SYSIF, a low frequency seismic profiler for near-bottom marine geophysics

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Summary

Ifremer has recently developed a deep-towed seismic system designed for High to Very High resolution near-bottom marine seismic surveys. This paper presents this new tool which is dedicated to the study of deepwater geological objects especially geohazards. After a technical description of the system, we expound an overview of the complete workflow from survey design to amplitude preserved processing illustrated by data acquired during sea trials.

Introduction

High (100 Hz) to Very High (1 kHz) Resolution marine seismic surveys is of common use for detailed sub-bottom investigation. The frequency range of these systems lays between 200 to 4000 Hz providing a metric to sub-metric vertical resolution. The lateral resolution of such systems is driven by the width of the first Fresnel zone and therefore by the distance (altitude) between the seismic layout and the targets. Typical applications of these high-resolution marine seismic include geotechnical and geological applications such as sediment characterization, stratigraphy and geohazards studies.

Marine experiments with seismic source and receivers towed close to the seafloor have already been conducted in the past (Nouze et al., (1997) and Chapman et al. (2002) among others). These experiments were set up in order to limit the energy loss related to wave front divergence and unwanted 3D effects or diffraction hyperbolas deteriorating the quality of the seismic image. Although some of the former improvements could theoretically be obtained through appropriate processing of surface seismic data, this would require unaffordable 3D acquisition and unlimited signal frequency bandwidth.

The technological challenge is thus to provide users with an appropriate seismic acquisition system able to deal with high hydrostatic pressure which forbids the use of any conventional surface-towed explosive source. The low frequency piezoelectric transducers comply with the former requirements, nevertheless conventional Tonpilz transducers, used for sub-bottom profiling, are limited in term of penetration by their frequency range, making it mandatory to explore other technology to reach lower frequency. This paper presents the deep-towed seismic system developed at Ifremer and its performance.

Description of the Ifremer deep-towed seismic system

Source and reception

The Janus-Helmholtz acoustic source, initially designed for low frequency active sonar, is made up of a piezoelectric ceramic stack inserted between two similar headmasses. This structure, called Janus driver, is mounted inside a vented rigid cylindrical housing providing a Helmholtz cavity. The coupling of a mechanical resonance and a fluid resonance allows a large frequency bandwidth and offers a highly repeatable acoustic signal perfectly tailored for accurate soil characterization.

Preliminary studies (Le Gall, 1999) included the design of a 580 to 2200 Hz transducer (figure 1, JH650-6000), this system being light enough (height 61 cm, diameter 45 cm, 90 kg in air, 55 kg in water) to be operated on board small research vessels. The acoustic source is operated together with a 3 kVA class D power amplifier which allows acoustic levels up to 196 dB (ref. 1 µPa@1m) to be reached in the whole frequency band (the frequency modulated electrical signal is compensated in amplitude in order to flatten the acoustic response). According to the excellent results achieved during the early sea trials and in order to reach higher penetration, a lower frequency seismic source has been designed (figure 1, JH250-6000). This new source is slightly bigger (height 112 cm, diameter 72 cm, 450 kg in air, 300 kg in water) and its performance together with a 6.5 kVA class D power amplifier allows acoustic levels up to 196 dB (ref. 1 µPa@1m) to be reached in the 220 - 1050 Hz frequency band.

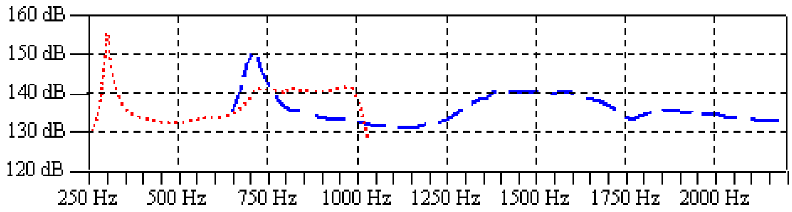

Figure 1: Axial TVR of the JH 250-6000 (red) and JH 650-6000 (blue) transducers Units in dB ref 1µPa/V @ 1m.

