

The Seafloor Borehole Array Seismic System (SEABASS) and VLF Ambient Noise

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Abstract: The Seafloor Borehole Array Seismic System (SEABASS) has been developed to measure the pressure and three-dimensional particle velocity of the VLF sound field (2–50 Hz) below the seafloor in the deep ocean. The system consists of four three-component borehole seismometers (with an optional hydrophone), a borehole digitizing unit, and a seafloor control and recording package. The system can be deployed using a wireline re-entry capability from a conventional research vessel in Deep Sea Drilling Project (DSDP) and Ocean Drilling Project (ODP) boreholes. Data from below the seafloor are acquired either on-board the research vessel via coaxial tether or remotely on the seafloor in a self-contained package. If necessary the data module from the seafloor package can be released independently and recovered on the surface. This paper describes the engineering specifications of SEABASS, the tests that were carried out, and preliminary results from an actual deep sea deployment. VLF ambient noise levels beneath the seafloor acquired on the Low Frequency Acoustic-Seismic Experiment (LFASE) are within 20 dB of levels from previous seafloor borehole seismic experiments and from land borehole measurements. The ambient noise observed on LFASE decreases by up to 12 dB in the upper 100 m of the seafloor in a sedimentary environment.

Introduction

The Seafloor Borehole Array Seismic System (SEABASS) was developed to measure the pressure and three-dimensional particle velocity of the VLF sound field (2–50 Hz) below the seafloor in the deep ocean (water depths up to 6 km). (A summary of common acronyms used in this paper is given in Table I.) The system can be deployed from a con-

ventional research vessel in Deep Sea Drilling Project (DSDP) and Ocean Drilling Project (ODP) boreholes (which have re-entry cones) using the wireline re-entry capability (Spiess *et al.*, 1989a, 1992). Data from below the seafloor are acquired either on-board the research vessel via coaxial tether or remotely on the seafloor in a self-contained package.

A review of borehole seismic measurements in the deep sea up to 1987 is given by Mutter and Balch (1987). Prior to the development of the SEABASS system, borehole seismic measurements in the deep sea either were obtained at only a single fixed depth, as in the Marine Seismic System (MSS; Harris *et al.*, 1987; Adair *et al.*, 1987) and the Ocean Sub-bottom Seismometer (OSS; Byrne *et al.*, 1987), or were obtained directly from the drill ship and were contaminated by ship and drill pipe noise (for example, Stephen *et al.*, 1980; Stephen and Harding, 1983; Stephen and Bolmer, 1985). There had been an indication from previous seismic work, both at sea and on land, that borehole seismometers had two major advantages over surface or seafloor seismometers: both ambient noise levels and signal-generated noise levels (bottom reverberation or coda) decreased with depth below the solid surface and signal quality, particularly on horizontal components, was better for borehole receivers because of improved coupling to true earth motion. SEABASS was developed to provide conclusive, *in situ*, quantitative observations to test these hypotheses in a deep sea environment.

TABLE I
Some common acronyms used in this paper

A12G4	CGG Recording Format
BCU	Bottom Control Unit
BIP	Bottom Instrument Package
BRG	Borehole Re-entry Guide
BSF	Below the Seafloor
CIEM	Communication and Interface Electronic Module
CGG	Compagnie Générale de Géophysique
DRU	Data Recording Unit
DSDP	Deep Sea Drilling Project
DTU	Data Telemetry Unit
GOES	Geostationary Operational Environmental Satellite
IU	Interface Unit
LFASE	Low Frequency Acoustic-Seismic Experiment
LOPACS	Low Power Acquisition Control Storage System
MSS	Marine Seismic System
OBS	Ocean Bottom Seismometer
ODP	Ocean Drilling Project
OSS	Ocean Sub-bottom Seismometer
ROSE	Rivera Ocean Seismic Experiment
SOPEMEA	Société pour le Perfectionnement des Matériels et Equipements Aérospatiaux
UTC	Universal Time, Coordinated
VHA	Vertical Hydrophone Array
VSP	Vertical Seismic Profile

