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OCEAN BOTTOM REFRACTION SEISMOGRAPH (OBRS)*

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Abstract. This paper describes a pop-up ocean bottom seismograph designed primarily for refraction surveys both on the continental shelf and in deep sea. Its development is the extension of our system based on seismic detectors located on the sea floor with radio transmission of seismic signals and used for seismic refraction studies on the continental shelf. The seismic detectors (vertical geophone or hydrophone and two orthogonally mounted horizontal geophones) are located outside of the pressure vessel on the main frame. Optionally, the seismic sensors may be decoupled from the main frame assembly. This decoupling is performed by a mobile arm positioning the separate three component sensor package on the sea floor.

1. Introduction

Our experiments with seismic detectors on the sea-floor started in the fall of 1970 in a study of the Western Approaches of the English Channel by seismic refraction. Instead of sonobuoys the use of seismic detectors on the sea-floor with data telemetering to the surface vessel (Behrens, 1960; Ewing and Ewing, 1961) was necessary because of the prevailing high tidal currents and bad weather conditions in this area. It was known from previous experiments that under such conditions the performance of standard sonobuoys is at best mediocre due to the unfavourable signal to noise ratio as well as the poorly known position of the buoy over a given geological structure.

After some experimental work, the final assembly we used was as follows (Avedik and Renard, 1973; Avedik, 1975): the signal of the seismic detector (vertical geophone or hydrophone) positioned on the sea-floor was amplified and linked to the surface radio-buoy by a single-conductor steel-armored cable (ϕ 5.5 mm). The signal transmitted by the radio-buoy was received on the ship's receiver and recorded on tape for further processing. A 150 kg anchor was clamped to the cable about 25–30 m from the detectors. A gimbal assembly was not used for the vertical geophone, but two geophones were mounted in opposite directions, in a flat, round frame (40 kg), with spikes, so that one was always in the right direction when the frame landed on the sea-floor. A mercury switch assured the connection of the upright geophone to the amplifier. The amplifier gain controller (discrete steps or automatic gain control with a dynamic range of about 60 db) was located in the surface radio-buoy. Typical radio ranges averaged between 20–30 km for transmitters with 177 MHz carrier and slightly over 50 km for the 87 MHz carrier transmitters. Launching and recovery of the assembly on the continental shelf in water depth from 100 to 200 m took 15–20 min and 40–50 min respectively.

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An example of a profile in the Western Approaches of the English Channel (Figure 1) demonstrates the favourable signal to noise ratio obtained. The simplicity and ease of operation, the low price, and the good seismic performance make such a refraction system suitable for short-to-medium distance profiles on the continental shelf.

However, the difficulties in using such a system for deep sea work and long range profiles are evident. The economical and technological limits are set by the price and the relatively difficult handling of long conductor lines as well as by the limited radio range of transmitters working in the VHF range.

There are two ways to avoid the above-mentioned difficulties:

(1) Use of a self-contained instrument attached by nylon rope to a surface float (Rykunov and Sedov, 1967; Asada and Shimamura, 1974).

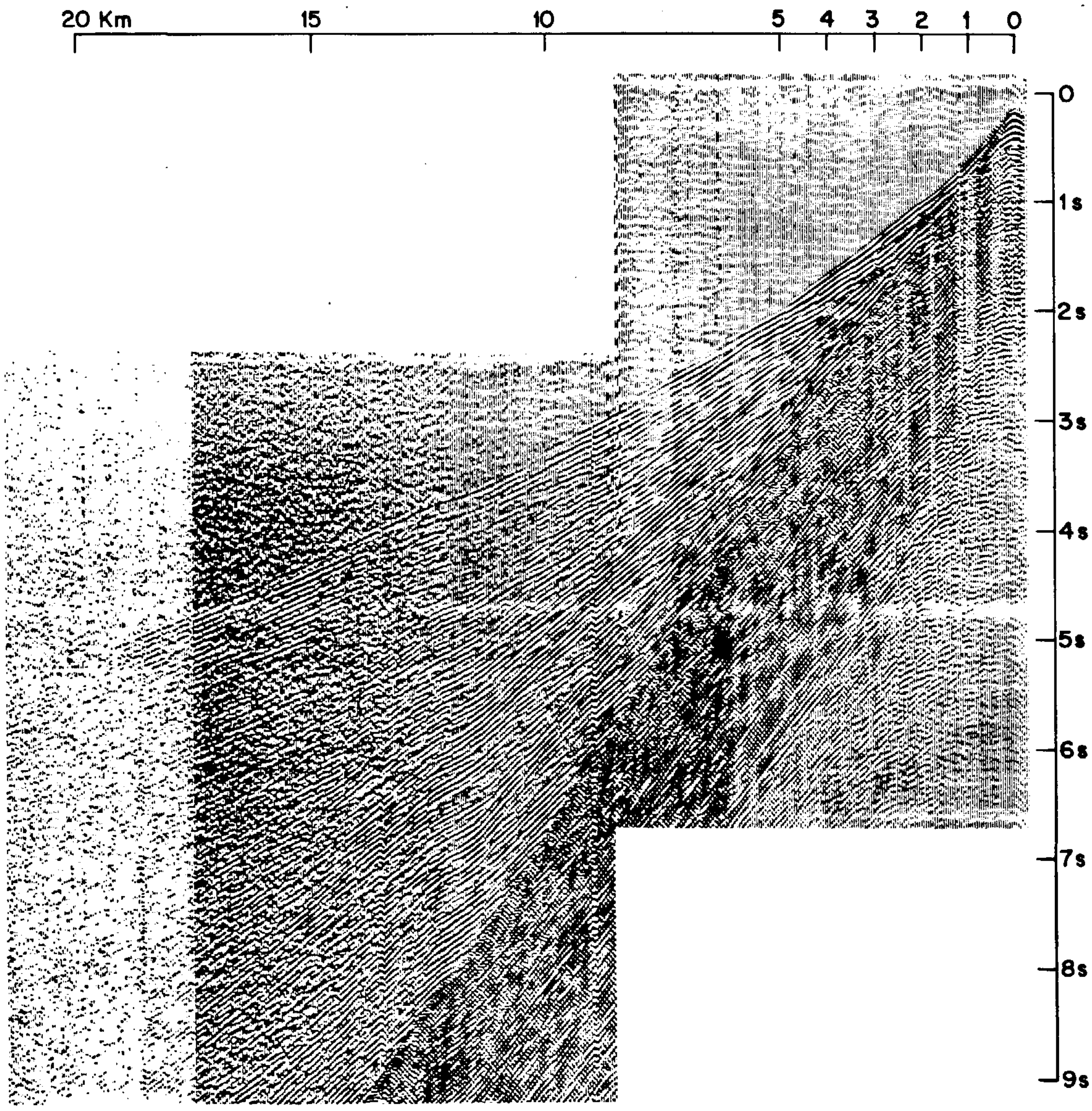

Fig. 1. An example of seismic refraction profile with vertical geophone on the sea floor. Water depth: 130 m; air gun 0.65 liter (40 cu. in.); shot rate: 1/15 s or 1/46 m.

(2) Use of a completely independent, 'pop-up' seismograph (Charmichael *et al.*, 1973; Bradner, 1964; Arnett and Newhouse, 1965; Whitmarsh, 1970; Johnson, 1974; Francis *et al.*, 1975; Lister and Lewis, 1975).

During the first four months of 1975, we built a simple, tethered type instrument. The first launching at 4500 m gave satisfactory results, as no system generated noise was found. The second launching at about the same depth ended 'tragically' as fishermen cut (within our sight) the mooring line and the instrument was lost. Due to the likelihood of such an incident reoccurring the decision was taken in July 1975 to build only 'pop-up' type seismographs.

2. Design Philosophy and General Description

Large explosive charges are usually employed in crustal refraction. Since the number of these shots is small, the survey technique has limited resolution. Also, it becomes increasingly difficult for ecological reasons to use explosives particularly on continental shelves. To a certain extent, pneumatic sound sources (air guns) seem to offer the best replacement for explosives, as they provide a high repetition rate and stable, relative low frequency output wave forms. However, lack of sufficient energy limits their use for long range experiments.

For several years at the Centre Océanologique de Bretagne experiments were conducted (and are under way) to increase the energy of shots with air guns, using larger volumes (up to 140 liters), higher pressures ($\approx 250.10^5$ Pa), air guns arrays, stacking, etc. . . . . As the results obtained with these sources were encouraging, the specifications of our bottom seismograph were fitted in many respects to meet the requirements of seismic refraction surveys with pneumatic sound sources on the continental shelf as well as in the deep sea.

