New technologies in marine seismic surveying: Overview and physical modelling experiments

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ABSTRACT

New marine seismic technologies include ocean bottom cables, dual sensor (hydrophone and geophone) cables, sub-sea seismic, three component geophones and vertical hydrophone cables. All of these recording systems promise specific improvements in seismic imaging. We have conducted physical model seismic surveys to simulate these new marine methods. The surveys were made using ultrasonic transducers over a sand channel model. Two-component sensors were in contact with the solid model at the bottom of a water layer. Pressure sensors were used just above the sea floor, and just below the water surface, to simulate hydrophone cables. A set of vertical measurements in the water completed the surveys.

INTRODUCTION

In conventional marine seismic acquisition, a ship tows receivers (1 to 12 streamers at depths varying from 7 m to 12 m) and a seismic source (generally an array of air-guns at depths between 4 m and 7 m). Several new developments have lead to improved marine imaging. They include ocean bottom cables, dual sensor cables, three-component (3-C) sub-sea geophones, and vertical hydrophone arrays.

Ocean Bottom Cable (OBC) refers to conventional streamers (with hydrophones only) adapted to lay on the sea bottom. Tension is applied at the end of the cable to keep it both straight and in the desired position (Zachariadis and Bowden, 1983).

When an ocean-bottom cable with both hydrophones and geophones are used, the system is called dual-sensor. the dual -sensor systems have been used to de-reverberate the recorded seismic data. The Sumic (from sub sea seismic) system uses hydrophones and 3-C geophones which are planted on the sea floor by Remotely Operated Vehicle (ROV).

For hydrocarbon exploration and exploitation, the main advantages for OBC and dual sensor over the conventional streamer are: in areas with navigational obstacles, it is not necessary to use undershooting which can be both expensive and may not be effective for shallow targets. Data can also be acquired with different azimuths and it can be much more reliable for time-lapse seismic due to the use of the same receivers at a fixed position. Other advantages are the absence of tow noise, better positioning information, avoidance of strong maritime currents, and a uniform pattern for acquisition (Zachariadis and Bowden, 1983).

Vertical cables use a geometry similar to the VSP case. An anchor is attached at the end of the cable to keep it in the vertical position. It has the same advantages as dual-sensor cables, except for the absence of shear waves. According to Krail (1991;1994) it is necessary to perform a pre-stack migration because post-stack migration fails on this geometry.

Each of these systems has advantages and disadvantages, depending on factors like the purpose of the work, budget, and water depth.

The OBC and dual sensor acquisition configurations involve at least two boats: one for receivers, which remains stationary, and another for the source. In general, synchronizing the two vessels is not a problem. Sometimes one or two support boats are necessary.

Zachariadis and Bowden (1986) present a detailed report on the utilization of OBC, attached to a receiver ship, in shallow water (60-90 m) at Gulf of Mexico. A comparison between OBC and conventional streamer shows better quality data for the former.

The advantage of using both pressure (hydrophone) and velocity (geophones) information is stressed in the literature, from both pure theoretical (Igel and Schoenberg, 1995) and more practical (Barr et al., 1990, Dragoset and Barr, 1994, Paffenholz and Barr, 1995) point of view. The more important aspects of this analysis are discussed below.

The ghost generated by the energy reflection on the water/air interface creates notches on the receiver (either hydrophone or geophone) amplitude spectra, due to destructive interference between down going and upgoing parts of the wavefield. These notches are related (on the hydrophone case) with the streamer depth, h, via the expression 1500/2h (1500 m/s being the acoustic velocity of water).

In shallow water, OBC use has the same problem. This can be solved by recording the signal from both hydrophones and geophones at the same time, as pressure and velocity sensors have a symmetric behavior related to the ghost (i.e., they have opposite polarity related to the downward part of the wavefield). This symmetry causes the presence of peaks on the amplitude spectrum for a type of sensor at the same frequencies where the other type of receiver has notches. The sum of both signals, after some necessary scaling is applied to the geophone data, leads to an amplitude spectrum which is notch free.

Dragoset and Barr (1994) present a good discussion about the importance of the scale factor and how to obtain it directly from the data. According to the authors, this factor must be obtained on every receiver location, as it is a function of sensitivity for the two sensors, coupling, geophone orientation and water bottom reflectivity. They also present a very interesting alternative to the expensive use of special calibration shots: a searching factor which cancels water/air interface reflections. The method presented should be applied to any data which is not noisy, although it can also be helpful on extremely noise data.

