VERY SHALLOW WATERS; A BRIEF REVIEW OF SOME ACOUSTIC BASED METHODS TO EXPLORE THE ENVIRONMENT

RANZ GUERRA, CARLOS

Instituto de Acústica-CSIC
C/ Serrano 144, 28006 Madrid, Spain
Iacrg32@ia.cetef.csic.es

This paper is a brief summary of how acoustics can help man in going into the environment defined by what is understood by very shallow waters (from 30 m depth up to the surf zone). This scenario is very complex under oceanographically and physical points of vie. The main part of the civil works and activities take place in this part of the seas. Harbours, estuaries, bays, etc.., play important roles in man's activities. These kinds of waters are not always friendly enough to go by. The visibility plays an important role and when optics do not support a secure activity, to switch to acoustics is other way to overcome the possible difficulties. The acoustic camera helps in "seeing" in turbid waters. The sediments are the whiteness of many processes that take place in and around those waters. To explore them and to evaluate their economical impact in specific activities is another work in which acoustics plays a main role.

INTRODUCTION

The Interest of our laboratory at the Instituto de Acústica, in studying the very shallow waters environment comes from many years ago. At that time, 1986, we had the opportunity of having two small boats: Decibelio I and Decibelio II that could be towed by car. The Buendía Reservoir, near Madrid was a very good spot where to train and get experiences specifically in bottom sedimentary studies and in evaluating sonar systems. Then we transferred to the sea near shore, into the close waters of Galicia, NW, Gulf of Cadiz, SW and into the calm waters of the Med, Mazarron Bay, SE. Because of that experience, several years ago a geological engineering company approached our laboratory. They wanted to control the dredging of an important harbour of the Med coast of Spain. They needed first to know the working site, in order to evaluate the number of m^2 to dredge and the depth of sediment to extract. In the low visibility waters of the harbour, the optical systems have failed, therefore the monitoring of the required works needed to switch to acoustic systems. First, one acoustic image device with possibility of 3D operations and high resolution and a second system able to quantify the depth of the sediments to dredge giving insight on the hardness of the sea bottom. These two systems will be the topic of this presentation.

1. SHALLOW WATERS ENVIRONMENT COASTAL WATERS

The potentiality of the resources located in the continental margin differs from those at the deep ocean floor or from those found at the continental dorsals. At the continental margin, or coastal waters, apart from the upper most sedimentary layers, the rocks found in it are similar to the nearest an emerged continental masses. The upper most layers consist in unconsolidated sediments, many of them coming from the emerged zones near by. The erosion processes and related actions as currents and coastal water motion conform mineral detritic deposits able to be economically exploited. The potentiality of coastal exploitation of minerals increases yearly.

Another source to be of use by man in the very shallow waters environment is the mechanical energy coming from the wave motion. The energy coming from the waves is many thousands times greater than that from tides (i.e., a wave 1.8 m high moving over a depth of 9 m has 10 kwtts of power, by each meter of front), [1]. To gain profit from that energy can became a civil works main activity

Wave Height	Wave Length	Power per meter
0.6 m	20 m	0.9 kwtts
1.8 m	38 m	10.1 kwatts
3.0 m	57 m	30.9 kwatts

The sea is not only a saline solution integrated by all the chemical components in varying proportion; the sea is the main water deposit on earth. Desalination is one of the most popular industrial activities carried out at the coastline. The greatest part of civil work involved in desalination is done in very shallow waters.

Very shallow waters are also the site where the pollution presents the highest levels. The pollution consist in adding artificial materials, generally chemical products, it can also consist in an increment, over the normal level, of materials usually present in the seawater. The most important pollutants are divided in five groups: 1) Residuals as mud from drains or dragging, 2) Phosphates and other materials influencing the biological cycles of the sea, 3) The heavy metals , such as mercury, 4) The oil and its sub products, 6) The chloride hydrocarbons: plastics, PCB, etc ..

The pollutants coming from dragging processes (80%) in relation with keeping and maintaining harbours and the navigation around are important contributions by man to the ocean pollution, in very shallow waters. The importance comes not only because the visibility is reduced but also because the dispersion of waste products of industrial and biological origin. 43% of all the world dredging materials are polluted [1]. Along the years the pollutants remain within the shallower sediment layers where is easy to remove and send them back to the water. The evaluation of sediments with very narrow resolution is an important activity in very shallow waters. 30 years ago, there were no rules against dumping industrial waste into the sea, or they were very few, specific, located, and referred in or close to some coastal spots. Figure 1.