The seismograph is based on the following design concepts:

- Depth capacity 6000 m.
- Ruggedness and simplicity of operation, to be able to operate from small and unsophisticated vessels without the need of highly specialized personnel.
- Modular buoyancy. As ship time is one of the most costly items in oceanography, we intend to couple seismic experiments with other types of data collection such as current measurements, deep sea photographs, etc. . . ., so buoyancy has to be in balance with the increased payload. We feel that this type of additional information can be useful in evaluating the performance of the seismographs.
- Descent velocity ≈ 1.5 m s^{-1}; ascent velocity ≈ 1 m s^{-1}.
- Optional decoupling of the seismic sensors from the seismograph assembly. This is to gain information on the sensor response by changing coupling parameters. Number of sensors: minimum three (hydrophone or vertical geophone and two, orthogonally placed horizontal geophones for shear wave detection).
- Acoustic tracking and release command plus additional, pre-set safety release.
- Radio-beacon and flashing light to facilitate tracking of instrument once on the surface.

The recording characteristics were to meet the following requirements:

- Dynamic range ~ 60 db, representing a realistic value proven by experience. Some clipping of intense water waves is accepted.

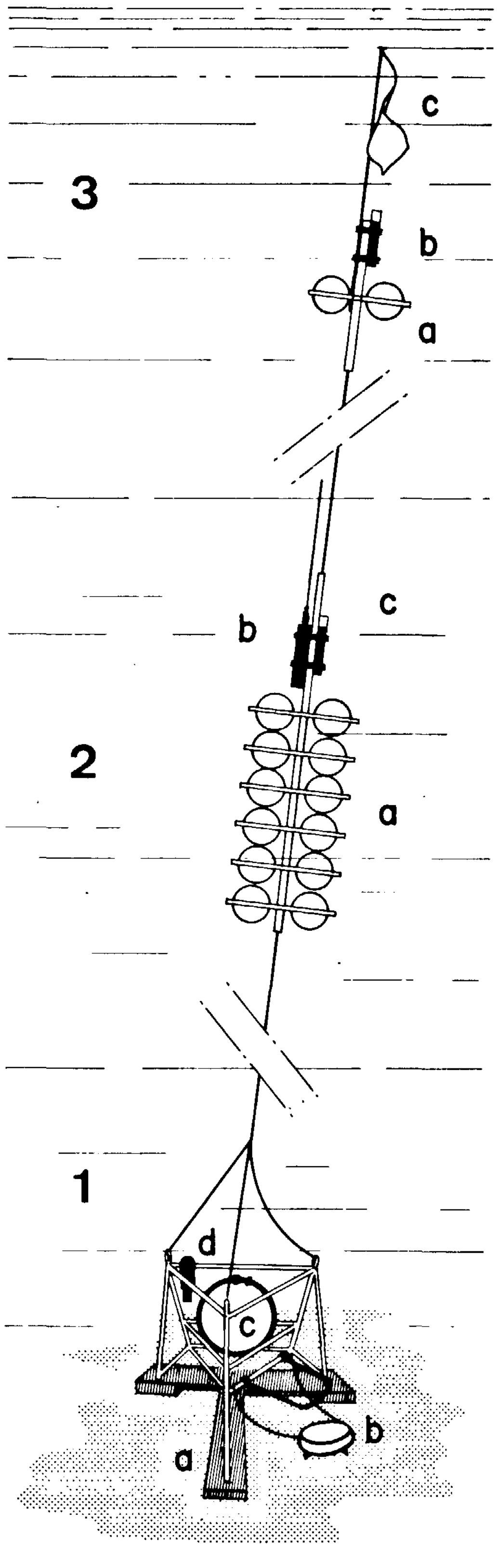

Fig. 2. General lay-out of the system. 1. Ocean Bottom Refraction Seismograph: (a) sinker weight; (b) detector package; (c) frame and pressure vessel; (d) acoustic transducer. 2. Modular float assembly: (a) float unit; (b) radio beacon; (c) flashing light. 3. Auxiliary float assembly: (a) float; (b) flashing light; (c) flag or radar reflector.

- Bandwidth from 5 to about 50 Hz.
- Recording mode: start-stop governed by a programmer synchronized with the ship-borne seismic programmer which triggers the solenoids of air gun(s) or continuous.
- Recording time: $> 1000 \times 60$ s recording cycles.
- Stability of programmer: ≥ 10 ms day^{-1}. Drift should be, as far as possible, independent of 'thermal shocks'.
- To avoid lengthy testing and manufacturing processes we used the maximum commercially available systems and parts in the present instrument. A series of five instruments were completed from September to December 1975.

The system consists of three assemblies (Figure 2):

(1) OBRS (Ocean Bottom Refraction Seismograph) with sinker-weight.
(2) Modular float assembly.
(3) Auxiliary float assembly.

2.1 *OBRS*

The tubular (steel), three-leg frame rests on a three-arm sinker weight (Figure 2, 1a) and houses the pressure vessel, the release mechanism and the acoustic transducer used for the acoustic link between the OBRS and ship. Such a frame is easily built by any machine-shop, equipped with electrical welding apparatus. The height and maximum width of the main frame is 0.85 and 1.2 m respectively. Optionally, to be able to dissociate the seismic sensors and the main frame the latter is equipped with a mobile arm supporting the detector-package (Figure 2; 1b). The detector-package (Figure 3) contains two horizontal geophones placed orthogonally and the hydrophone or optionally the vertical geophones as well as an 'attitude detector' (mercury switch). So far, the geophones have been mounted without gimbals but such a mechanism may be incorporated later on. At the beginning of recording, following a signal from the programmer-clock, a 50 cycle synchromotor (in silicon oil under hydrostatic pressure) activates a one turn (360°) cam and releases the mobile arm, which gently drops the detector package to the ground about 60–80 cm away from the main frame. Spikes on the under side of the detector package should insure good coupling of the geophones to the ground. In case the sensors are mounted on the main frame, the synchro-motor and the mobile arm are removed.

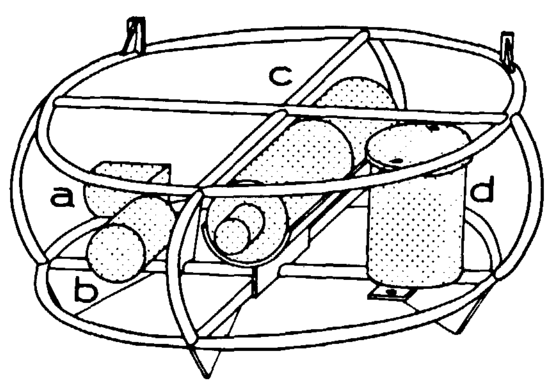

Fig. 3. Lay-out of detector package. (a), (b), horizontal geophones; (c) hydrophone or vertical geophone; (d) attitude detector.

The steel pressure sphere (O.D. 444 mm, I.D. 420 mm), the only one readily available to us, containing electronics batteries and the recorder, consists of two stamped hemispheres bolted to a stainless-steel equatorial ring with 'O'-ring seals. The internal and external surfaces of the hemispheres are nickel-treated. A protective paint coat is applied on the external surfaces. The weight of the empty pressure vessel is about 90 kg in air and 40 kg in seawater. Four access-holes with Marsh-Marine 6 pin pressure-proof connectors and a bolt (to attach the vessel to the frame) are located on the lower hemisphere. The 4 connectors are used for: (a) seismic signals; (b) release motors and explosive release; (c) acoustic transducer; (d) synchronisation of programmer clock to the ship-borne seismic programmer. This plug is also used to check the inner clock function as well as the seismic signals once the pressure vessel is closed.

On the upper hemisphere are two ventilation holes with pressure proof plugs which serve to fill-up the vessel with freon gas, to avoid condensation at the low temperatures prevailing on the ocean bottom when working under hot and damp climates. One of the plugs has a hook to facilitate the handling of the upper hemisphere. Only the upper hemisphere needs to be removed to gain access to all internal parts.

