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High-resolution sub-bottom profiling using parametric acoustics

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To get sub-bottom information several equipment for sediment echo sounding is used. There are some important advantages of non-linear echo sounders compared to linear ones. This article discusses some advantages of non-linear echo sounders for high-resolution sub-bottom profiling in general as well as INNOMAR'S parametric sub-bottom profiler systems SES-96 and SES-2000. These systems provide not only the exact water depth determination, but give also detailed information about sediment layers and sub-bottom structures with very high resolution.

Echo Sounding and Echo Sounder Parameters

There are some important parameters to classify echo sounder systems that should be discussed briefly.

Directivity

The directivity of the transmitted sound beam depends on the transducer dimensions related to the sound frequency. There is a main lobe with a certain half-power beam width and side lobes. The sound at the border area of the main beam has a longer travel time than the sound in the centre of the beam. This makes the reflected signal longer than the transmitted signal. Particularly in deep-water areas refraction due to changes of the sound velocity may enlarge the sounded bottom area that makes the echo signal longer. Longer signals will mean less vertical resolution. The horizontal resolution depends on the area that is hit by the sound beam. Wide beam width means bad horizontal resolution and diffraction hyperboles occurs at small structures. A wide beam width also leads to greater surface and volume reverberation. Another problem are side lobes that cause echoes from outside of the desired direction.
To get echo prints with high spatial resolution you need a narrow beam without side lobes.

Frequency, pulse length, pulse ringing and pulse repetition rate

The penetration depth that can be expected depends on the attenuation of sound inside the sediment layers. The attenuation coefficient is proportional to the frequency and depends on type and structure of the sediment. For greater penetration depths lower frequencies should be used. On the other hand the vertical resolution depends on the pulse length of the transmitted signal. Shorter pulses will result in better resolution, which could mean using high frequencies. For different survey tasks different frequencies may be optimal, the echo sounding equipment therefore should be cover a wide frequency range.
Short pulses can be transmitted only by systems with a high frequency bandwidth. The ringing effect at the end of the transmitted pulse depends on the transducer bandwidth. The ringing time should be as short as possible for echo sounding in shallow water.
For safe detection of small sediment structures or buried objects the same bottom area must be hit several times. Therefore the pulse repetition rate should be as high as possible.

Beam steering and stabilizing, heave compensation

Caused by rough sea the transducer may move during the survey in 6 directions. The most important unwanted motions are roll, pitch and heave. They should be compensated, if high-resolution echo prints are required. Therefore beam stabilizing and heave compensation should be possible, especially at greater water depths. At slopes it is useful to direct the beam perpendicular to the bottom surface to make sure to get the best penetration. For that reason beam steering should be possible. Beam steering may also be used for widening the search area without losses in the horizontal resolution (multi-beam sediment echo-sounder).

Real time signal processing and size, weight, mobility

To get first survey results immediately, echo prints should be calculated in real-time. Therefore a powerful real-time signal processing is necessary. If you need mobile equipment to use on small, maybe different ships, the size and weight of the echo sounder system and in particular of the transducer will be important.

The ideal echo sounder

The ideal echo sounder for surveying should have

- Narrow beam width and no side lobes
- Wide frequency range
- Short sound pulses without ringing
- High pulse repetition rate
- Beam steering and stabilizing as well as heave compensation possible
- Echo prints calculated in real time
- High mobility and therefore small and light equipment

Some of these desires are only to fulfil using non-linear acoustics.

Linear and Non-linear Acoustics

Linear echo sounders generate the sound pulse of the desired frequency directly. The directivity depends on the ratio of the transducer dimension and the signal frequency. A narrow beam at low frequencies requires large transducers while using linear acoustics.

Parametric echo sounders transmit two signals of slightly different high frequencies at high sound pressures (primary frequencies). Because of non-linearities in the sound propagation at high pressures both signals interact and new frequencies are arising.