SEABASS itself consists of four borehole sondes and a data telemetry unit, based on the Multilock Seismic Tool (Géomécanique and Compagnie Générale de Géophysique, 1987), and a Bottom Instrument Package (BIP), designed and built at Woods Hole Oceanographic Institution (Koelsch *et al.*, 1990; Stephen *et al.*, 1993). Each of the borehole sondes consists of a three-component seismometer (with a natural frequency of 4.5 Hz) and a clamp, to couple the sonde to the borehole wall. The top sonde can have an optional borehole hydrophone attached. The Bottom Instrument Package is designed to internally record up to 41 hours of data (600 Mb) and to operate SEABASS autonomously on the seafloor for periods up to two months.

SEABASS is deployed in the configuration shown in Figure 1. The wireline re-entry technique requires a Borehole Re-entry Guide (BRG) below the borehole array, to locate the borehole on the seafloor, and a thruster above the Bottom Instrument Package, to position the array prior to re-entry. (The BRG and thruster were designed, built and operated by the Marine Physics Laboratory of

Scripps Institute of Oceanography (MPL/SIO). MPL/SIO also carried out the bottom navigation, ship dynamic positioning, borehole re-entry and data telemetry from the BIP to the surface ship.) When SEABASS is in place the four seismic sondes are clamped at fixed positions in the borehole and the Bottom Instrument Package sits in the re-entry cone. During shipboard recording the thruster is maintained within a 100 m watch circle and it is connected to the BIP by a 'slack tether'. The thruster is supported from the surface vessel by an armored, coaxial cable. For autonomous seafloor recording, the 'slack tether' is disconnected from the BIP. Recovery is accomplished by grappling, using the thruster and a hook. If grappling fails, the Data Recording Unit (DRU) alone, a sub-component of the BIP, can be released acoustically, allowing it to float to the surface for recovery.

The system was successfully deployed in the Blake-Bahama Basin (off the coast of Florida) in August–September, 1989, as part of the Low Frequency Acoustic Seismic Experiment (LFASE; Spiess *et al.*, 1989b, 1992; Stephen *et al.*, 1989, 1990). Prior to deployment of the complete system, subsystems were tested in shake-table studies (in Paris, France), two land borehole tests (near Marolles, France, and Traverse City, Michigan) and a system wet test (off Martha's Vineyard, Massachusetts).

This paper presents the specifications of SEABASS, reviews the development and testing procedures that were carried out, and gives examples of the results.

The Modified Multilock Array

OVERVIEW

The borehole array components of SEABASS are based on the Multilock Seismic Tool (Institut Français du Pétrole (1987); Géomécanique and Compagnie Générale de Géophysique, 1987). [The Multilock seismic system was designed by Institut Français du Pétrole. It is presently built by Ateliers Mécaniques de Saint-Gaudens (AMG) and Géomécanique and it is marketed by Compagnie Générale de Géophysique (CGG).] The Multilock system was developed as a Vertical Seismic Profile (VSP) tool for the petroleum industry. VSPs provide interval velocities, at seismic frequencies, of the formation around the borehole and can be used to trace the origin of subsurface reflectors. They are