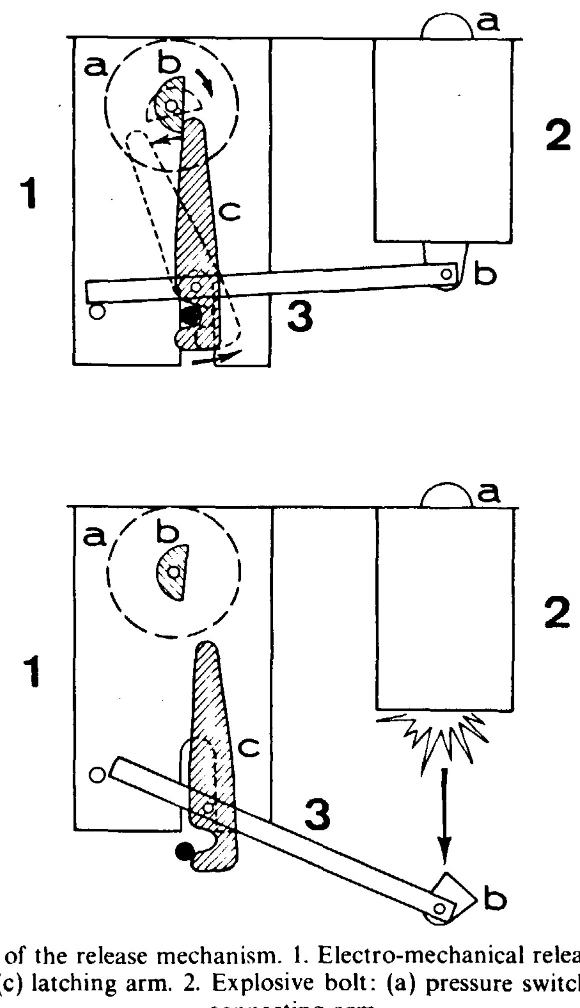

Fig. 4. Schematic view of the release mechanism. 1. Electro-mechanical release assembly: (a) synchromotor; (b) release cam; (c) latching arm. 2. Explosive bolt: (a) pressure switch; (b) shear pin. 3. Interconnecting arm.

The release mechanism (Figure 4) consists of two interconnected parts: the electromechanical latching assembly (1) and the explosive bolt (2). After reception of the acoustical release command (see 4.4), the 50 cycle synchro-motor (1, a) activates the one turn (360°) cam (1, b). After a 90° turn the latching arm (1, c) is liberated and releases the sinker weight. In case of a sticking latching arm (mud?) the cam after about a 160° turn pushes the arm forward. In case of non-release, the explosive bolt is set off by means of a signal from a separate self-contained, pre-set timer. The head of the bolt (2, b) is then sheared off, pushing downwards the interconnecting arm (3) as well as the latching arm, thus releasing the sinker weight. The explosive bolt can hold a weight of about 500 kg. It contains 2.5–3.0 gr of black powder and has a double filament igniter. A pressure switch, (2, a) set to about 20 m equivalent pressure prevents accidental ignition on deck. The explosive bolt is manufactured by Société SUBER (29200 Brest, France).

A three-arm U-frame weight (Figure 2, 1a), with 50 kg steel weight welded to the under side at the end of each arm, sinks the OBRS. The total weight in air is about 180 kg.

Figure 5 shows a photograph of the OBRS with sinker weight connected.

2.2. *Modular Float Assembly*

Considering the price and availability of various deep submergence buoyant materials, it has been decided to use glass floats (maximum operating depth 8000 m). Up to now these floats seem to give the best buoyancy/dry weight as well as price/net buoyancy ratio, having sufficient depth capacity to work safely down to 6000 m. In addition such floats are currently used in our Centre for other applications.

The float assembly (Figure 2, 2) consists of a central tube (aluminium) on which rings, each containing five floats, are piled up. The maximum length and the diameter of the assembly is about 2.7 and 1.1 m respectively. The modular construction of the float permits easy matching of buoyancy with increased load due to additional instruments such as camera, current meter, etc. . . . . Also the float assembly's frame protects the relatively fragile glass floats from rough handling on deck. This protection is worthwhile even though some net buoyancy is lost due to the weight of the frame. On the top of the float assembly the radio-beacon and a flashing-light are located, each with a pressure switch. About 2–3 m of nylon rope connect the float assembly to the OBRS.

2.3. *Auxiliary Float Assembly*

The auxiliary float assembly (Figure 2, 3) is connected to the main float assembly by a floating nylon rope about 25–30 m long. The assembly has an aluminium frame with three glass floats, a flashing-light and optionally a radar-reflector or a flag attached to the top of the frame. This float assembly serves only as an aid for recovery, mainly at night and under bad weather conditions.

The dry weight of the OBRS when prepared for a drop is about 430 kg, with the float assemblies equipped to give about 60 kg net buoyancy in sea. The free fall and ascent velocities are 1.3 and 0.9 m s^{-1} respectively.

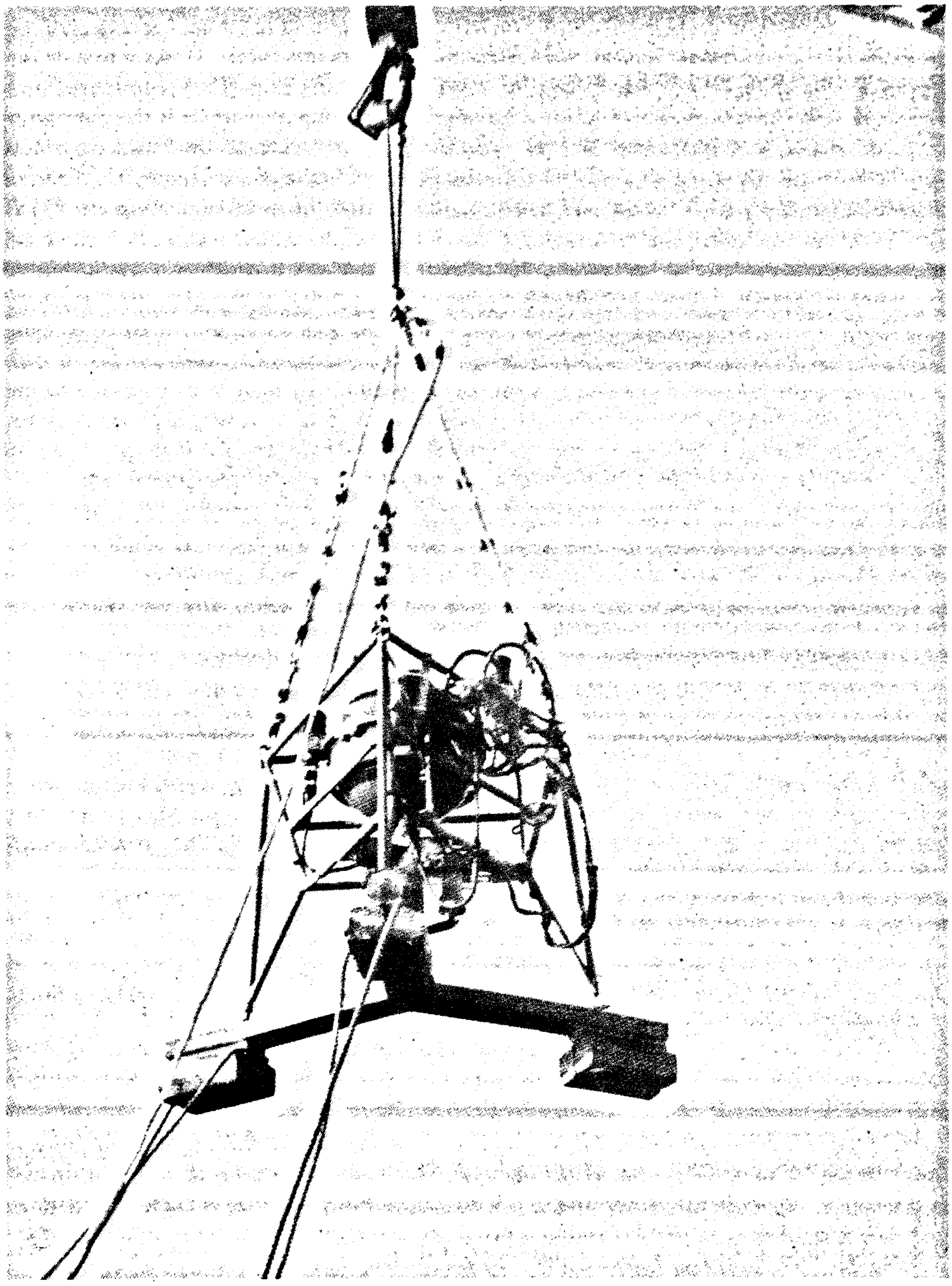

Fig. 5. OBRS with sinker weight prepared for launching.

3. Seismic Detectors

Our present arrangement consists of two orthogonally oriented horizontal geophones and a hydrophone (or optionally a vertical geophone) mounted in the detector package or on the main frame. Using the detector package, it swings away from the main frame of the OBRS at the beginning of recording and lands on the sea-floor. In this position only two slack, non-floating nylon ropes and an electric conductor (attached to one nylon rope) connect the detector package to the main frame.

Geophones are the commercially available and commonly used HS-1 HP refraction geophones of Geo Space Corp. (U.S.A.), with a natural frequency of 4.5 Hz and a coil resistance of 215 ohms. Damped at 52%, their output is 0.16 V cm^{-1} s^{-1}. Also, geophones with 900 ohms coil resistance are used, their output being 0.3 V cm^{-1} s^{-1}. The geophones are in a pressure case with two pressure connectors and have a pressure capacity of 1400.10^5 Pa. The height and diameter of the geophone is 7.3 and 5.0 cm respectively, they weigh 0.5 kg (dry weight).

