Rio et al. (1993) analyzed its major physiographic features, therefore, there are still little known of morphological features in Palma Bay and the environmental processes that control the recent sedimentations.

The bay of Palma has an area of 250 Km^2 (17 Km by 19 Km) and its depths increase uniformly in the southwest direction, reaching 70 m at the outer boundary of the bay. It is limited to the northwest by the stowage Sierra de la Tramontana, characterized by steep areas and coves, which are oriented in a NE-SW direction. The southeast portion is defined by a zone of low cliffs, the Cap Blanc area, which corresponds to the continuation of the Serra Central, differentiating two sections of NE-SW direction connected by a third NW-SE. Finally, in the central part of the bay display a set of sedimentary systems that are oriented in a NW-SE direction (Díaz del Río et al., 1993) on the settles the Arenal beach

Table 5. The *BSPPM* landfall area pipeline route soils survey summary and their geographical localization. Source: Pre-lay survey & geotechnical activities of Saipem (2008).

Sample Ref	Approx KP (km)	Water Depth (m)	Soil Type (core sample)	Relative Density DR %	Particle Size D10 (mm)
MBNSM08	145.705	11.7	0.0-0.8m: Fine to coarse SAND 0.8-1.8m: Dense fine to coarse SAND 1.8-2.3m: Moderately strong CONGLOMERATE comprising 50% fine and medium GRAVEL, 50% fine to coarse SAND	85	0.20
MBNSM10	145.705	11.7	0.0-1.0m: Fine and medium SAND 1.0-1.6m: Medium dense fine and coarse SAND, GRAVEL and COBBLES 1.6-3.2m: Weak CONGLOMERATE comprising 60% medium and coarse SAND, 40% fine and medium GRAVEL	65	0.16
MBNSM12	144.905	16.5	0.0-0.8m: Fine to coarse SAND 0.8-1.0m: Coarse GRAVEL and COBBLES 1.0-2.1m: Moderately weak to moderately strong CALCARENITE	75	0.20
MBNSM14A	144.505	19.2	0.0-0.30m: Slightly gravelly fine to coarse SAND 0.3-1.50m: Medium dense fine to coarse GRAVEL 1.5-3.5m: Dense and very dense GRAVEL and COBBLES	60	0.20
PCPT-EOI-30	143.205	25	0.0-1.6m: Very loose to loose SAND 1.6-2.1m: Firm to stiff CLAY	80	0.10
VC-EOI-09a	141.005	40	0.0-0.6m: Fine to coarse SAND 0.6-2.0m: Very weak CALCARENITE strongly cemented between 1.62-1.68	75	0.10

Fig.17 Examples of sand and gravel sediment typologies of the *BSPPM* landfall area sea bottom with presence of *Posidonia oceanica* forming part of big meadows.

In the Bay of Palma, there are two different physiographic domains that correspond to the litoral region and the continental shelf. In the littoral dominance has only distinguee infralittoral subdomain, reaching the lower limit till -30 m depth. The continental shelf is relatively broad, and includes inner and half shelf sectors.
The waters of the Bay have dynamic oceanographic characteristics of low energy and water mass inside of it that is highly protected while resting against the waves and currents.
Under a morphological aspect, we observed that soil into study area it's biogenic (resulting from the activity of living organisms). The shapes of this kind of soil are due to settlement of macrobenthonic communities'. The dense populations of macrophytes act as sediment trapping traps. They determine a particular form of sea grass morphology with varying the dimensions, depending on their different levels of development.

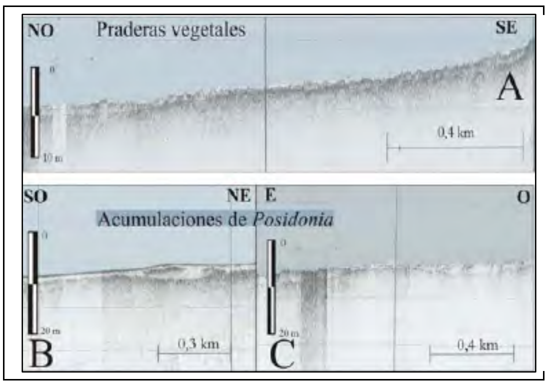


Fig. 18 Examples of seismic profiles (3.5 sediment profiles kHz) with biogenic morphologies.