Seismic Array Deployed and in Tethered Mode

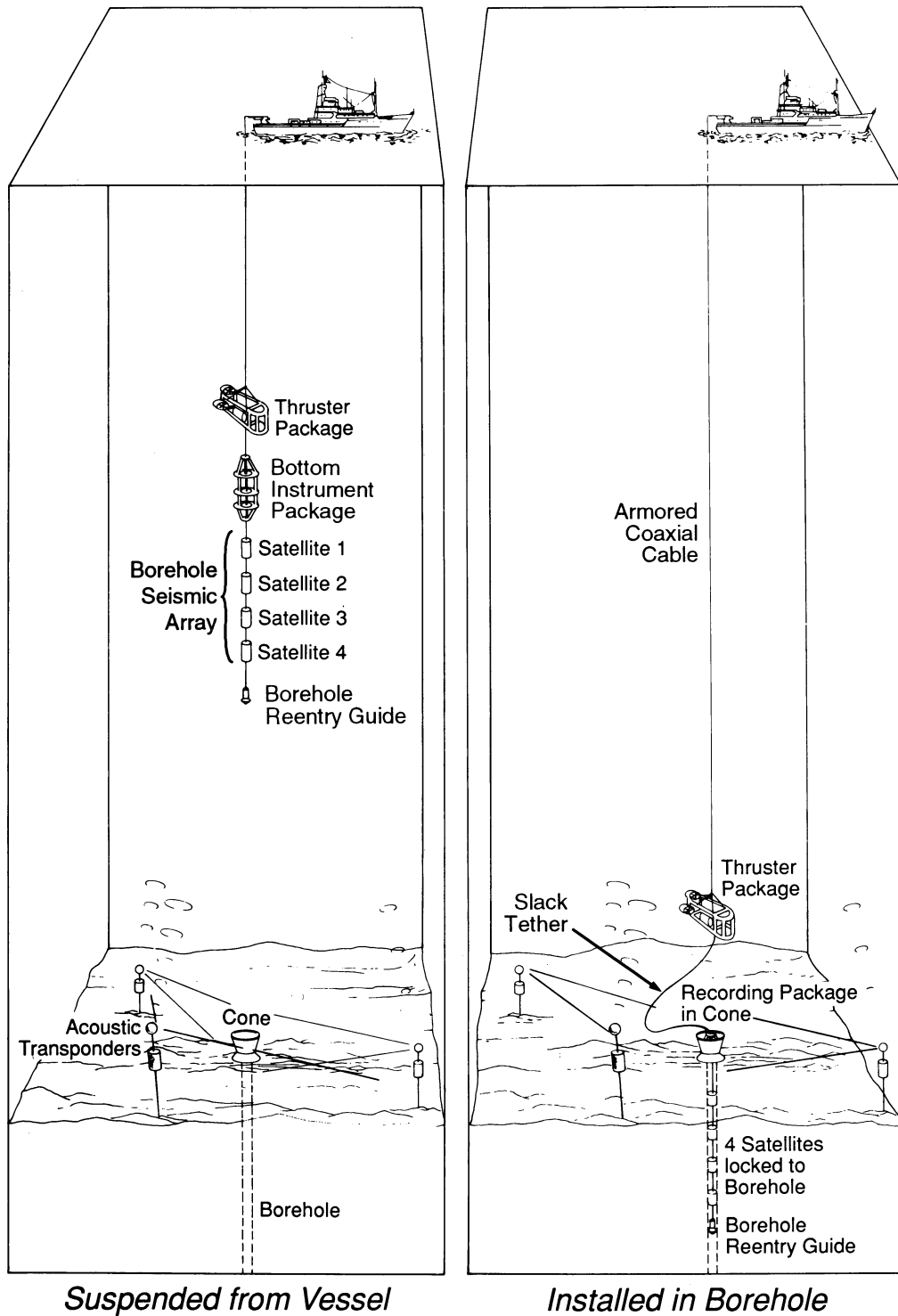


Fig. 1. SEABASS is deployed with a re-entry system like the one used on LFASE. SEABASS consists of the Bottom Instrument Package and the four node borehole array. The Borehole Re-entry Guide is used to locate and enter the borehole and the thruster is used along with dynamic positioning on the ship to position the system above the hole. The left frame shows the system deployed in the water column. The right frame shows the system installed in the borehole in 'tethered mode'. The tether can be disconnected to leave the system operating autonomously on the seafloor.