The hydrophone is general purpose type ICT 8014 A manufactured by International Transducer Corp. (U.S.A.). Its frequency range is 2–10000 Hz, pressure range 0–700 $\times$ 10^5 Pa. The hydrophone sensitivity is -188 db $volt^{-1}$ $micropascal^{-1}$. With the built in preamp the system sensitivity becomes -168 db $volt^{-1}$ $micropascal^{-1}$. The four-pin bulkhead connector is a Marsh-Marine type RM-4-BCL. The hydrophone dimensions are 6.4 $\times$ 24 cm, and the weight in air is about 5 kg.

4. OBRS Electronics

The inner sphere contains the
(1) seismic amplifiers;
(2) seismic programmer with the auxiliary clock for explosive bolt;
(3) tape recorder;
(4) acoustic tracking and sinker weight release;
(5) power supplies.

The general layout of components is shown in Figure 6 and the block diagram of the electronics in Figure 7.

4.1. *Seismic Amplifiers*

The three seismic detectors are linked to three, separate seismic amplifiers, equipped with a filter network and automatic gain control. In addition, the geophone amplifiers have 30 db preamplifiers. The p–p input noise is $\leq 1.2\ \mu V$ at 900 Ω source impedance in the relevant bandwidth.

The filter characteristics are:

- hydrophone: 5–25 Hz with high-pass section 24 db octave,$^{-1}$, low-pass section 15 db^{-1} octave;
- geophones: 5–25 Hz, no high pass section, low-pass section 15 db $octave^{-1}$.

The automatic gain controller (AGC), one for the hydrophone channel and one for the two geophone channels, adjusts the back ground noise-level to about 12 db above required minimum recording level. The integrator's time constant is, at the present, 30 s. Increase or decrease of the noise causes gain-changes over a range of

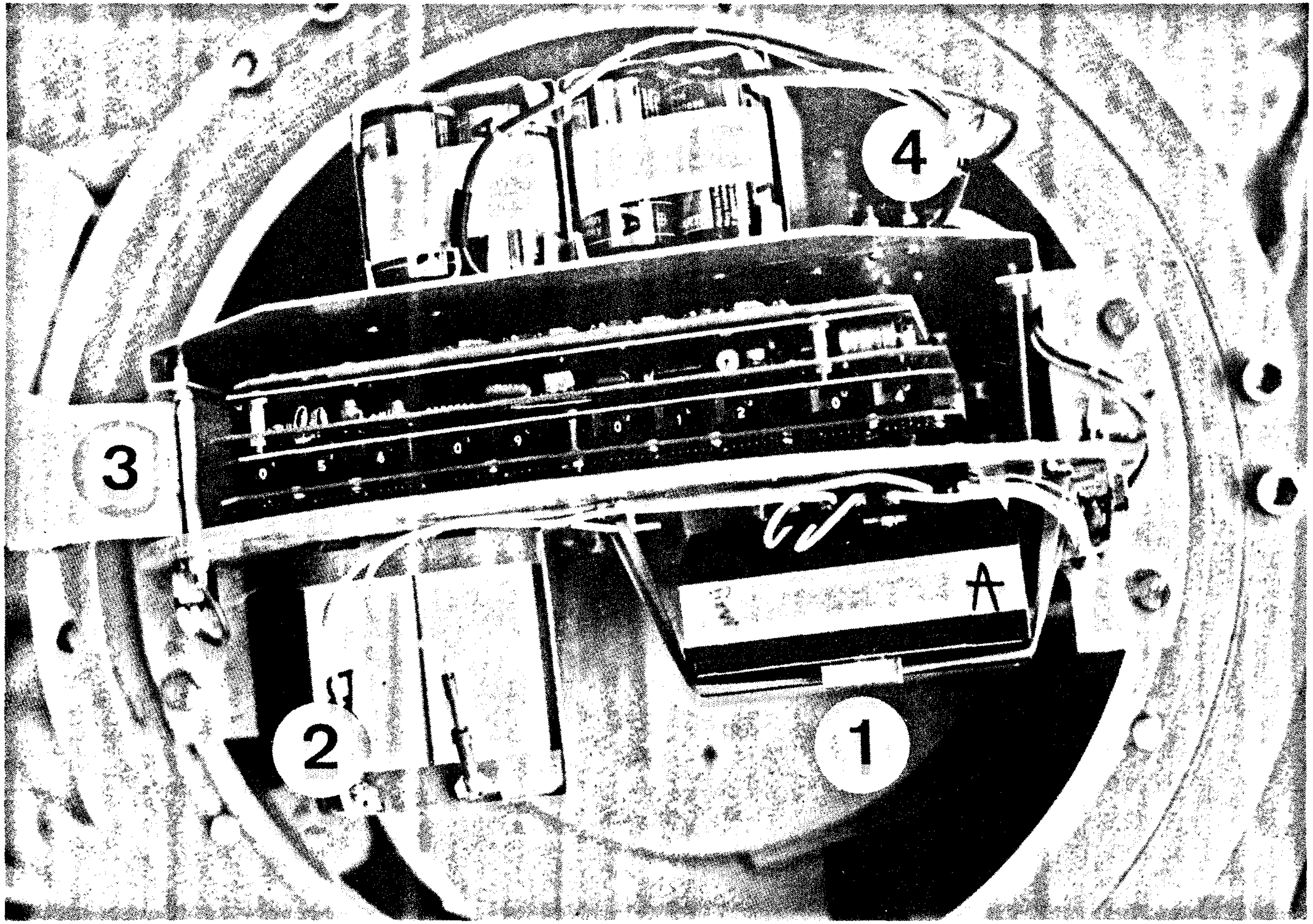

Fig. 6. Photograph showing the lay-out of the inner-sphere components. 1. Tape recorder. 2. Power pack 'A'. 3. Electronic boards (note digit switches of the seismic programmer). 4. Power pack 'B' and 'C'.