In the near shore waters the oil and its distilled products are the most extended pollutants. They come into water by different ways. 1) Natural filtering from the geological deposits; 2)Accidental losses during sounding processes; 3) Accidents or incompetent management during loading and unloading; 4) Navigation collisions and shipwrecks; 5)

Cleaning of tankers with sea water; 6) Atmospheric transport of the most volatile components; etc..

Fig.1 Deposit of industrial waste into the sea (From Oceanus, Vol. 33, Nº 1, 1999)

Statistical evaluation of oil losses gives a figure of 0.5% of all produced oil that goes into the sea, and the greatest part of it remains in the coastal regions. The oil pollution directly goes into the biological path. Many components of the oil are in the origin of many types of cancer if their concentration goes over some given levels. Their effects on some microorganisms, fish and shellfish could originate their virtual destruction.

Fish farming, in near shore waters, needs to count fish, also to detect predators of protected species. To carry out behavioural studies of fish is also necessary, and several others activities, as, for instance, rising alarms to avoid fish going into water intakes or industrial water or polluted water discharge systems.

There exists a wide scope of inspection purposes in and around very shallow waters. Civil works as pipe lying need to be continuously monitored when optics are of no use. The monitoring is done from a ROV, by a diver or from a fixed position. Important is the touchdown of the pipe when the sediment becomes disturbed and the optical visibility still lowers more. The post pipe laying activities: inspection, maintenance, sea floor bed construction and fixing are phases where turbidity prevents easy identification and can drive to dangerous operations.

Accidents derived from natural disasters (the late Katrina hurricane is the most clear example) scattering structures, pipes, houses, etc., in very turbid waters have shown the level of good work and the help of acoustics.

To conclude, the very shallow waters environment is not only the result of the natural sea activity but also, and in an important part, the result of the action of man. To recover the shallow waters environment and to keep it as preserved as possible, implies first, a better knowledge of it. While being necessary to penetrate it, to explore it, to work in it, is mandatory to lower the effect of man's activity. Therefore, the civil work will never be eliminated but the aggression should be null or kept as low as possible. All these green activities will now be, and in the future, the responsibility of man.

The very shallow waters environment is very complex. This complexity increases as the depth lowers; also it grows near any source of some disturbance: pollution, particles in suspension, inflow of water, etc... Man can access to this environment, figure 2a, but he needs some kind of support to "see" first and to react in

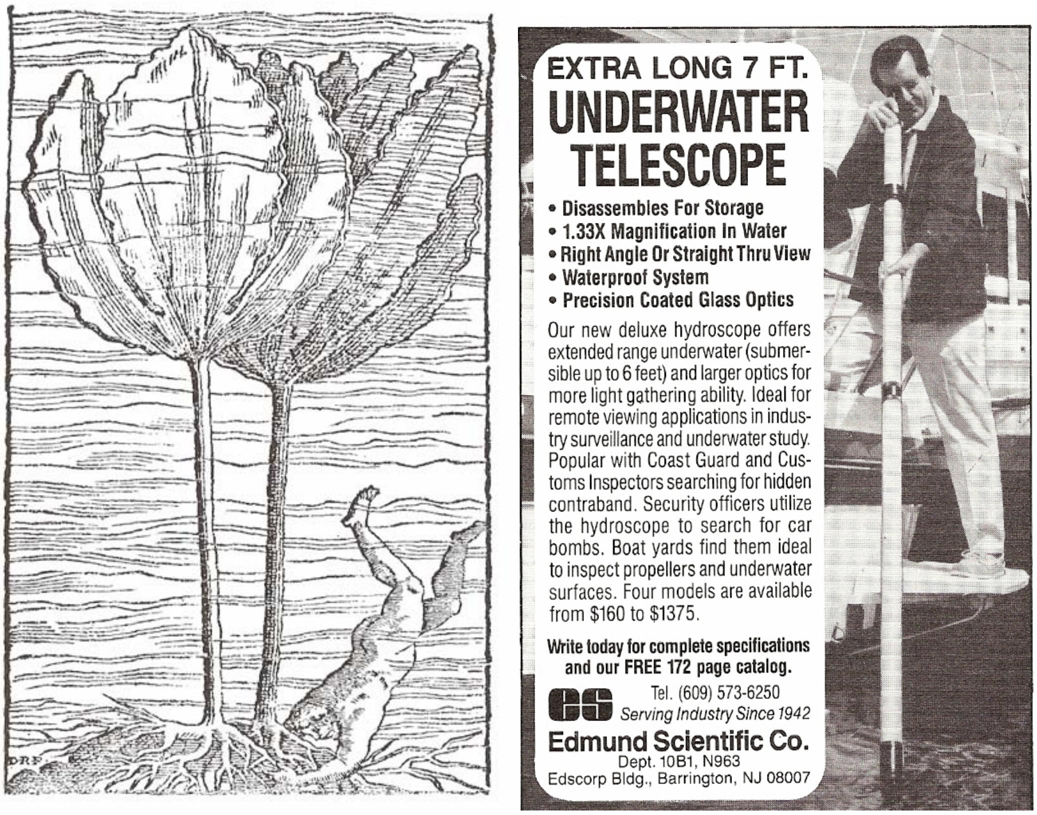
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Fig.2. a) Direct access to the sea bottom, from Historia Naturalis, by Ferrante Imperato, Messina, 1599. b) Advertising the Underwater Telescope to see into the sea