The so called secondary frequency (difference of the transmitted frequencies) is low and penetrates the sea bottom. The primary frequencies may be used for exact determination of water depth even in difficult situations, e.g. soft sediments.

The directivity for the difference frequency is similar to the primary frequency. Therefore narrow beams at low frequencies can be transmitted by small transducers. For different secondary frequencies the directivity is nearly the same and the sounded bottom area will have nearly the same size. This is important if echo prints from different frequencies should be compared. There are no significant side lobes for the difference frequency.

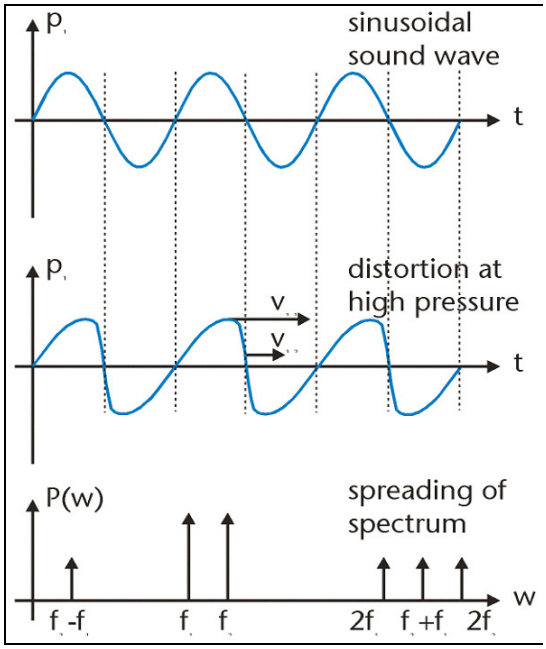

Fig. 1: Principle of non-linear acoustics

Caused by the high system bandwidth of a parametric system really short signals can be transmitted without ringing. This makes parametric systems useful in particular in shallow water areas.

Due to the small beam width and the high frequency bandwidth the bottom echoes from parametric echo sounders have a steeper slope than echoes from linear echo sounders. These steeper signals are better to detect at low signal to noise ratios, so in areas with dredging activities. Therefore a high resolution of layers and detection of small changes in the acoustic impedance becomes possible.

Short pulses, narrow beams and the absence of side lobes results in less volume reverberation and less reverberation from the bottom surface compared to linear systems. This results into a better signal to noise ratio, especially in areas with siltation.

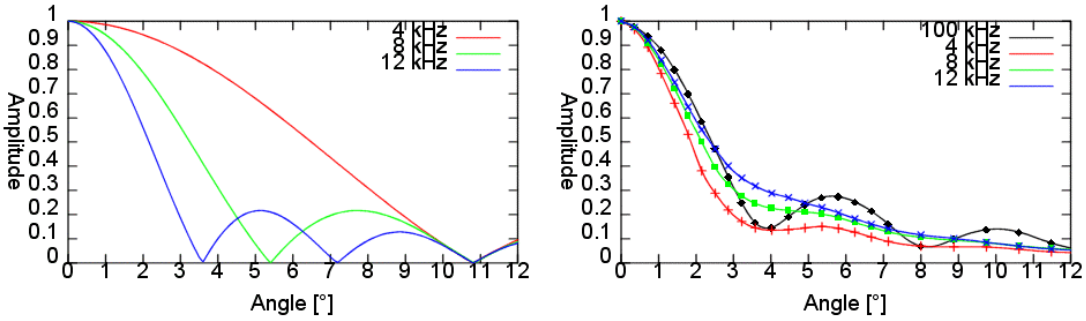

Fig. 2: Directivity pattern for linear (left; computed) and parametric transducer (right)

The Parametric Echo Sounder Systems SES-96 and SES-2000

Based on fundamental research and components developed by the Underwater Acoustics Research Group of Rostock University, INNOMAR Technologie GmbH Rostock developed a product line of new parametric echo sounders.