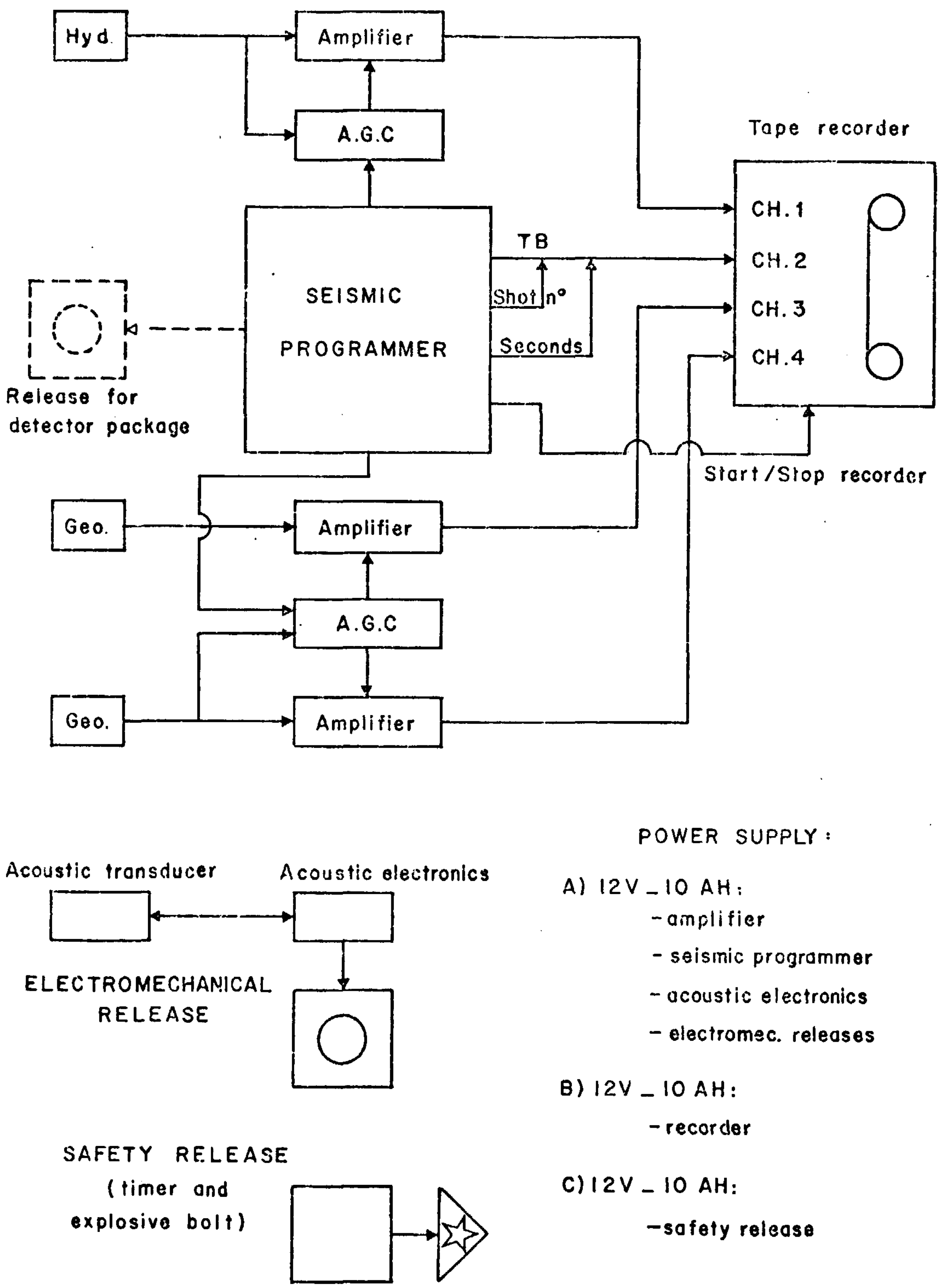

Fig. 7. Block diagram of electronics.

60 db in 10 discrete 6 db steps, to maintain the above-mentioned signal level. Gain changes are authorized by the seismic programmer only between recording periods. When the tape recorder starts, the gain of the amplifier is locked and the gain-step is recorded on all three seismic detector tracks on the tape recorder during the five seconds preceding the time-break or shot instant. The coding uses four binary bits. The total power consumption of the seismic amplifiers is 8 mA at 12 VDC. At present, the recording is preceded by a stage of linear signal compression, 1 : 1 up to 50% of the recorder's dynamic range, 1 : 5 in the remaining range.

4.2. *Seismic Programmer*

A crystal controlled seismic programmer performs the following functions:

(1) An initial delay from 1 to 99 h in one hour steps allows the postponement of recording until the OBRS is on the bottom and the shooting is ready to start.

(2) The programmer defines both the frequency and duration of recording intervals. The frequency of recording intervals can be varied from 10 to 9990 s in 10 s steps, the duration of recording from 10 to 990 s again in 10 s steps.

(3) The programmer sends to one channel of the tape recorder the time break or shot instant (T_0), the BCD coded shot number (0 to 999) and the second marks (Figure 8).

Thermal shocks, to which programmers were subjected, simulating descent and ascent (cycles from 25° to 3° C and from 3° to 25° C) did not appreciably modify the linear drift of crystals.

A separate, crystal safety-timer fires the explosive bolt after a delay which can be set from 1 to 999 h in one hour steps. This function is provided in case the acoustic release command fails. The power drain of the seismic programmer is 0.17 W and the one of the safety-timer is $\ll$ 10 mW.

The timing of the programmer is set by switches located on the electronic board.

4.3. *Recorder*

Because of the limited time available for the construction of the instruments, only tape recorders available 'off the shelf', offering small dimensions, limited power drain and sufficient recording capacity could be considered, limiting considerably our choice as well as demands on stability and dynamic range. As a suitable compro-

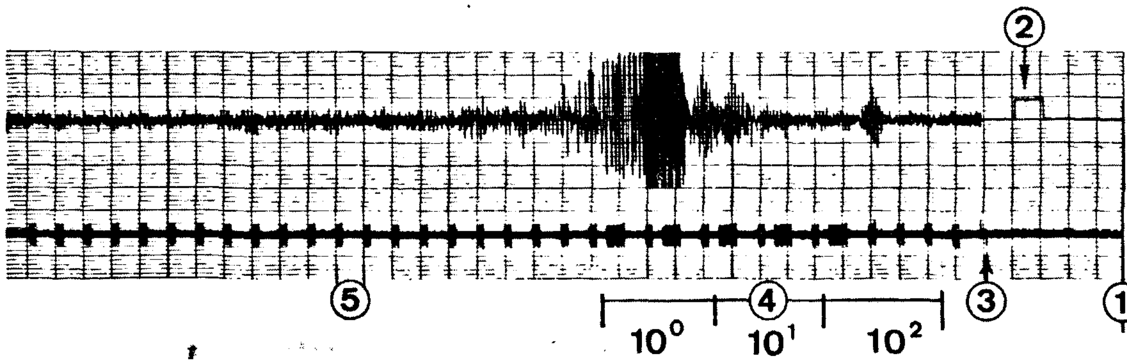

Fig. 8. Example of a 40 s cycle recording period for one detector and time channel. 1. Start of tape recorder. 2. Gain setting (4 bits binary code). 3. Time break or shot instant (T_0). 4. BCD coded shot number (shot number shown is 155). 5. Second marks.

mise, a casette-type, four channel recorder manufactured by Inter-Med-Craft (U.S.A.) has been integrated in the instrument. Tape-speed of 6 mm s^{-1} (15/64″) on 120 m cassettes provides 8 h of continuous recording or 480 cycles of 60 s. The recorder's dynamic range of about 20 db is extended to about 44 db with the signal compression. Three channels are PWM (pulse width modulation) and record the hydrophone and the two horizontal geophone signals. The fourth channel provides direct recording of the time informations and shot numbers. Band width of the PWM channels is from DC to 50 Hz and that of the direct channel is from 0.2 to 1.25 kHz.

Playback of the information is performed by the cassette-reader either in real time or time-scale compression by a factor of eight. The timing accuracy of recording and reproduction is $\sim 3\%$. The signals are fed to a graphic or photographic recorder (monitor records on the vessel can be obtained in less than 2 h after the OBRS has been retrieved from the sea) or to a digital computer via a converter at the laboratory. Several monitor-records are shown in Figure 9.

4.4. *Acoustic Tracking and Sinker Weight Release*

The acoustic section has two functions:
- distance-tracking of the OBRS;
- release of the sinker weight.

– The acoustic distance-tracking of the instrument is accomplished by discrete interrogation frequencies in the 9–16 kHz band. The answer frequencies range from 8–16 kHz. Answer duration is 10 msec. A 'double ping' (with 0.1 s interval) is emitted in case the 'off-levelling' of the instrument (or of the detector package) is greater than 20°. The 'level sensing' element is a simple mercury switch. Ranges are read directly in meters on the shipborne unit. They can be automatically corrected for sound-velocity variations from 1470 to 1550 $msec^{-1}$.

The second function of the acoustic unit is to release the OBRS from its sinker weight, actuating the electromechanical release-assembly, after reception of a double-frequency coded signal (in 1 s intervals).

– The presently used interrogation-answer frequencies as well as the release frequencies are tabulated in Table 1.

– Several other combinations of frequencies are readily obtained by simply changing jacks on the electronic board.

TABLE I

Acoustic frequencies (in kHz) used for tracking and release (other combinations also available by simply replacing jacks on the electronic board)

	Interrogation	Answer	Double release-frequency
A	9.50	13.50	8.50–10.50
B	9.50	12.00	8.00–11.00
C	9.50	12.50	8.00–10.25
D	9.50	13.00	8.75–10.25
E	9.50	11.50	8.75–11.00