function of any difficulty or activity, figure 2b. The visibility is mandatory for man or UMV's with, or without, umbilical; the extra absorption, dispersion, scattering, etc, of light put the human eye or the optical systems out of use. In these instances, some different supporting technique is necessary. No one of the methods of figure 2, are good and reliable enough. It is necessary to step forward.

This presentation would not describe vehicles of any kind. The military application will also remain, out of the scope of this paper.

2. THE ACOUSTIC CAMERA

The principle of the Acoustic Camera, is very simple: It consist of an array of high frequency sound emitters/receivers, generally in two dimensions. The acoustic camera becomes in a high-resolution ultrasonic imaging device that can produce underwater video sequences in surveillance of coastal areas, [2]. The acoustic camera concept appears many years ago but the real implementation of such device comes in the late eighties and early nineties, [3]. After that time many improvements were introduced. These improvements came from Sonar and some applications of Medical Ultrasound. The acoustic camera is high frequency sonar with some sophistication referred to presentation of near video quality images; it uses a mixture of acoustic lenses and high frequency sound radiation to resolve very fine details in images through a very narrow sound radiated beams. The beams are formed with the help of acoustical lenses. Due to the limited coverage, the insonified sector is restricted to a given solid angle. Therefore, to cover a wider view of the environment the system has to “move” to focus to the desired direction. The focus can manually be operated and readjusted to the range interval of interest or any specific device (i.e., a small motor) can continuously move it. The help of acoustic lens plays an important role in the process of getting images by forming acoustical beams over a wide “field” (field of view, FOV), at several frequencies and in real time. The acoustic lens system in the acoustic camera requires less processing capabilities than a shading processing in a transducer array, [4].