P. oceanica is considered a priority ecosystem by the European Union Habitats Directive (92/43/EEC) *P. oceanica* is the dominant sea grass in the Mediterranean Sea covering about 50,000 Km^2 of coastal sandy and, occasionally, rocky areas (Bethoux and Cópin-Motegut, 1986). *P. oceanica* develops millenarian ecosystems that affect surrounding biological production, as well as the biogeochemical and physical processes in littoral regions (Mateo et al., 1997). The dependence of sea grass performance on water quality is so high that sea grasses may be used as robust light meters that integrate water quality conditions over time scales of weeks to months, depending on the species,

4. Discussion

The obteined resuts allowed evaluating how seabed substrata affect during the marine engineering process of pough depending on where study areas are applied. For the study areas, here are summarized main significances:

1) Differences concerning marine engineering costs were due to:

   i) Sea bed substrata:

The Castor Project

Due to the study area's proximity to the Ebro delta, all the above sedimentary processes and the related ones with the delta evolution were aplicable. Almost all the sedimentary contributions of the study area come directly from Ebro river. Because of the distance between the location of the corridor and the mouth of the Ebro (36 Km, 203º), the material from this area of study is mostly **Very Fine SAND** sediment typology with a Particle size of 0.07 mm and relative density of 25 %.

The Balearic Submarine Pipeline Project-Mallorca Landfall Area

The sedimentary fill of the Bay of Palma is caused by the accumulation of fine material has been provided by the continental drainage and resuspended by currents and waves, and is transported as bed load and suspended by currents to the places where they lose their competition. Just above of this fine material sedimented there is a development of extensive sea grass (*Posidonia oceanica*) that occupies much of the shallow bottom of the bay (around 35 %).

in coastal monitoring programs (Dennison et al., 1993). *P. oceanica* appears to be experiencing widespread losses in the Mediterranean (Peirano and Bianchii, 1995) caused by anthropogenic impacts, especially from marine plough engineering that affects water and sediment quality and other large scale environmental changes (Marbà and Duarte, 2010; Orfila et al., 2005).

The particularity of sea grass and the consolidate substrata as **SAND, CLAY** and **GRAVEL** and unconsolidated substrata as **Conglomerate, Cobbles** and **Calcarenite** where makes the Bay of Mallorca values of the Particle size of 0.2 mm and relative density of 73.3 %.

The comparison of relative density (%) of benthonic species of the sea floor analysis between the two study cases, we observe that in the case of the *CP*, the average value of it is 25 %; and in the BSPPM *area* study case, it is 73.3 %. So, the difference of Relative density (%) between the cases studied is of 48.3 % between cases been superior in the *Balearic project* than in the *Castor Project.*

From another side and consequence of the densities, the particle sizes (D_{10}), in the *Castor Project* case are 0.07 mm; and in the BSPPM landfall area study case they are 0.2 mm.

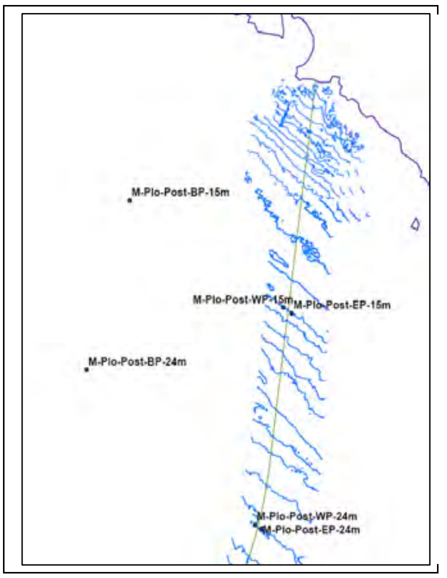


Fig.19 Location of *Posidonia oceanica* (sea grass) monitoring stations in *the* Mallorca landfall area. One station at each side (**E**ast and **W**est) of the trench at -15 m & -24 m depth; and two **B**lank control stations at same depth.

Particularly, we do not have access to the detailed costs of each landfall study area due to the fact that were activities performed by private companies and that the specific activity where we are looking at is part of a lump-sum of the total project. But as is detailed on Table 4, we deduce that due to the factor of time used for this kind of marine engineering and also the mobilization, the costs were very high.

ii) Environmental impact on *Posidonia oceanica*

The Castor Project

Mapping sea floor habitat is the fundamental first step necessary for for monitoring environmental change and for assessing the impact of anthropogenic disturbance on benthic organisms. Benthic habitat is primarily determined by substrate type (sediment or rock), which reflects past and present physical processes in the near-bottom environment. The substrate determines to a large extent the presence or absence of a particular benthic species and modifies the effect of disturbance on the benthic community (Greene et al. 1995, Auster & Langton 1999).