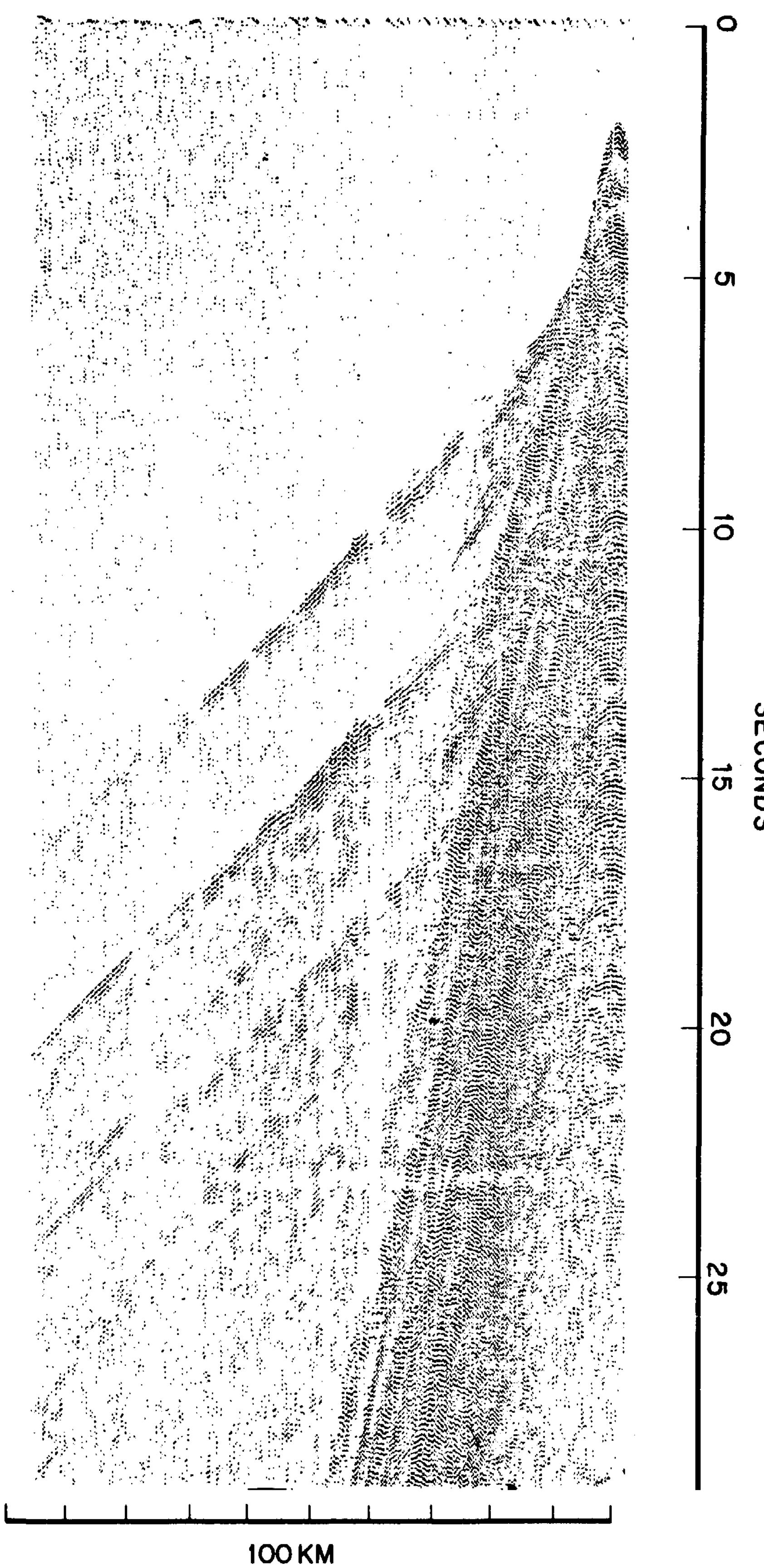

Fig. 9a.

Fig. 9a–c. Examples of seismic refraction profiles (monitor records), filtered 5–16 Hz with OBRS in deep sea and on the continental shelf of North-western Norway. (a) and (b): hydrophone and horizontal geophone record with OBRS at 3023 meter depth; (c) hydrophone record from the continental shelf, OBRS at 133 m. Sound source: 45 liter (2746 cu. in.) air gun. Air pressure: 210.10^5 Pa.

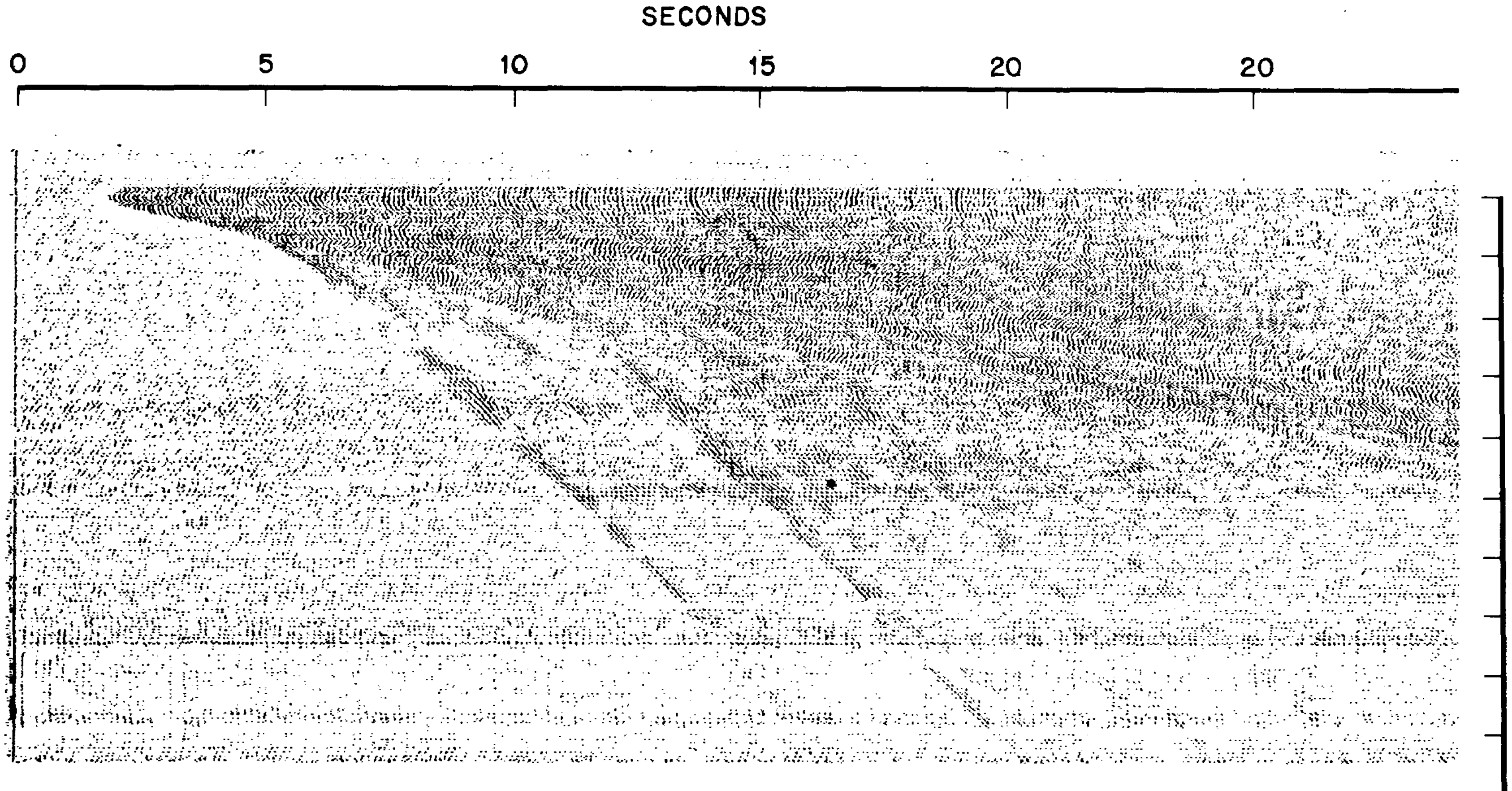

Fig. 9b.