Paffenholz and Barr (1995) used a different method - based on the Backus filter, which obtains the first peg-leg element on a reverberation sequence - to obtain the water bottom reflectivity from the data, and apply it as a scaling factor.

A Sumic survey consists of a submersible cable with attached 3-C geophones. The cable is laid on sea floor and geophones are planted using a ROV. Each station has both an inclinometer and a compass to record the geophone orientation. Sonneland et al. (1995) present a good explanation of the acquisition system and its potential applications.

Berg et al. (1994a,b) report acquisition and analysis of a 2-D Sumic line from a gas chimney area (2-4% gas saturation) in a North Sea field. According to the authors, low frequency and dispersive boundary waves (Scholte waves, similar to ground roll) were extremely weak on all components. The identification of geological interfaces and the extrapolation of well logs interpretation, which could not be performed on conventional 2-D or 3-D data because of dispersive wavefront behavior of compressional waves, were possible with the new information.

Vertical cable technology is a more recent developed system, and does not yet have widespread use. Most results available from the oil industry came from Krail (1991;1994). According to him, this technology came from walkaway VSP and studies by the US Navy for antisubmarine warfare. The cable is kept close to a vertical position (less than 5 degrees) using an anchor attached to the lower end of the cable. The recorded 3-D information is stored on tapes (up to 5 Gbytes per tape) housed in a buoy attached to the top of the cable. When compared with a VSP, its advantages are the absence of head waves and economy of expensive or standby rig time.

Krail describes the acquisition of a 3-D data set using vertical cable technology in 520m of water, offshore Louisiana. A comparison with conventional 3-D has the following advantages, according to him: low background noise, separation between up and down going wavefront due to enough distance between adjacent receivers, real 3-D geometry due to presence of various azimuths, better subsalt imaging and considerably lower costs.

Another 3-D survey was acquired, using six vertical cables at a water depth of 1,000m, in an attempt to image below salt in the Gulf of Mexico. The vertical cable data quality is considered by Krail to be better than conventional 3-D data. The price for the vertical cable acquisition is about half the price of conventional acquisition because the seismic ship does not have to tow a cable, leading to faster coverage, and infill shooting is not necessary.

The radius of subsurface areal coverage is approximately equal to the water depth. To process the data, the CDP concept is not valid, and a 3-D pre-stack migration operation is applied.

As of August 1996, the worldwide distribution for seismic acquisition was (Leading Edge, 1996), in number of channels, 32,896 for land, 4,680 for transition zone and 4,548 for marine. Conventional (streamer) marine seismic had 3,508 channels and OBC data 1,040 channels. All OBC data is from the United States.

EXPERIMENTAL SETUP

The model used for the experiment was an existing CREWES model of a meandering sand channel (Lawton et al.,1988). A scale factor of 1: 5000 was used in this experiment because of the frequency (250kHz) of the piezoelectric transducers. All measurements refered to in this paper are scaled units and are in meters.

RECORDING INSTRUMENTS

The CREWES physical modeling facility (Gallant et al.,1993) was used to record both the acoustic and the elastic waves in the five part marine survey. Although we can record a 3-component geophone line, this experiment was a 2-D line and did not record the transverse component of the wave train. The source used in this survey was a spherical piezoelectric transducer manufactured by International Transducer

Corporation, Model #ITC1089. The ocean bottom geophones are the Panametrics V153 shear wave and the V103 compressional-wave transducers. The V153 shear-wave transducer was used to record the radial component and the V103 to record the vertical component at the ocean bottom. A modification to the V103 compressional-wave transducer resulted in an adequate hydrophone that is sensitive to a marine type pressure wave Figure.1. The same hydrophone transducer was used in the acquiring of the streamer data, the vertical cable data, and the data from the hydrophones on the sea floor.