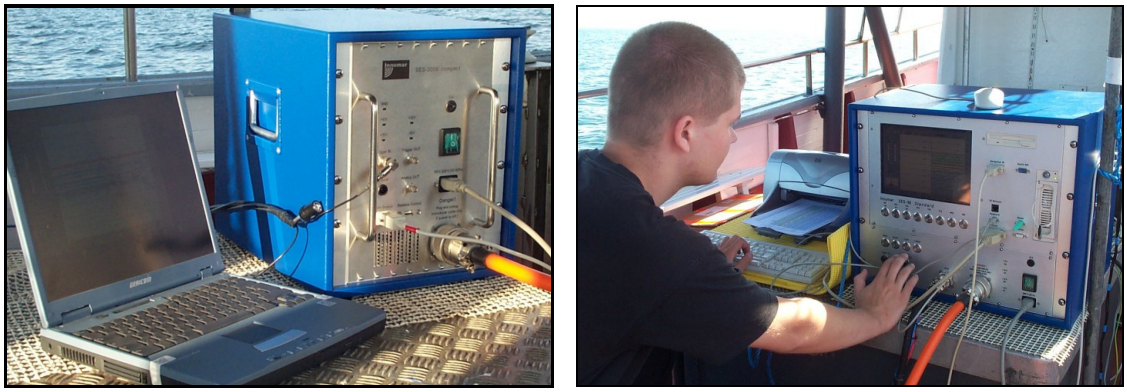

Fig. 3: SES-2000 compact (left) and SES-96 standard (right)

Today there are four different system variants available. The SES-96 light and SES-96 standard systems are used worldwide for a great variety of shallow water applications from 1 meter down to 400 meters of water depth. The new variant SES-2000 medium is designed for a water depth down to 1500 meters. The SES-2000 compact model is the smallest sub-bottom profiler equipment, especially for the lower budget.

The compact design of these family of echo sounders, only the transducer and one water protected 19 inch unit is required, allows very easy and mobile installations. The accuracy of the depth measurement fulfils the IHO standard and the resolution of the low frequency channel is significantly higher than with any linear system on the international market.

Electronic beam stabilization and beam steering is possible. This might be useful especially for applications offshore and under rough survey conditions. Additionally the search for embedded objects will be more effective.

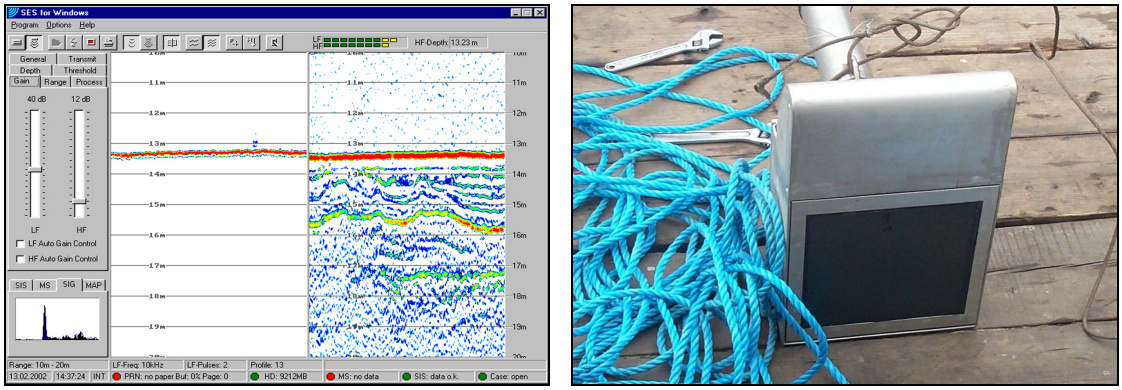

Fig. 4: On-line control software with dual channel view (HF and LF) and transducer in streamlined housing (right)