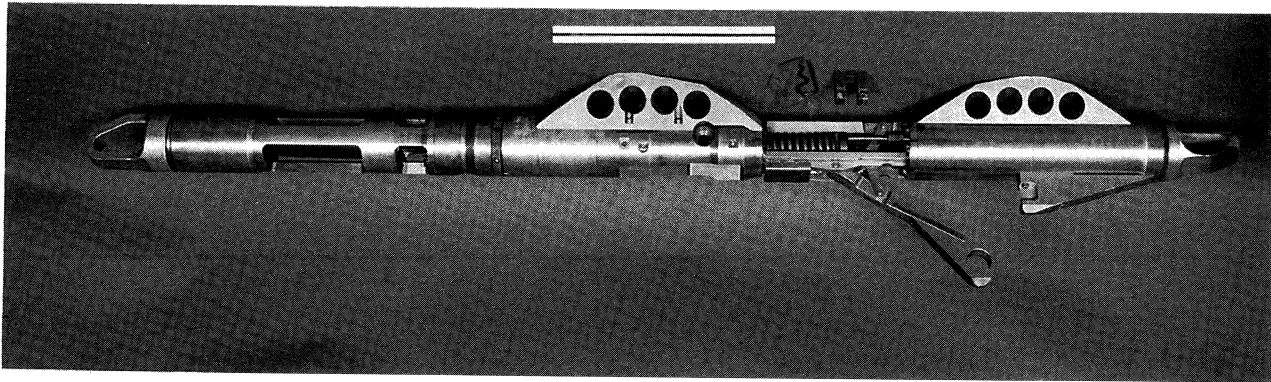


Fig. 2. Each node of the Multilock array on SEABASS consists of a three component seismometer with a clamping arm and pads. The optional borehole hydrophone is attached.

considered to be a valuable adjunct to surface multi-channel seismic profiles when a borehole is available. By using four sondes simultaneously, the Multilock system reduces the cost of acquiring VSP profiles.

Some of the modifications to the Multilock tool that were necessary for SEABASS were: i) The frequency response of the system was changed to 2.5–40 Hz using geophones with a natural frequency of 4.5 Hz; ii) an optional borehole hydrophone was provided for the top node; iii) telemetry and power supply functions were modified for operation over a short cable to other electronics packages and batteries on the BIP frame; and iv) since the modified unit was intended primarily for seafloor use, the temperature specification was reduced from 180 °C to 0–20 °C with the primary operating temperature at 0 °C.

The modified Multilock can be used in three configurations: i) It can be run as a normal four sonde VSP tool on seven conductor logging cable; ii) the system can be run as a fixed borehole array in a land or offshore borehole with the digitizing and acquisition electronics in a recording hut; or iii) the system can be deployed as a fixed array in the deep seafloor with self-contained recording capability as in SEABASS.

MECHANICAL SYSTEMS

Mechanically the borehole array component of SEABASS consists of four satellites (Figure 2) and a Data Telemetry Unit (DTU) housing (Ateliers Mécaniques de Saint-Gaudens, 1988a, 1988b). A selection of arms and removable back pads are available to provide for secure coupling of the satellites in boreholes ranging from 178 mm (7.0

inch) to 407 mm (16.0 in). The clamping arm and two pads are located 120° circumferentially from each other. The DTU is a separate borehole unit which does not have a clamping mechanism.

The cable connecting the four sondes and the DTU is 36 conductor (eighteen twisted pairs) double-armored logging cable with an outside diameter of 16 mm (0.65 in). Shear pins are built into the lower connector of each cable to provide weak links in case a sonde is stuck in the hole. These are designed so that the shear pins will separate before any of the components higher in the string mechanically fail. In the event of a shear pin separation, a clean, well-defined connection is left in the hole that can be 'fished' using a variety of tools on either a wireline or drill string.

ELECTRICAL SYSTEMS

The ground motion transducer in SEABASS is a Mark Products L-15-LBTWHT long-travel geophone with a natural frequency of 4.5 Hz, a coil resistance of 600 Ω and a moving mass of 23 g. Each geophone is damped to 60% of critical with a 2.87 K Ω resistor. Each of the three orthogonal components (one vertical axis and two horizontal axes) consists of two geophones in series. The 'long travel' version of the L-15 geophone operates to specifications with tilts up to 25° for the vertical sensors and up to 5° for the horizontal sensors.

The pressure transducer in SEABASS is a hydrophone built by Ocean and Atmospheric Science, Inc. (Model E-2SD). It has a sensitivity of -187 dB re:1 Volt/Pascal. Since the hydrophone is a capacitive device a hydrophone preamplifier is necessary before sending signals up the cable to the DTU. The hydrophone and its preamplifier are attached to the