The most evident result of the present study is a clear relationship between macrobenthic community' structure and depth.
In the shallower station, crustaceans are the dominant group, which are gradually substituted by polychates, that however is the most important group in the studied area.
Total macroinfaunal abundance showed a clear negative pattern from the shallower to the deeper sampling stations, as showed in the next Fig. 20.

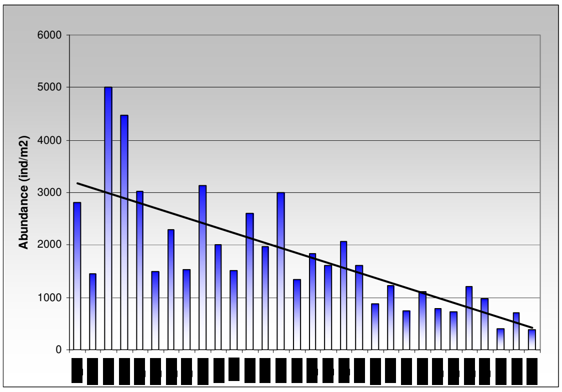


Fig.20 Total macroinfauna abundance results by stations obtained during campaign of July 2011.

Among them, polychates can be observed in depth pattern, with *Lumbrineris latreilli* as the dominant species in the shallower and intermediate depth sampling stations. *Tharix marioni* is the second one most important species among polychates, reaching high abundances at the intermediate depth sampling stations. Finally *Sternaspis scutata* is more abundant at deepest stations.

In consequence, the results of this study in terms of benthic macrofauna, indicate that species (basically polychaetes) in the area affected by ploughing activity, have a recruitment (numbe of new juveniles species reaching a size/age where they represent a viable target for the subsistence for a given species) with a lower intensity respects to a normal choice.

The Balearic Submarine Pipeline Project- Mallorca landfall area

The results obtained during 2012 indicate the general ecological parameters (mead leave length, richness, etc...) are intermediate values between monitoring's performed during the winter of 2009 and 2010. The same was true in the case of the *Posidonia oceanica* meadow at -15 m and -24 m depth (Fig.19), where the density and the length of the leaves are intermediate between all periods monitored. Finally, in terms of affected trench evolution, no improvement was observed during this period.

Conclusions made by Tecnoambiente S.L concerning these *Posidonia oceanica* are brieflly summarized below:

a) Unsignificant improvement of sheet growth neither space occupied was observed at -15 m (Fig. 21) with few rests of Posidonia oceanica neither at -24 m (Fig.22) with no presence of it after two years following the submarine pipleline installation.

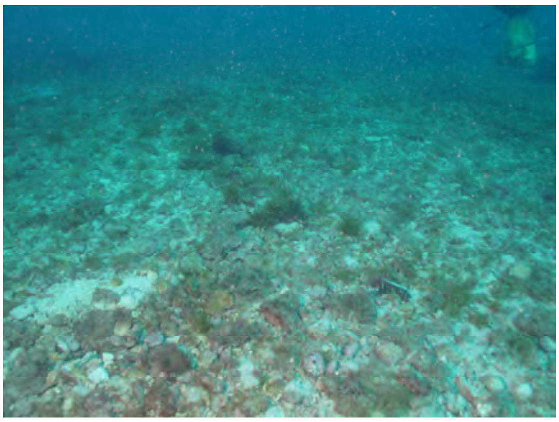


Fig.21 The edge of the trench affected by the submarine gas pipleine pass (-15 m).

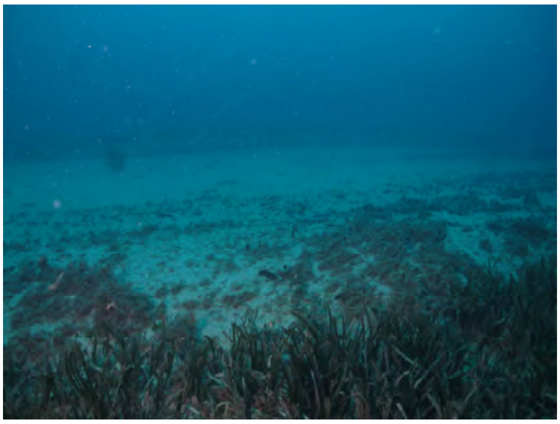


Fig.22 Edge of the trench affected by the submarine gas pipleine pass (-24 m).

b) The improvement tendency of *Posidonia oceanica* leaf lenght (Fig. 23)