Seismic acquisition is two-sided: source and receiver. The potential of the formerly described acoustic sources may be reached only if the sensitivity of the recording array is designed to take full advantage of the quality of the emitted signal. To this purpose, hydrophones and streamer were designed to meet the requirements of the high hydrostatic pressure environment: the developed technology includes hydrophones with a –193 dB (ref. 1 V/µPa) receiving sensitivity and a loss in sensitivity limited to 1 dB between 0 and 600 bar. The actual antenna is a dual channel streamer; the first trace is a single hydrophone designed for amplitude processing, the second trace is made of 6 hydrophones, 30 cm apart, parallel-mounted to increase the Signal to Noise ratio. Both traces include a 100Hz-3000Hz band pass filter (18 dB/octave) and a 26.3 dB preamplifier, data sampling is achieved through a 26 bits analogue to digital converter at a 10 kHz rate.

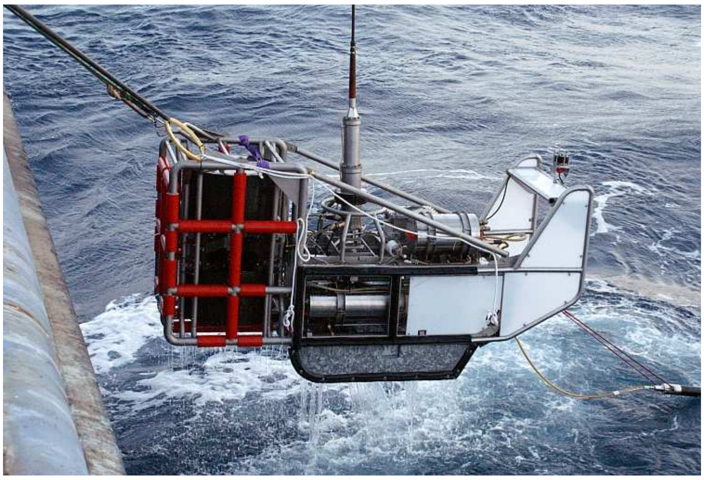

Figure 2: SYSIF deep-towed system mounted with the JH250-6000 transducer.

System Architecture

SYSIF (figure 2) is a towed heavy vehicle (2.4 tons in air), supporting at the same time a high resolution seismic source, either JH250-6000 or JH650-6000, and a 15m long dual channel

streamer. In a near future, SYSIF will operate as the depressor for Ifremer's SAR acoustic system including high-resolution sonar, sub-bottom profiler and 3-component magnetometer.
The system is towed via an armoured electro-optical cable delivering the 1000VAC surface power supply and bi-directional telemetry for the seismic payload and the safety controls. The positioning is achieved through an acoustic 120 kHz altimeter, a quartz pressure sensor, a miniature attitude and heading reference system and a 14-16 kHz Ultra Short Base Line. The whole system fits in a 20" container to enable easy transportation and handling on different ships.

Acquisition, processing and performance

Pitfalls exist in deep towed seismic acquisition and surveys have to be carefully planned to avoid them. Amazingly, working in deep water do not prevent seismic records from interaction with water multiples. Furthermore, the frequency content of downgoing events, i.e. sea surface reflections, is strongly affected by the roughness of the interface making difficult, if not impossible, any removal processing. Therefore, shot spacing has to be carefully chosen according to the bathymetry of the surveyed area. A simple ray tracing algorithm was developed to this purpose which takes into account the source ghost and sea bed multiples up to the third order.
Operating a vehicle close to the sea bottom requires constant actions on the towing cable and thus implies variation in the immersion/altitude of the system. The positioning parameters must be recorded at a rate appropriate to their frequency content in order to correctly remove artefacts from the recorded seismic sections
The designed system allows to process the reflection data in a preserved amplitude way. The main steps of the conventional processing workflow are: immersion/altitude correction, source signature deconvolution, spherical spreading correction and Q inverse filtering. A quantitative seismic approach is possible with the knowledge of the acoustic level emitted and the calibration of the receivers. Seismic attributes such as instantaneous amplitude, reflectivity and attenuation can be derived so as to help sediment characterization.
Numerous sea trials have been achieved in various geological environments and in water depth down to 2500 meters. Acquired data illustrated by figures 3 and 4 underline the potential of such breakthrough technology (quantitative characterization of the medium together with very high resolution imaging).