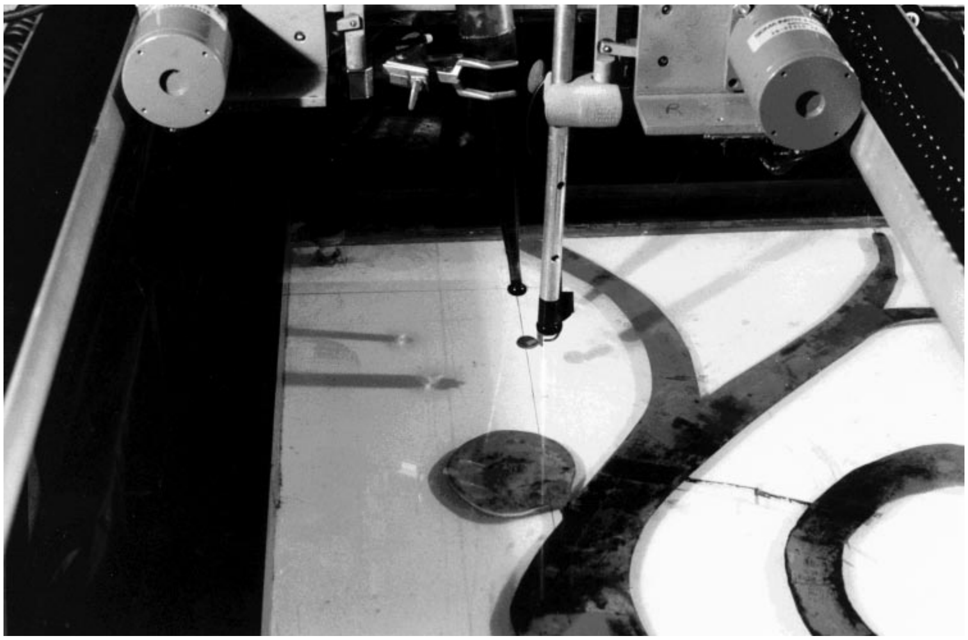

Fig.1 Picture of acquisition system showing ITC #1089 source and Panametrics V103 hydrophone over splay and sand channel used to record the 2-D five part survey.

GEOMETRY

There were 267 receiver stations and 134 shot stations Figure.2, for each of the five parts of the 2-D survey, for a total of 178,890 traces. The shot positions are at 15m over the 2000m spread. The ocean depth of the experiment is 160m. The streamer is 2000m in length, with hydrophones at every 7.5m. It is at a depth of 5m. The vertical cable is 160m long with a hydrophone spacing of 7.5m for 20 receiver stations from the surface of the ocean to the sea floor. The ocean bottom vertical geophone and the horizontal geophone are in contact with the sea floor and are also at the 7.5m receiver station spacing, as are the hydrophones which are 5m above the sea floor.

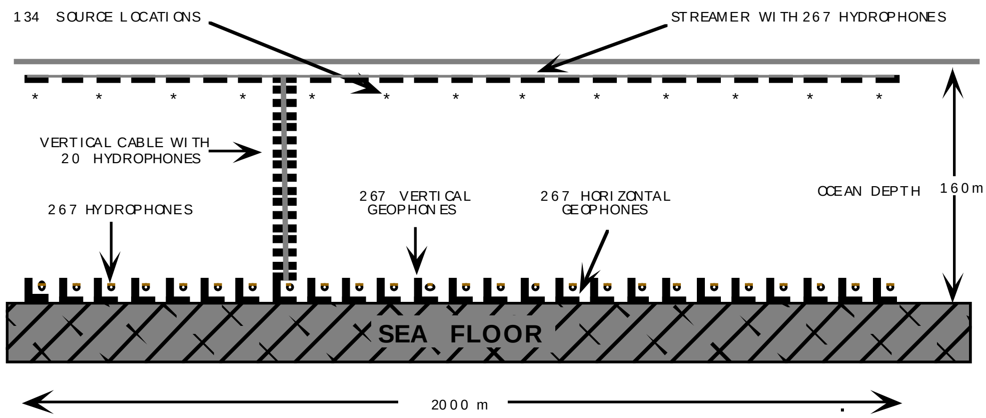

Fig.2 Schematic diagram showing the subsea five part geometry. Drawing is not to scale.