The signal processing is completely digital and gives coloured echo plots in real-time allowing very quick adaptations of the survey. Operated via a graphical MS Windows® on-line control software the system has very short training requirements. The digital storage of the echo sounder data together with the data from attached positioning systems, like DGPS and from motion sensors (Seatex, TSS, Octans), allows complete post processing. INNOMAR provides the user with a post processing software package, mainly used for the extraction of the bathymetry, any sub-bottom layering and detected object positions in the form of compatible ASCII files for further visualization, charting and volume calculations. The comparison with real probes, like from borings or from density measurements, is also possible during the post processing. Data conversion to SEG-Y and XTF is possible.

Water depth range	0.5 … 1500 m
Vertical resolution	<6 cm
Penetration depth	up to 50 m
Accuracy of the depth measurement	0.02 m + 0.02% of the water depth
Primary transmitter frequency	ca. 100 kHz
Secondary transmitter frequency	4, 5, 6, 8, 10, 12, 15 kHz
Transmitter pulse length	0.07 … 1 ms
Repetition rate	up to 50 s^{-1}
Beam width	±1.8° @ 4 … 15 kHz
Beam steering range	±16°
Transducer dimensions	ca. 20 × 20 cm

Main Parameters SES-96 and SES-2000

Application examples

The SES-96 and SES-2000 sub-bottom profilers are used for a great variety of applications in the marine field by customers worldwide, mainly by dredging companies, general survey companies and waterway and shipping offices. Very good results could be achieved in shallow water areas as well as in water depths up to more than 1500 m.