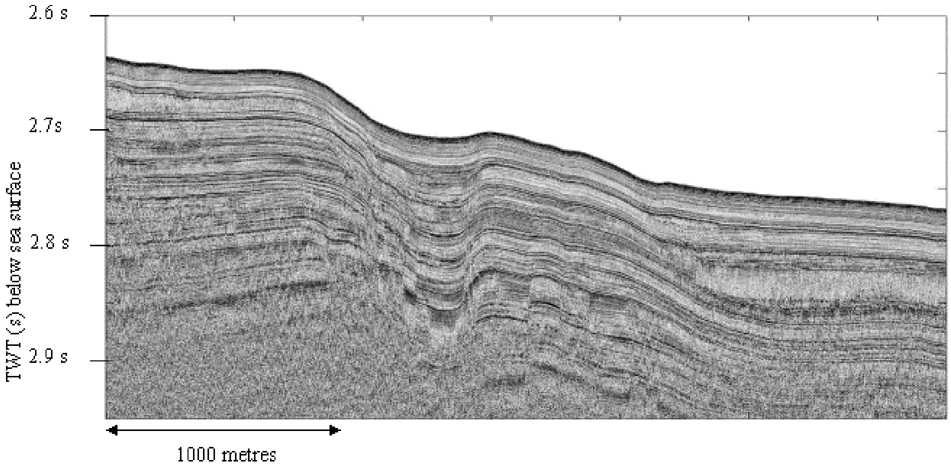

Figure 3: Seismic section (JH650-6000 transducer). Data collected in 2000 metres water depth offshore Nice (France).

Data presented in figure 3 were collected in late 2007 with the JH650-6000 configuration, in the Mediterranean sea offshore the mouth of the river VAR in 2000 metres water depth. The penetration reaches 200 ms (two way traveltime) in this environment. This section reveals

stratified series globally isopach affected by syn-sedimentary faults sealed at different stratigraphic levels and. the presence of a Mass Transport Complex.
Figure 4 shows data collected in 2006 by the JH250-6000 configuration, in the Atlantic Ocean on the Meriazdek terrace in 1000 metres water depth. The penetration reaches here 500 ms. The seismic line displays various units according to the geometry of the reflectors as well as the acoustic facies (sigmoidal facies to transparent) and two marked topographic steps with lateral impedance variation.

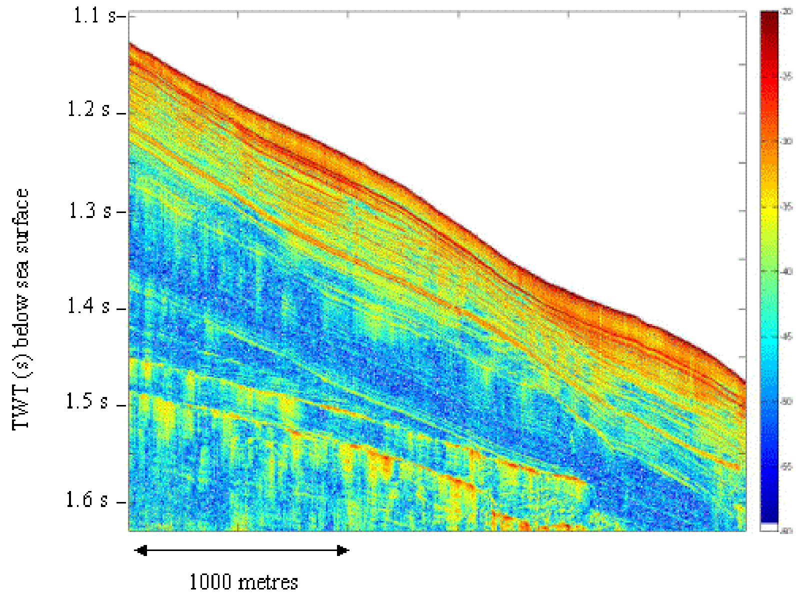

Figure 4: True amplitude seismic section (JH250-6000 transducer). Data collected in 1000 metres water depth offshore Britanny (France).

Conclusion

The deep-towed seismic system developed by Ifremer offers to scientists and industrials a very well-suited tool to investigate deepwater geological targets especially geohazards. The fundamental breakthrough is to allow a quantitative seismic characterization based on a deterministic and highly repeatable source signature associated to a careful calibration of the receivers. The near future of the tool is to be employed in scientific cruises which focus on hydrate system and slope stability. On going development concerns a multichannel configuration of the system and addresses the challenging issue of underwater positioning.

Acknowledgment

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