DATA

The sections below are shot and receiver gathers of the five subsea surveys acquired. Figure.3 is a shot gather of the 20 hydrophones in the vertical cable. The source position is at the center of the spread and the receivers are at 250m offset. Figure.4 is a shot gather of a streamer hydrophone. Figure.5 is a shot gather of the ocean bottom hydrophone. Figure.6 is a shot gather of the vertical geophone. Figure.7 is a shot gather of the horizontal geophone. Figure.8 is a fixed offset *P-P* survey over the splay and sand channel.

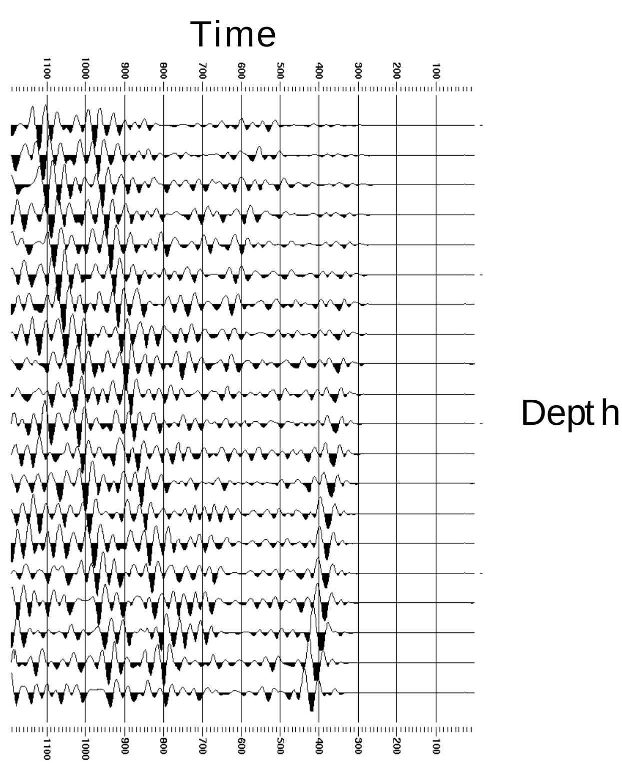

Fig.3 A shot gather of the 20 hydrophones in the vertical cable . The source offset is 250m and the receiver position is at the center of the spread (1000m). Hydrophone spacing is at 7.5m from the surface down to the sea floor.

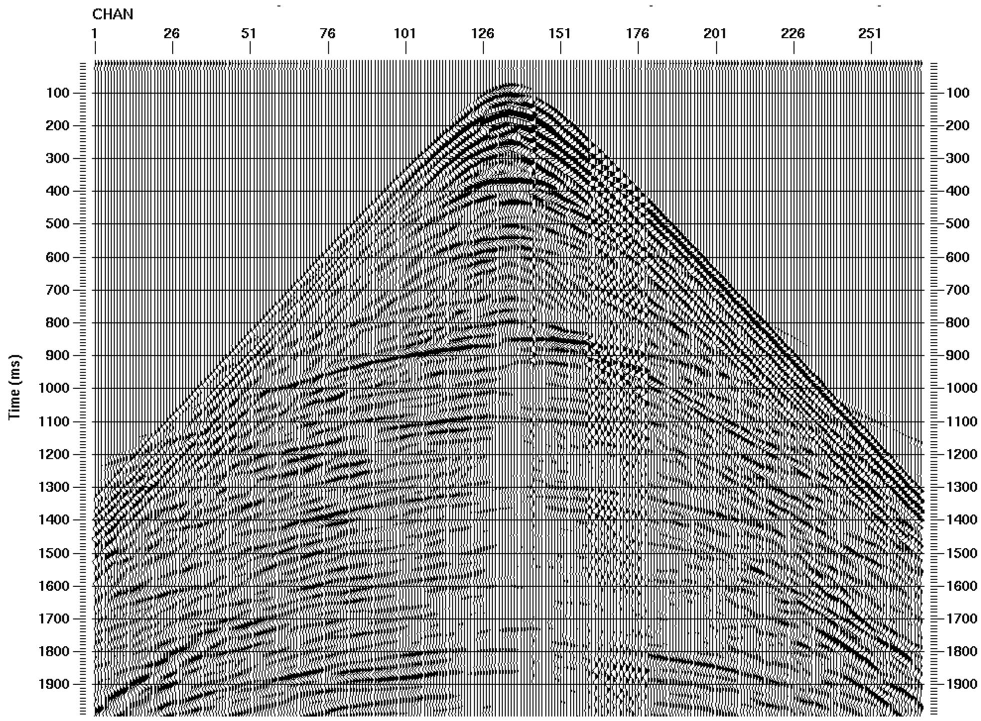

Fig.4 A shot gather of the 267 streamer hydrophones with the source at the center of the spread