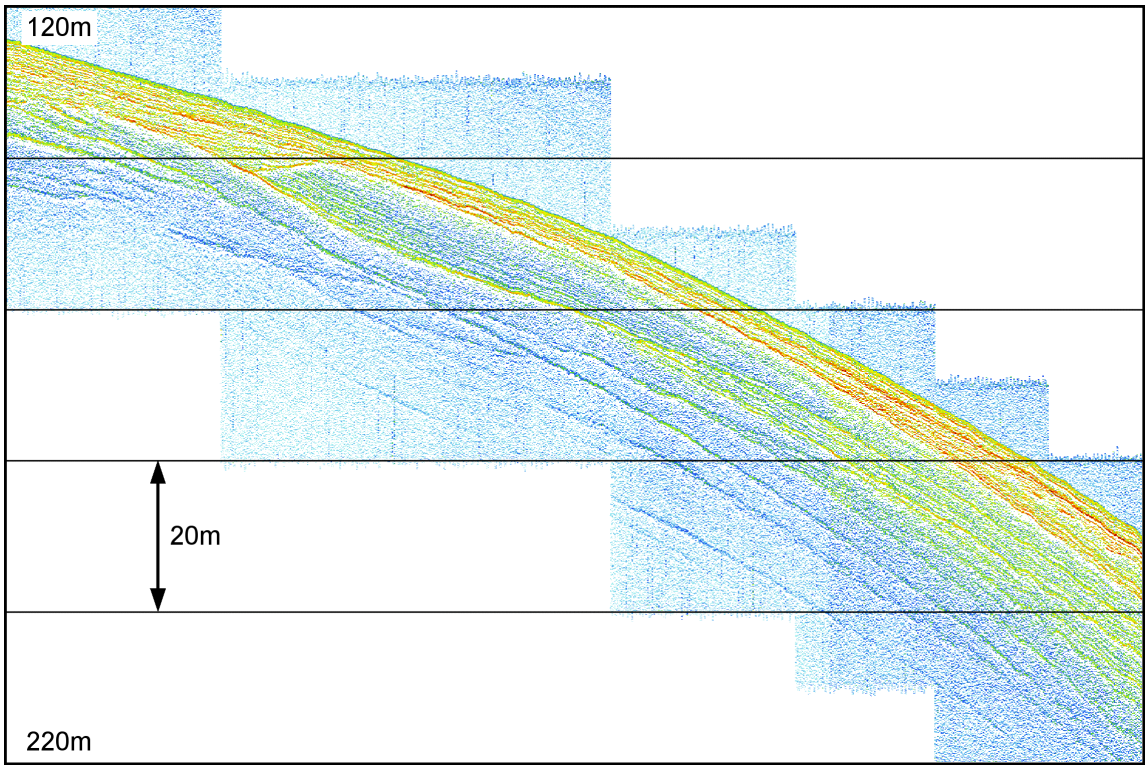

Fig. 5 : Echo print SES-2000 (Peru; 8 kHz; Range 120 ... 220 m)

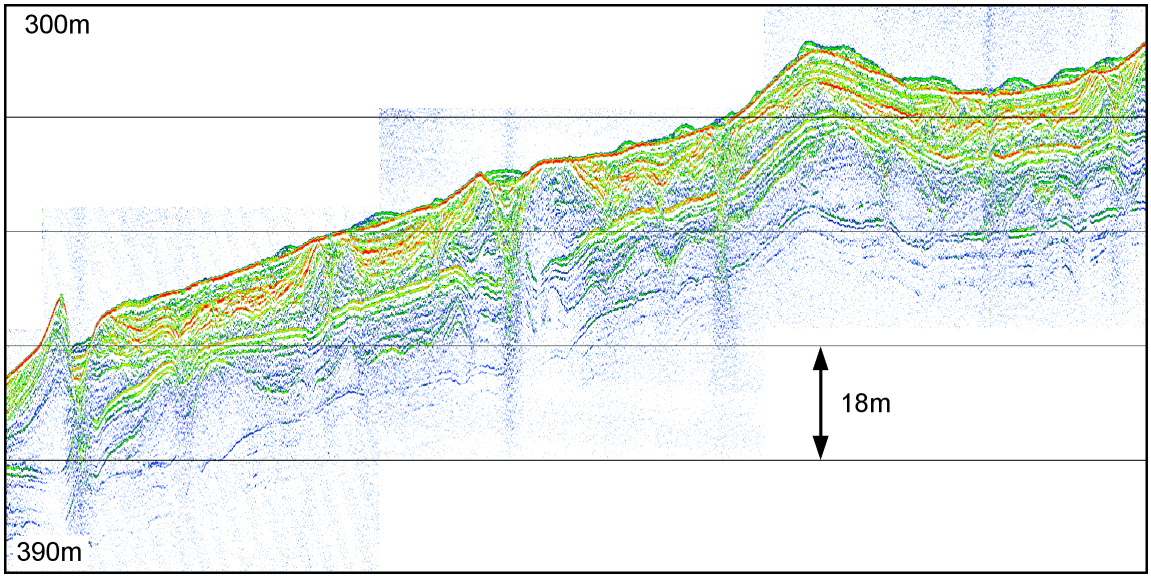

Fig. 6 : Echo print SES-2000 (Peru; 5 kHz; Range 300 ... 390 m)