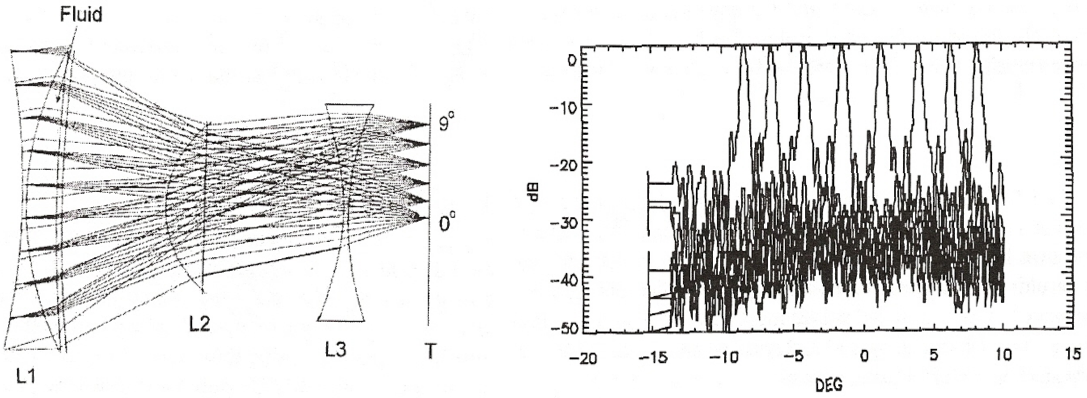

Fig.3 a) Diagram of the lenses system of a commercial acoustic camera. The lenses: L1, and L3 are fixed; L2 mouves to change the focal distance. T is the plane of the array of sensors. The diagram shows the image extending up to 9º. B) Measured beampatterns for angles between -9º and 9º. From Ref. [5]

About the lenses, it is important to say that to reach the goal of optimum resolution (for instance, resolution limited by diffraction, is easier to reach it by acoustics than by optics). It is known that waves collected through a fine aperture are diffracted, but this effect is less when the ratio of aperture length/wave length increases. This diffraction limitation is much more evident in acoustic systems where λ is 10000 longer than it is in optical ones. As a result, good acoustic lenses are always diffraction limited. The design of an acoustic lens is necessary to predict the beam width and the side lobes of the whole system and is necessary to know how it behaves in front of the changes induced by the unpredictable changes of salinity and temperature in very shallow waters. The lenses used in site A are not necessarily well suited for site B. The treatment and processing differ depending on how a point object is recovered as a point or a line as a line, both in azimuth and in elevation. Sometimes the shading is implemented to reduce the height of the side lobes, figure 3. This process depends on the frequency and, if necessary, it can be complemented by introducing extra absorption in the lens system (low density polyetilene, rubber or epoxy components), in such a way that those signals entering close to the limiting borders of the front lens are greatly absorbed than those going through the geometrical centre. For frequencies greater than 1 MHz this extra absorption is not implemented due to the high absorption level of the process itself. On the other hand, the lens material is chosen with acoustic impedance close to that of water to reduce the reflected signal at each water-lens interface. Also the reverberation within the lens has to be reduced. Although the reverberation level is small in front of the image level, the reverberation can appear as a noise bright floor.[5].

The Acoustic camera, AC, is of use by a diver alone, or mounted on a ROV or an AUV; it can be sent to explore some given region and helping in identifying objects, figure 4. While the AC is necessary in turbid waters, it has important shortcoming in front of the optical systems.: 1) Limit in the sight range; 2) Low SNR, due to the transducers dimension, compared to the wavelength; 3) Lower resolution because the larger wavelength of the sound radiation (The number of pixels in any given direction is limited); 4) Inhomogeneous insonification due to the anisotropy of ultrasound radiation from the sound emitter system. To avoid some or all of the above limitations exist many algorithms to treat and to raise the images enhancement such as denoising, deblurring and increasing the resolution, [6 - 8]. On the other hand there are also important factors that can limit the use of the acoustic camera by itself: One is the frame rate presentation that varies in function of the range; the power consumption, in acoustic cameras without umbilical, introduces a limited time of use depending on the batteries capability. The image presentation depends on the type of camera but generally consist in a video monitor, up in the base platform (i.e., a ROV), or on a screen at the back of the camera, or even these images can be transferred to a glasses type of screen that a diver can carry on his head, figure 5. The low weight is then a prerequisite very important and then influences into the balance of sound frequency, resolution and the SNR that dictates the final reach of the camera. The working frequency ranges from 1 to 5 MHz, so the reaching range is limited to several tens of meters, at the most. The frequency will also dictate the cross and down resolution.