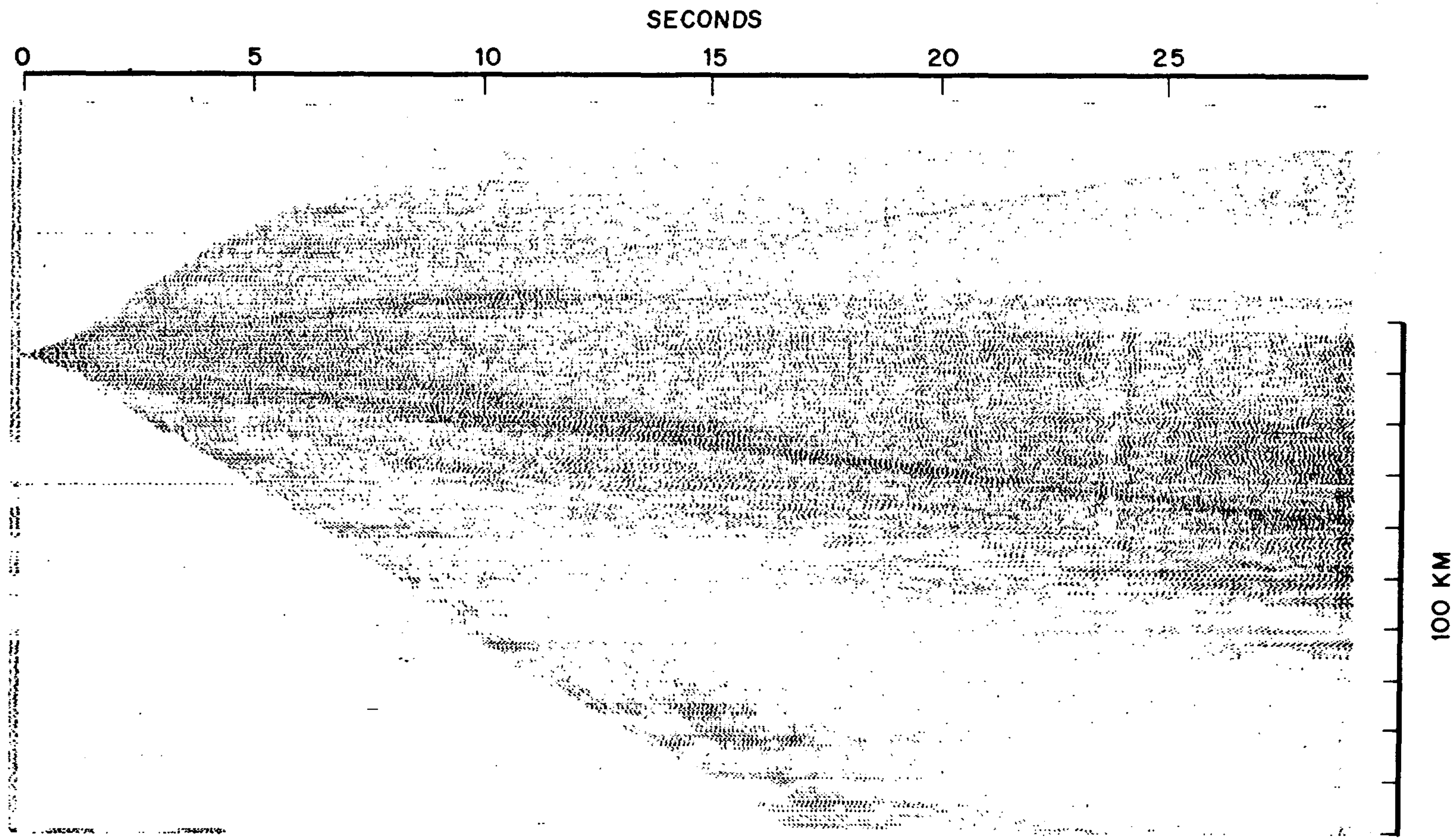

Fig. 9c.

The power consumption of the acoustic electronics is 18 mW in stand-by mode or 100 W during answer (10 ms), the 50 Hz synchron motors of the electromechanical release assembly (and the one for the detector package) draw 2 A at 12 VDC for a period of 15 s.

- The commercially available acoustic link is manufactured by SUBER (Brest, France).

4.5. *Power Supplies*

- To increase the overall operational reliability of the OBRS, independent power supplies were installed, to power the different functions of the instrument:

- Power pack A:: Ni-Cd, 12 V 10 Ah rechargeable batteries power the seismic programmer, the seismic amplifiers, the acoustic electronics as well as the release motors. The available power allows 1×10^5 interrogation-answer cycles plus about 100 h of operation of the electronics, release included.

- Power pack B: alkaline manganese dry cells (12 V 10 Ah) insure power for the tape-recorder which draws 0.150 A during the recording cycles. The fact that power is still applied to the recorder upon commands from the seismic programmer even after all the tape has been expended necessitates the use of a separate supply for the recorder. This avoids an unnecessary drain of power from other vital functions such as acoustic release and tracking.

- Power pack C: alkaline manganese dry cells (12 V 10 Ah) power the safety-timer and actuates the igniter of the explosive bolt.

Only the Ni-Cd batteries and the recorder pack need recharge or replacement after drops. As the current drain of the safety timer is $\ll 1$ mA, the power supply lasts several months.

5. Operation at Sea

Prior to launching, battery packs as well as the cassette are installed, the seismic programmer is set, electronics are powered, the pressure vessel is closed and filled up with freon gas. The programmer is synchronised and its functions and those of the seismic channels are checked through a pressure plug. The OBRS is connected to the sinker weight, and raised by a crane in order to close the gap between legs and sinker weight by means of adjusting screws located at the lower end of each leg. Then the float assemblies are attached. The OBRS is now ready to be launched.

The launching is performed by swinging the crane's arm over the water and releasing the crane's hook. The small auxiliary float assembly is then launched by hand.

After the delay set on the OBRS's programmer has elapsed, at the beginning of the first recording cycle, the OBRS drops the sensor package to the sea floor (if applicable), so the shooting of the profile may start. The shipborne seismic programmer, driven by a stable clock triggers the air gun's solenoid which is synchronized with the time break (T_0) of the OBRS programmer. Using explosives, the detonation of the charge is recorded via a hydrophone on a fast paper recorder together with the shipborne programmer time break (T_0), so the time delay can be measured and corrected for. After termination of the profile, the sinker weight of the OBRS is released following the acoustic release signal sent from the ship's transducer and the OBRS's path during ascent is tracked. In bad visibility the OBRS once surfaced may be approached using the emission of the emerged radio beacon for azimuth and the acoustic link for distance. At night the flashing lights give visual aid for detection.

For recovery, the ship steams parallel to the floating line connecting the two float assemblies, straightened by the combined action of currents and winds. Grips are used to catch the line and the assemblies are heaved on deck by pulling on the nylon rope.

Once the OBRS is on deck, its seismic programmer's stability is checked by recording the clock output signals through the pressure plug, with respect to the shipborne programmer's timebreak (T_0). Then the upper hemisphere is lifted away, the batteries and dry cells replaced, the tape-recorder reloaded with a new cassette. After recovery, the OBRS can be made ready for a new drop within about 30 min. The data contained on cassette is then played back and recorded in the already mentioned manner.

6. Results

– Four OBRS have been used on four cruises from December 1975 to September 1977. Out of a total of 52 drops, 50 were successful, on two occasions, unfortunately, the OBRS was lost. Table II shows the date, position and depth of drops.

Cruise I (Bay of Biscay, December 1975)

– Two instruments, completed in November 1975, were tested during this short cruise. During descents on cable (1000, 2000 and 2 × 4000 m depth) the functions of the different release assemblies, transmission and accuracy of the acoustic link were tested. As no failure of the OBRS occurred during these tests, four free drops were made, two on the continental shelf and two at 3200 m, all under very bad weather conditions (winds 40–50 knots). Unfortunately, under these conditions, only a rough estimate of performance could be obtained.

The acoustic link worked satisfactorily, good responses and immediate release were obtained on the shelf at horizontal distances of about 3500 m and in deep sea to lateral offsets of about 4500 m.

Out of four refraction profiles run, only one, on the continental shelf, was correct. Clear refracted arrivals were obtained up to about 18 km where the profile was interrupted due to the failure of one of the two 9 liter (550 cu. in) air guns. On the three other profiles, the OBRS's seismic programmer was off-synchronisation. The trouble was found to be the over-sensitivity of the synchro-input of the programmer. External noise-spikes, induced on the line between the vessel's and the OBRS's programmer, were triggering the clock.

Launching and recovery did not present any serious problems although it seemed close to the limit of acceptable operating conditions.

Cruise II (Bay of Biscay, March–April 1976)

The first three profiles of the cruise resulted in unexpectedly 'sluggish' responses of the seismic detectors. The reason for this was found to be the leaking Marsh-Marine

TABLE II

Date	Position	Depth (m)	Remarks
Cruise I (Bay of Biscay, December 1975)			
December 18	47° 09.5 N 04° 44.8 W	125	
December 19	47° 19.3 N 04° 29.2 W	111	Programmer off-synchronisation
December 21	46° 30.8 N 05° 23.7 W	3204	Programmer off-synchronisation
December 22	46° 30.0 N 05° 24.0 W	3352	Programmer off-synchronisation

Date	Position	Depth (m)	Remarks
Cruise II (Bay of Biscay, March, April 1976)			
March 18	45° 43.3 N 06° 40.7 W	4774	Leaking pressure proof connectors
	46° 03.4 N 07° 25.6 W	4752	
March 20	46° 04.0 N 06° 02.3 W	4665	Leaking pressure proof connectors
March 21	46° 58.5 N 04° 41.5 W	149	-
March 23	47° 05.4 N 04° 35.2 W	140	-
March 24	46° 04.2 N 06° 1.7 W	4600	-
March 25	46° 09.1 N 05° 41.2 W	4594	-
March 27	47° 45.6 N 05° 25.8 W	131	-
March 31	45° 46.7 N 06° 51.1 W	4780	-
April 1	46° 26.6 N 06° 45.0 W	4786	-
April 2	46° 32.0 N 06° 23.0 W	4560	-
April 3	46° 49.0 N 06° 19.0 W	4130	-
	46° 19.7 N 05° 27.7 W	4503	-
April 5	46° 50.9 N 04° 53.5 W	155	-
April 6	46° 27.7 N 09° 16.2 W	4725	-
	46° 42.0 N 10° 18.0 W	4669	-
April 7	46° 51.0 N 09° 06.0 W	4171	-
April 8	47° 05.8 N 08° 49.5 W	4410	-
	47° 17.1 N 09° 47.0 W	4371	-
April 10	48° 28.0 N 07° 28.0 W	157	-
	48° 04.8 N 06° 28.9 W	150	-
April 11	48° 11.8 N 07° 01.3 W	157	-
	48° 43.9 N 05° 43.0 W	116	-