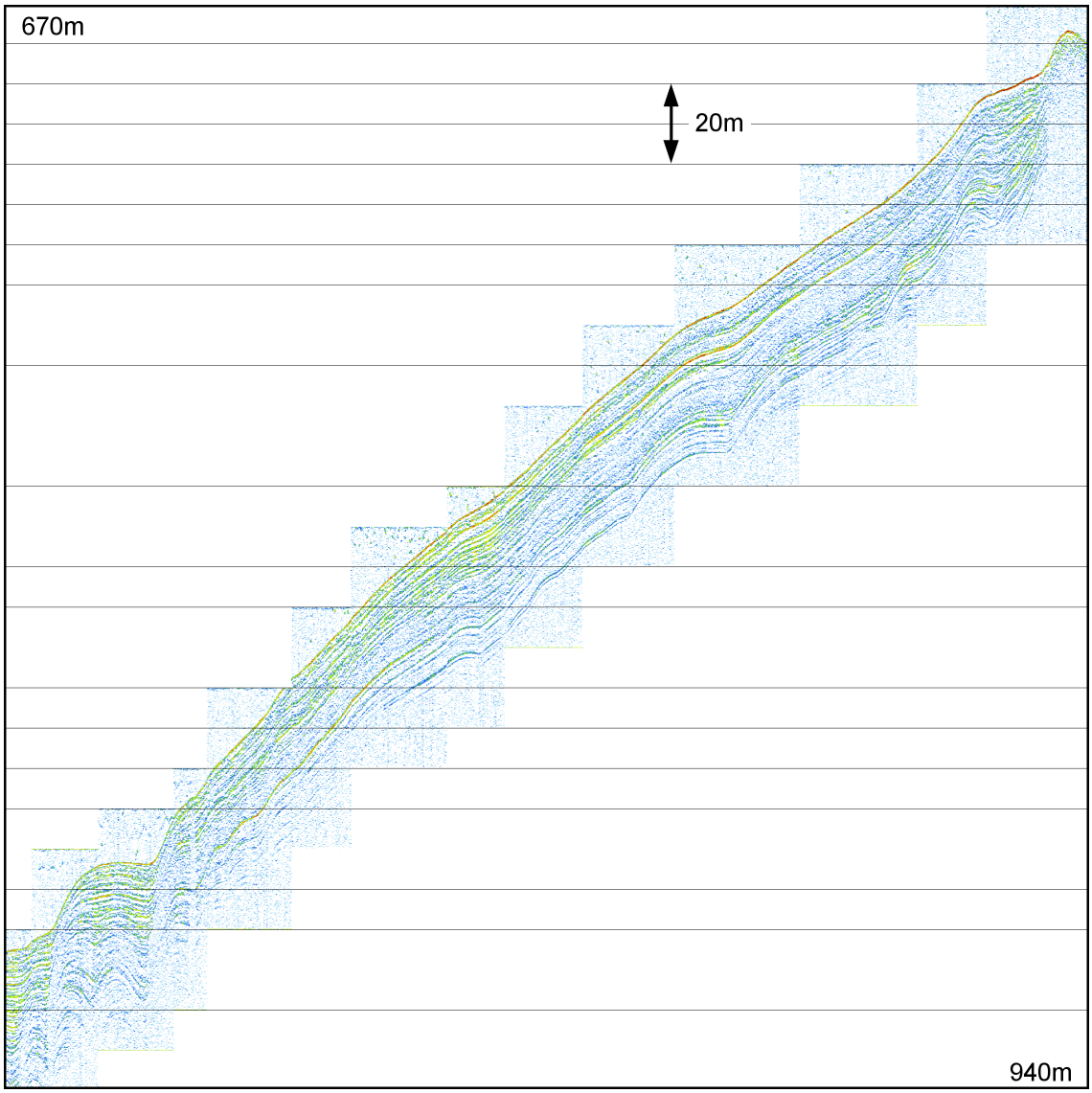

Fig. 7: Echo print SES-2000 (Sea of Okhotsk; 8 kHz; Range 670 ... 940 m)