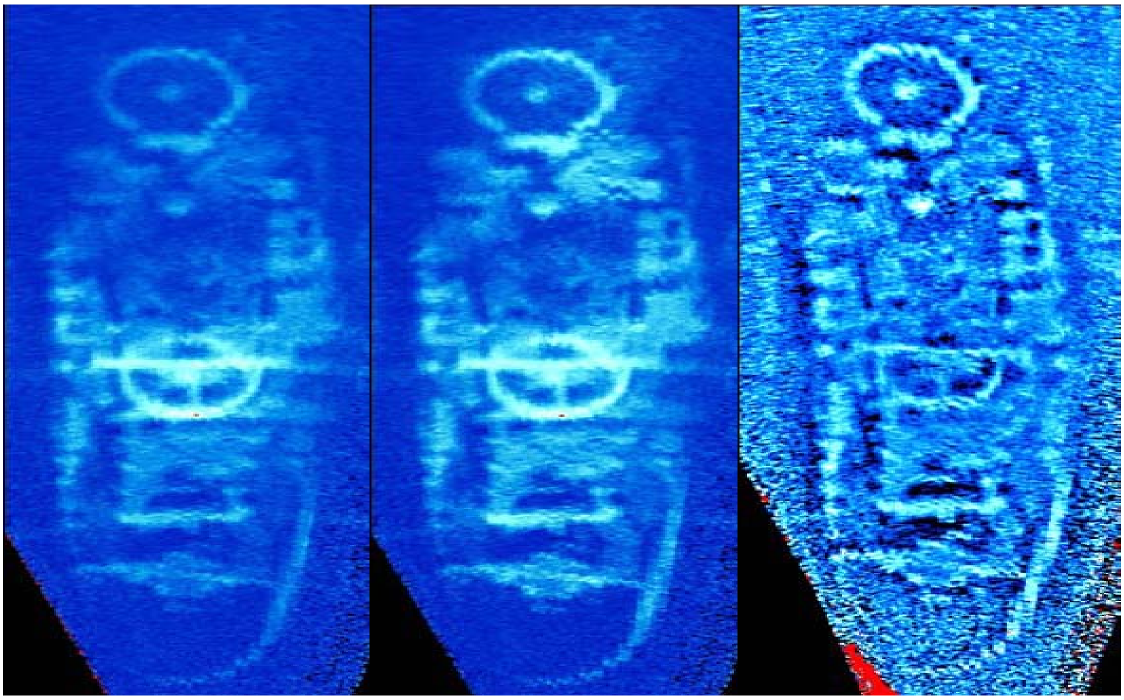

Fig.4 The effect of denoising processes is seen in figure 4 a) and b). Figure 4 c) shows the maximum likehood estimation of the mosaic image. Reproduced from Ref. [6]

The dual frequency acoustic camera is a novel approach to “first detect and then identify”. The dual frequency camera concept looks to the mine detection and counter mine military activities and it will not be examined in this paper. Its civil application could go in the chapter of obstacle avoidance in unclear waters, [9, 10]. The dual camera provides two sonar systems: a low frequency one (frequency lower than 100 kHz) for detection of buried or partially buried objects, and avoidance of obstacles, and high frequency sonar (frequency greater than 1 MHz) used for identification.

The acoustic camera represents an important step in giving “image” information where optics is of no use. The help of the acoustic camera is, with no doubt, important, when also can produce a permanent log of activities based on the images. Acoustics can inform, also, on valuable data referred to the sea bottom structure, specifically on the uppermost thinner sedimentary layers and how these layers are monitored if necessary. In the next chapter of this paper we deal with topic with more insight.

Fig.5 A diver with a camera and glasses type display. (Courtesy of DIDSON DH)

3. SEA FLOOR EXPLORATION

Very shallow water environment, coastal zones, bays, estuaries, harbours, are among the most active marine zones. The sea bottom in those scenarios plays an important role. This role derives from the sedimentary processes caused by an enormous variety of fluxes and also by the impact of the human activity. The sediments act as an archive, an historic record of natural and human derived activities. Besides the easier accessibility, compared to deeper waters, the very shallow waters environment present specific technological challenges: multiple replicas, extrabsorption due to occluded gasses, increasing influence of background noise and scattering nucleolus in the signal propagation, reverberation, and great care in keeping undisturbed the archaeological sites so numerous in those waters.

The characteristics of the work to perform in very shallow waters imply to focus on subsurface sediment characterization together with high resolution imaging, down to the centimetre scale, if possible. In very shallow water, layer resolution is often more important than overall penetration and detailed information on the upper few meters of sediment is crucial in many cases. Except for very special civil works (i.e., basement for huge and heavy platforms), the sediment depth of interest is no greater than 20 m. These restrictions do not allow employing some of the standard seismic methods such as boomer sources. Nowadays novel techniques of subbottom profilers with medium to high frequency range (30 kHz to 150 kHz) for the upper 20 m depth, have been developed in addition to novel deployment strategies to target very shallow environments, [11].