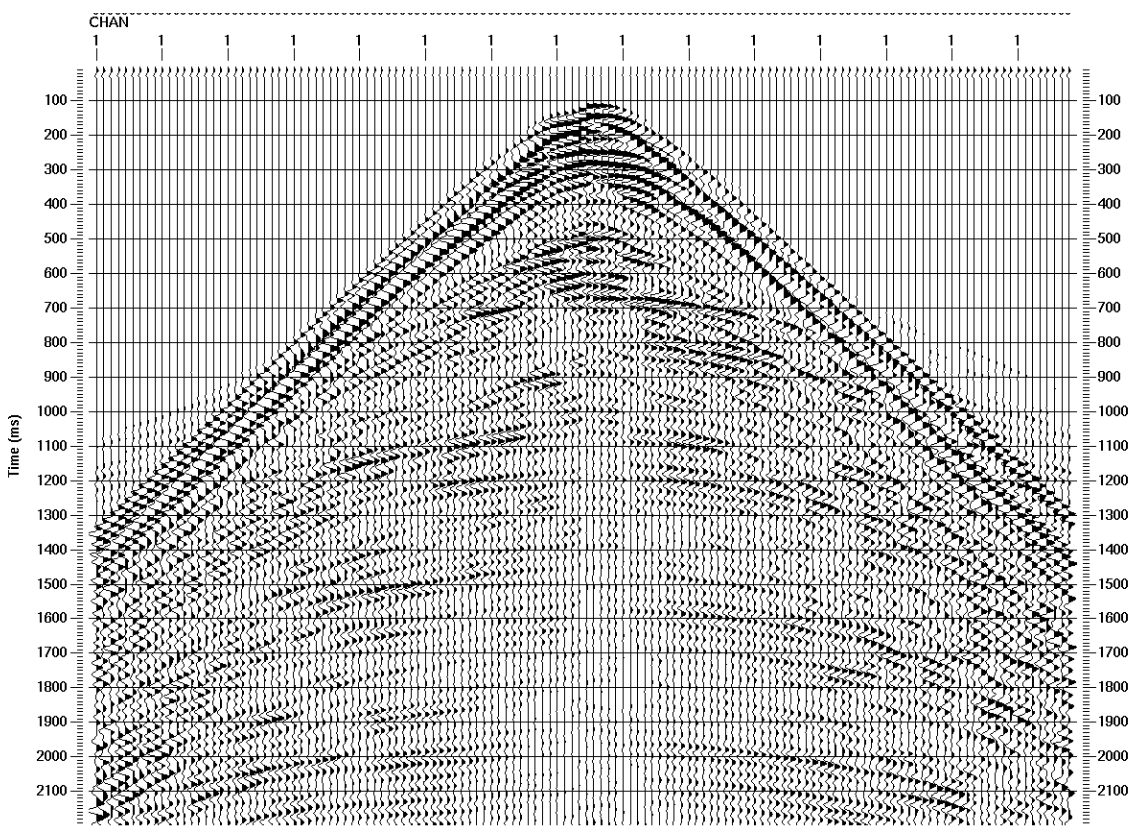

Fig.5 A shot gather of 267 ocean bottom hydrophones with the source at the center of the spread.