Date	Position	Depth (m)	Remarks
Cruise III (Norwegian sea, May–June 1976)			
May 26	67° 10.0 N 03° 00 E	1278	OBRS lost
	67° 45.3 N 04° 39 E	1265	-
May 27	67° 36.8 N 07° 02.7 E	1323	-
	66° 59.6 N 05° 01 E	1312	-
May 30	69° 23.3 N 10° 10.7 E	3034	Seismic detectors on main frame
May 31	69° 09.4 N 10° 36.5 E	3023	-
June 1st	68° 54.3 N 11° 09.8 E	2917	-
	68° 17.7 N 09° 04.2 E	2574	-
June 3	67° 59.0 N 09° 00.5 E	2102	-

Table II (continued)

Date	Position	Depth (m)	Remarks
June 5	67° 59.7 N 11° 01.7 E	185	Failure of seismic amplifiers
	68° 29.6 N 13° 00.7 E	198	-
June 10	68° 07.1 N 12° 45.2 E	133	-
	67° 30.6 N 10° 42.1 E	172	-
June 11	68° 07.4 N 12° 45.5 E	133	-
	68° 35.7 N 13° 16.7 E	133	-
June 13	68° 28.5 N 12° 04.1 E	161	Seismic detectors on main frame
	68° 44.1 N 11° 32.5 E	2076	-
	69° 00.0 N 10° 59.0 E	2965	-
June 15	69° 32.7 N 09° 54.0 E	2978	-
	68° 21.6 N 12° 19.0 E	153	-
	68° 13.0 N 12° 35.0 E	170	OBRS lost
Cruise IV (Norwegian sea, August-September 1977)			
Date	Position	Depth (m)	Remarks
August 27	66° 51.5 N 12° 18.6 E	255	-
August 28	68° 29.9 N 7° 19.9 E	2863	-
August 31	68° 31.0 N 7° 18.2 E	2860	-
September 1	66° 51.5 N 12° 19.4 E	260	-

pressure connectors. The leak must have developed during the low-pressure phase of the descent. Clamping of the connectors resolved the problem and no other difficulties with the equipment were encountered during the following 21 drops.

Typical distances at which refracted waves could unequivocally be detected were about 60–90 km in deep sea and about 110–120 km on the continental shelf.

During this cruise, several combinations of air guns have been experimented with total volumes varying from 16 to 77 liter (1000 to 4698 cu. in.). The most often used configuration was 2 × 16 liter guns (2 × 1000 cu. in.) or a single 45 liter (2746 cu. in.) gun shot at 210.10^5 Pa. However, the immersion of the guns was far from optimum, due to the insufficient length of air hoses. The shot rate was 1/120 s or about 1/250–300 m.

The drift of the different OBRS's programmer-clocks averaged $\pm 2.5.10^{-1}$ msec h^{-1} with relative errors between ± 0.12 to $0.24.10^{-1}$ msec h^{-1} as checked to our shipborne standard. During these profiles the seismic sensor package was decoupled from the main frame and positioned on the sea floor, the spikes at the lower part of the package penetrating about 5 cm deep into the floor. Unfortunately, noise generated by the heavy ship traffic in the area often interferred with our experiments. The average p–p background noise recorded by the hydrophone was $\sim 1.10^{-1}$ Pa at 10 Hz. It also appeared that the level on the recorder's geophone channels was somewhat low.

Appreciable lateral drift of the OBRS during descent and ascent was not observed and remained in the range of the accuracy of satellite navigation.

– The acoustic link between the OBRS and vessel worked well, steady readings at slant-distances of about 8–9 km were typical in deep sea.

– Also, the explosive bolt was checked twice, in deep sea and on the shelf, releasing the sinker weight on time.

Cruise III (Norwegian Sea, May–June 1976)

During this cruise the equipment of cruise II was used without modification. Sound sources were 2 × 16 liter (2 × 1000 cu. in.) or a single 45 liter (2746 cu. in.) air guns.

– Two OBRS were lowered at first on the north-western flank of the Voringen Plateau about 90 km apart. Very dense and strong echoes were detected on the PDR in the area, from about 50 m down to almost 600 m, and have been interpreted as fish-swarms. The acoustic response from the two OBRS were poor but both could be traced down to the bottom (~ 1250 m). After about 10 min on bottom, during which interrogation and detected reply continued at a rate of 4 s, the acoustics were turned off and the profile started. After completion of the profile, which ended over one of the two OBRS, neither acoustic reply was obtained nor was the OBRS detectable on the surface, the fish-swarms being always present. Also, as the pre-set time for the explosive release elapsed and the equipment did not surface, after several hours of searching, we had to give up the OBRS. The second instrument also obscured by the fish-swarms, surfaced after acoustic release.

During this cruise, seismic sensors mounted on the main frame as decoupled from and positioned on the sea floor were used, but no appreciable difference in the signal-to noise ratio could be detected.

– The only electronic failure of the OBRS during the cruise was due to the malfunction of a power circuit disabling all three seismic amplifier channels during a profile.

– The drift of OBRS's seismic programmer was essentially the same as during the preceeding cruise.

– Typical distances, at which refracted waves could be detected, were about 100 km in deep-sea and about 130–140 km on the continental shelf.

– During this cruise the detection capability of our OBRS could be checked against land stations set up at the Lofoten Islands and operated by our Norwegian colleagues using 1 Hz, three component seismographs. The comparison of records proved that the performances of the land stations and the OBRS are essentially the same.

At the end of the cruise, we lost the second equipment on the continental shelf under similar circumstances to those of our first loss, but this time without the fish. During descent and on the bottom (water depth ~ 170 m), the acoustic reply was good. After completion of the profile neither acoustic reply and release could be obtained, nor did the explosive bolt function. Fishing for the OBRS almost succeeded, the equipment surfaced but at the last moment in the fishing operations, the already damaged line broke and the OBRS sunk again.

– The only plausible explanation of the losses, which showed identical circumstances is the development of a small leak, most likely between the hemispheres and the equatorial ring. The slowly intruding sea-water shorted the connectors on the bottom of the lower hemisphere disabling all the electrical functions of the OBRS.

This possibility is further enhanced by the fact that prior to launching, the OBRS's sphere is filled up with freon-gas under slight pressure ($\approx$ 100–150.10^2 Pa). Normally, pressure vessels were tight up to 500.10^2 Pa of internal pressure. Checking our records we found that only on the two occasions the OBRS was lost, the gas was leaking from the interior at the equatorial ring at 350.10^2 Pa. To prevent the recurring of such an accident, all our further OBRS shall be equipped with water detectors placed on the bottom of the sphere and coupled to the release circuits. In case of water intrusion, the release functions are immediately triggered and the chances of losing the equipment will be further reduced.

Cruise IV (Meteor 45–3, Blue Norma, August–September 1977)

Two unmodified instruments from 1976 were used (the third, due to jammed reduction gears of the release motor, had to be withheld) in conjunction with several other detector assemblies equipped with radio-buoys, laid out by our German colleagues from the University of Hamburg. During this cruise, the sound source was explosive (shots ranging from 25 to 1500 kg). As the shooting of the profile lasted several days, and because of the limited recording capacity of our OBRS's, sequential recording was used (ex. 180 s every hour). This resulted by an appreciable strain on the shooting program as well as loss of data.

Four drops and recoveries were made during the cruise (in water depth of 260 and 2850 meters), the instruments performing correctly.

One instrument surfaced during a storm, after the pre-set time for the explosive release had elapsed, the ship being about 180 km away. More than 24 h later at night, homing in on the instrument's radio beacon and later on its flashing light, the recovery, about 5 miles away from the initial launching point, did not cause serious difficulties.

The maximum time the instruments remained on the bottom was 8 days.

7. Conclusion

The experience gained and results obtained with the instruments described allowed us to define more precisely the characteristics of the 'second generation' OBRS's which are now under construction.

The new instruments are improved mainly regarding:

- recording capacity (130 h continuous digital recording);
- dynamic of recording, which is now 60 db;
- detector sensitivity (several geophones in series);
- seismic amplifiers;
- safety of recovery, by installing water detector in the sphere which trigger the release systems in case of water intrusion. To improve the tightness of the sphere at low hydrostatic pressure, in addition to the mechanical closure, partial vacuum is created in the pressure vessel.
- weight, using aluminium sphere and frame, thus considerably reducing the amount of additional floating material (glass spheres).

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