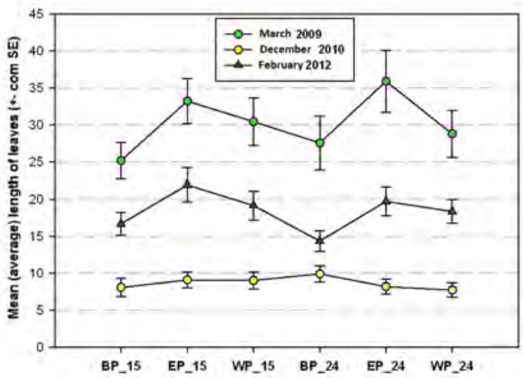


Fig.23 Mean (average) length of leaves of six stations according to Fig. 19 distribution (SE: Standard error).

c) Decrease in abundance or density of Individuals per square meter (Fig.24)

In consequence, we consider also remarkable to express that the impacts determined by ploughing and backfilling perturbation factors related to the method statements in the Mallorca landfall area are classified as Irreversible (permanent loss of environmental assets or environmental quality, requiring preventive action rather than restoration).

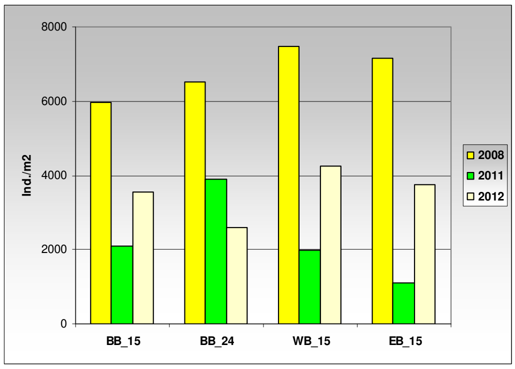


Fig.24 Density of Individuals per square meter according to stations. The yellow columns correspond to the pre-operational campaign (2008), before any activity.

Table 6. Time spent by vessels during ploughing activities according to differences in soil typologies in the study areas.

Study area	Trench section	Trench Section Length (Km)	Water Depth (m)		Operational time (hours) single pass	Speed average of ships (kn)
			Min	Max		
Castor Project	KP 1.000 -KP 21.637	20,637	11	59,5	42	0,26
Baearic Pipeline Project-Mallorca Landfall area	KP 140.93- KP 145.50	4,570	13	40	14	0,17

The comparison of the two speeds, demonstrates that sea grass combined with coarse sand and gravel as a tope soil typology of sediment layer and the conglomerate, cobbles and calcarenite below them in the *BSPPM* study case made the marine ploughing engineering effort (average speed of ships) **1.5 times slower** compared with the silty sand and very soft clay typology of the sediment encountered in the *CP*.

Finally, we would like to mention that the expenses' developing these recurrent's environmental controls (once a year) in the *BSPPM area* increases the final study costs. The analyses are mandatory by Authorities and they demonstrate that just one previous campaign would help to accept or to dismiss the area in study justifying those 1.5 extra costs due to soil type characteristics. So, the main object should be to minimize marine engineering cost while at the same time minimizing the ecolgical footprint.

5. Conclusion

The Castor Project study contains:

-Two (2) unconsolidated types of substrata: **Silty SAND** and **Very Soft CLAY**,

-The **average speed** of the plough was **0.26 Knots** (single pass) with lower costs for the marine enginnering development,

-Benthic macrofauna (basically polychaetes) affected by ploughing activity, have a recruitment (numbe of new juveniles species reaching a size/age where they represent a viable target for the subsistence for a given species) with a lower intensity respects to a normal choice (no plough existe existe) under an environmental point of view.

The *Balearic Submarine Pipeline Project-Mallorca landfall area* contains:

-Six (6) types of substrata: unconsolidated as **SAND, CLAY** and **GRAVEL** and, as consolidates, **Conglomerate, Cobbles** and **Calcarenite**,

-The **average speed** of the ploughing activities was **0.17 Knots** (single pass) with higher costs for the marine enginnering development,

-Decrease in abundance or density of individuals per square meter of benthic macrofauna into the ploughed area,

-Insignificant improvement of sheet growth neither space occupied of *Posidonia oceanica sea grass* into the afected ploughed area after three years of monitoring.

The findings of this study have considerables implications on the marine enginnering construction, in particular for laying of submarine gas pipelines, but with out the exception of other submarine instalations as electrical cable of comunication. Not only surveys with detail geophisics studies are mandatory before any marine enginnering activity but also environmental campaigns are strictly necessary. Potential environmental particularities (existence of sea grasses in the BSPPM in this case) of the study areas may conditonate with extra economical costs by companies in the moment to deploy their singular and expensive machneries. In consequence, alternative marine enginnering pipelines layings could be proposed.

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