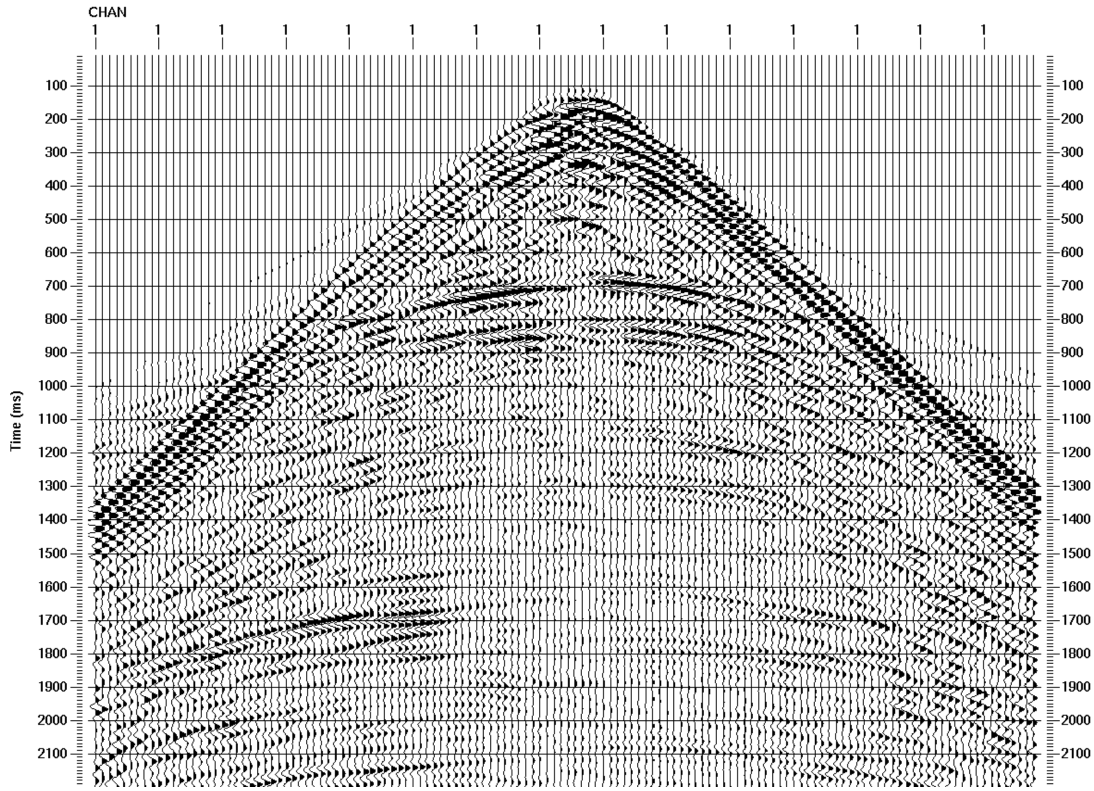

Fig.6 Ocean bottom vertical geophone with the source at the center of the spread.