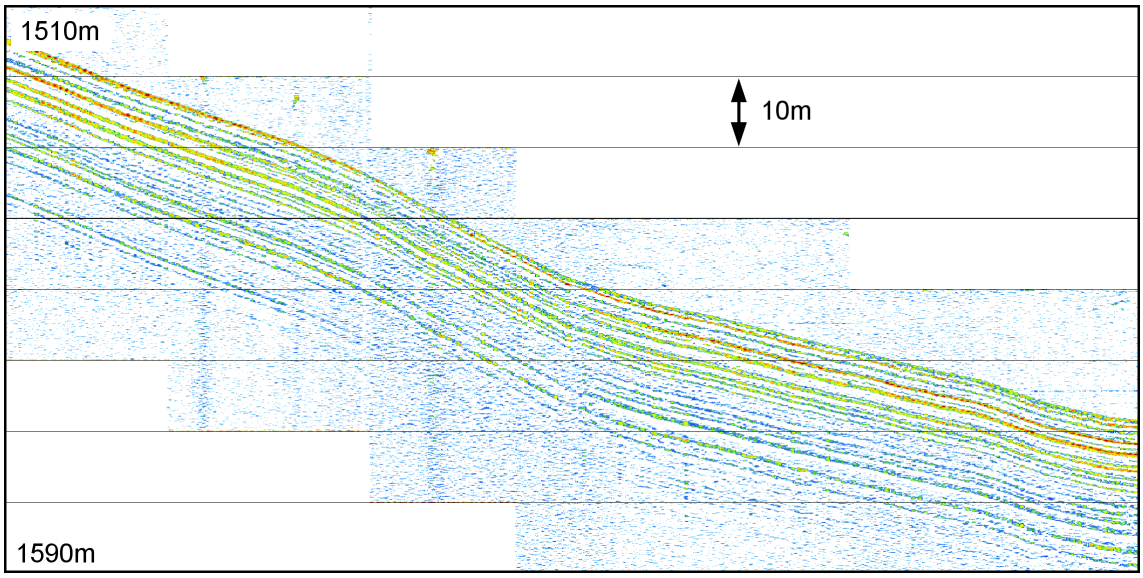

Fig. 8: Echo print SES-2000 (Sea of Okhotsk; 8 kHz; Range 1510 ... 1590 m)

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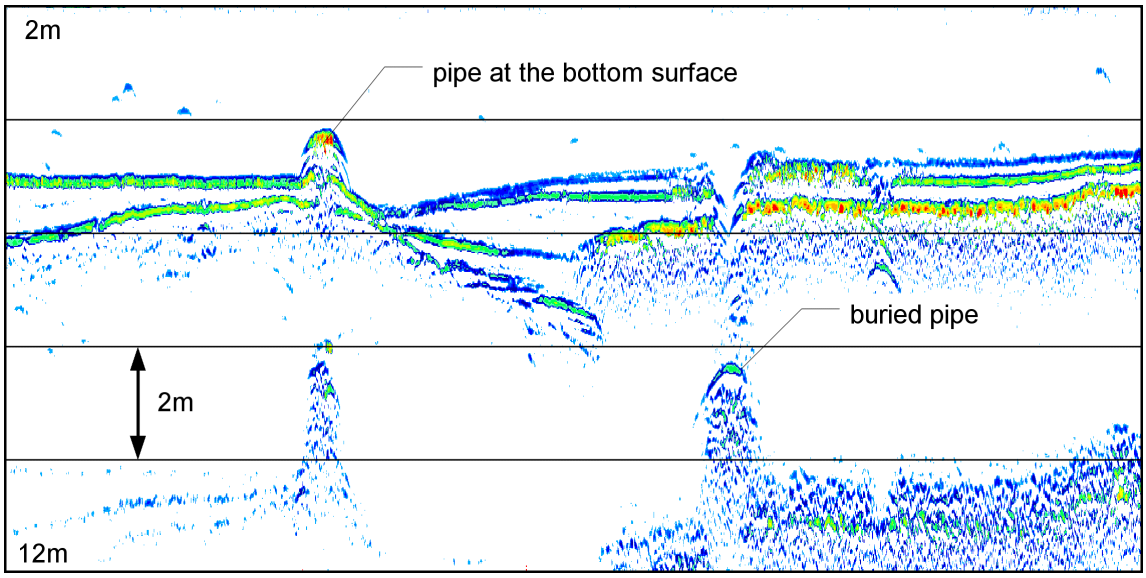

Fig. 9: Echo print SES-96 (shallow water pipeline survey; 8 kHz; Range 2 ... 12 m)

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