There exist many techniques to explore the sea bottom. An important part of them can be applied specifically to very shallow waters environment. Each technique is generally supported by a model or theoretical framework. To make a description of the most important parameters is out of the scope of this paper. A good overview of geoacoustics is given by Le Gac and colleagues in a recent publication, [12].

The vertical resolution is one of the most important aspects of sea floor stratigraphic mapping. Returning to the above cited work of dredging a harbour, is economically important to accurately quantify the cubic meters of mud and sediment to remove; an error of only 10 cm in the depth implies one error of 1 m^2 for each 10 m^2 of horizontal surface explored.

The vertical resolution is directly related to the duration of the transmitted pulse. The shorter is the pulse the greater is the discrimination capability. This resolution tells about the ability to discriminate close targets or reflectors. On the other hand the acoustic pulse needs to penetrate into the sediment layers. The penetration is a function of frequency. The lower is the frequency, the greater is the penetration.

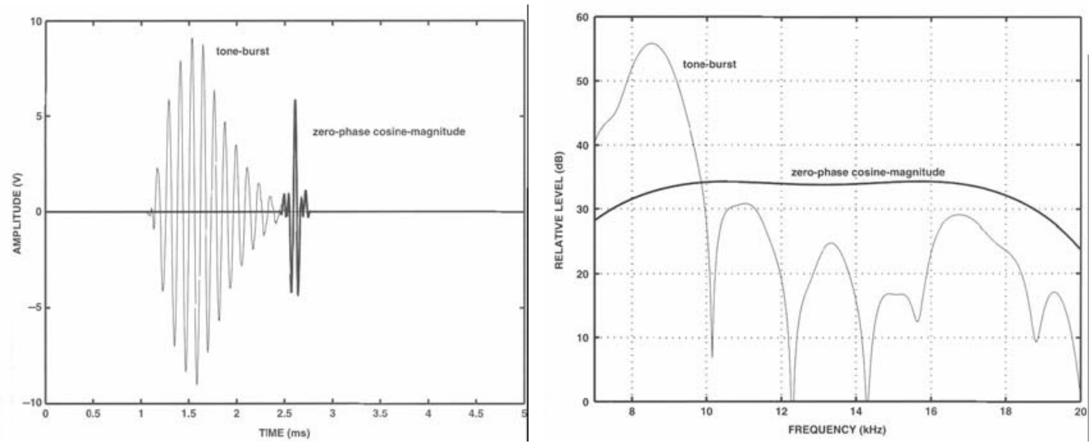

Fig.6 a) Time signal of a tone burst and a zero-phase cosine-amplitude pulses. b) Zero phase spectra of tone burst and cosine –amplitude

Therefore the interest is to have a low frequency system with a time signal as narrow as possible. Both qualities are contradictory unless a treatment of the signal is possible and the process allows for a reduction in the peak of the signal envelop, figure 6, [13]. Sonar systems used in bottom studies show a time signal corresponding to a narrow band emitter, figure 6a, with a spectrum showing a peak at the resonance frequency. Berkhout, [14] redefines the pulse length of a seismic signal and also shows how the amplitude spectrum that minimizes the pulse length is. This technique applied to the tone burst signal of figure 5a gives as a result the time signal of figure 5a under the caption of “zero-phase cosine-magnitude” that refers to the type of amplitude spectrum applied. Figure 5b shows the spectrum of both signals: the tone burst with a clear resonance peak and the spectrum of the modified signal showing a larger band with some reduction in the level in both envelop and spectrum. These experimental results refer to a Tonpilz transducer, resonating at 9 kHz, and they were measured at the Hydroacoustic Tank Laboratory in Madrid. The spectrum shown in figure 6b, calls for an implementation of a zero-phase cosine-magnitude wave form in the 6-20 kHz frequency band. The process finishes when the projector is driven by the synthetic wave form very far from the typical continuous wave modulated by a square wave. Each transducer has its own driving voltage wave form.