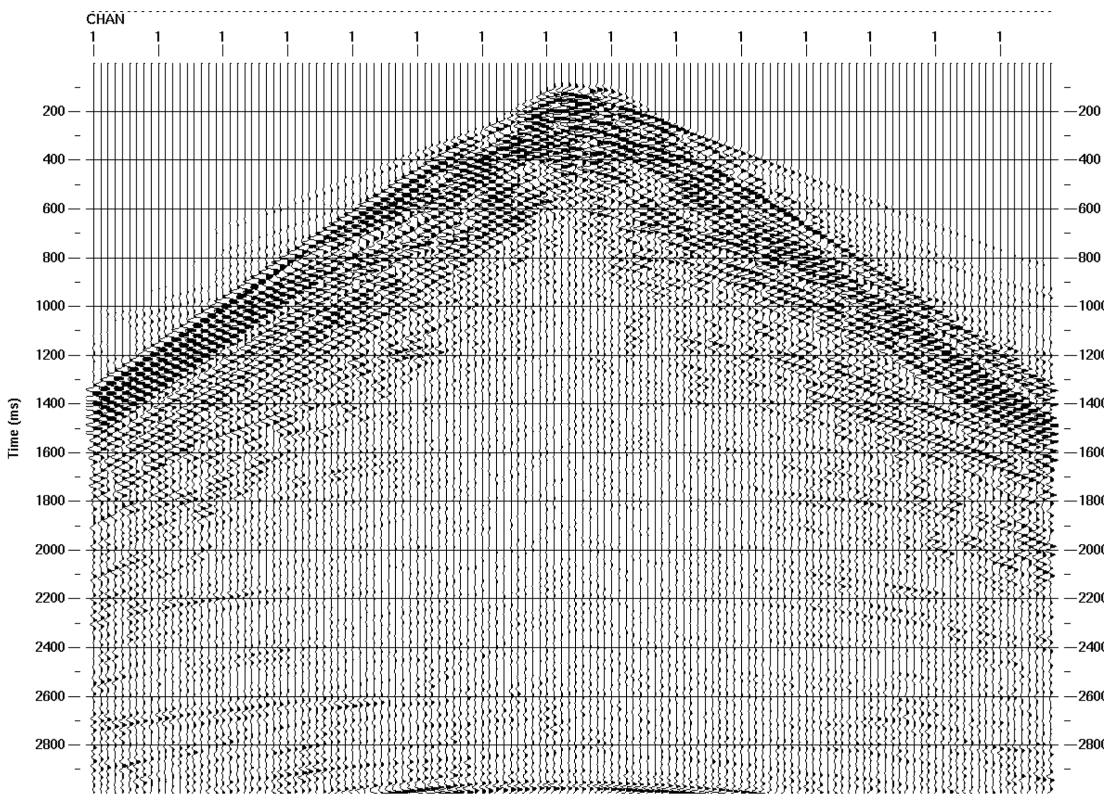

Fig.7 Ocean bottom radial geophone with the source at the center of the spread.

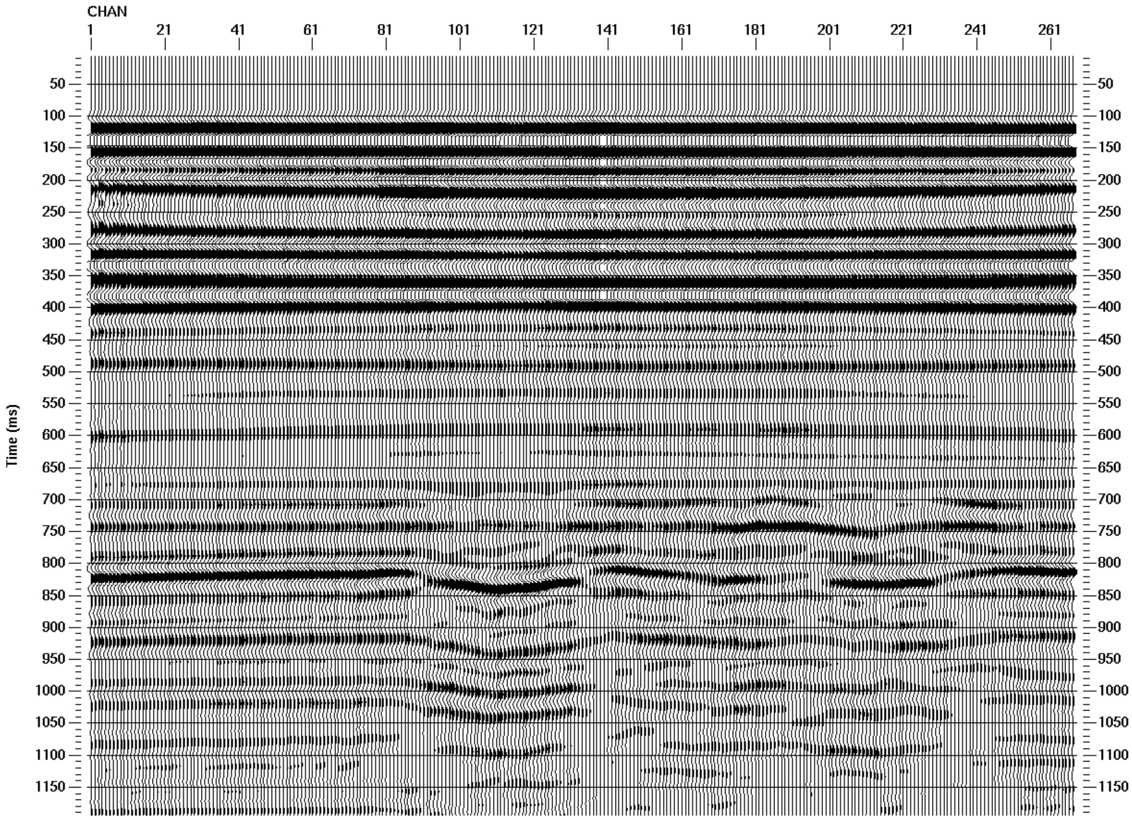

Fig.8 Fixed offset *P-P* survey over the splay and sand-channel .

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