Figure 7 presents some results where the ability of getting better resolution is obtained by different processes, [15]. In this experience the resolution, or let us say, the signal pulse length is shortened by defining and applying some specific (spiking) filters, [16, 17]. The brute echogram is in figure 7a with a SNR average value of 38 dB, while figure 7b shows one result, out of other three, of acting on the frequency bandpass in the filtering process and reducing the stabilization constant in the deconvolution process. As can be seen, both effects, widening of replicas by narrowing the bandpassing and narrowing of replicas by lowering the stabilization constant are approximately cancelled. The 2.5 ms of one way travel time corresponds to 4.5 m of penetration into the sediment (the first 5 m are of crucial importance), for a sound velocity equal to 1800 m/s. The water column was 17 m high.

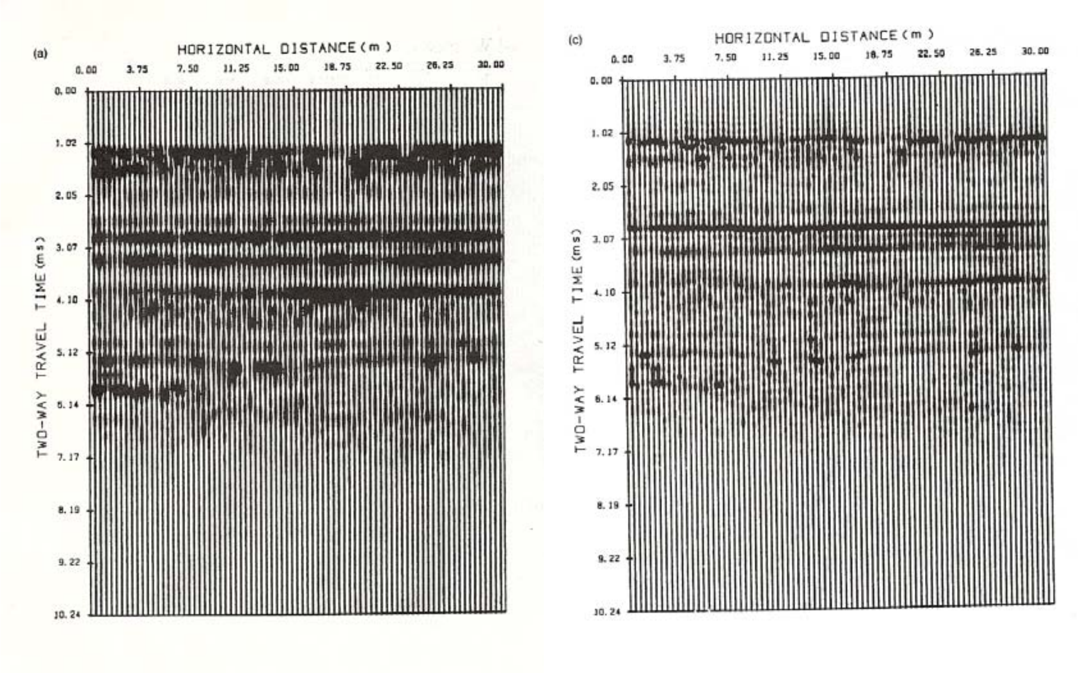

Fig.7 a) Brut echogram by ELAC LAZ 72 of a bottom reservoir. b) Echogram after traces being passed through a Kaiser-Bessel band-pass filter (30±14.6 kHz) and other spiking filters

4. CONCLUSIONS

The Very Shallow Waters environment while being not difficult to visit presents some handicaps to overcome. On the other hand the industrial, civil and economical activities: Harbours, estuaries, bays and many others shallow waters sites need the help of diverse technologies in order to do the work and to do it with security. Acoustics through devices such as the acoustic camera can be of much help. The fundamentals of the camera are very simple. Its implementation into a working technology has been complemented from other techniques from the field of video and electronics. Today is a very consistent technology used in a handful series of activities. The sea floor forms a very special part of the very shallow waters environment. The knowledge and evaluation of the sea bottom has a sharp importance in relation with all the activities of man in these waters, from a great variety of civil works down to archaeological studies, and from harbours keeping and maintaining down to navigation security. The level of resolution in the sediment structure calls for special type of sounders a little far from seismics. In this presentation a brief description of system that had been applied to this kind of studies were described.

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