A High-resolution Sub-bottom Profiling System for Use in Ocean Basins[1]

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ABSTRACT

A new high-frequency (3.5-kHz) sub-bottom profiling system is capable of relatively deep penetration into sedimentary deposits, with good resolution of thin reflecting layers. This system has been operated at cruising speeds up to 11 knots and gives up to 0.15 seconds of penetration. Profiler records made aboard the R.V. CAYUSE and R.V. ARGO indicate that this system is particularly useful for defining shallow structures and areas of outcrop and that it will undoubtedly be valuable in sedimentological and stratigraphic studies. Used in combination with a low-frequency profiling system, a good overall picture of the sediment and structure in ocean basins may be obtained.

Introduction. Numerous acoustic systems have been used to obtain continuous seismic reflection profiles of sedimentary deposits (*e.g.*, Smith 1958, McClure et al. 1958, Beckman et al. 1959, Ewing and Zaunere 1964). On the basis of the frequency of sound employed, these systems can be divided into two general groups: (i) those using low-frequency sound (10–500 Hz) that gives deep penetration of the sediments but poor resolution of thin reflectors, and (ii) those using a high-frequency sound source (3.8 to 14 kHz) that gives good resolution of thin reflecting layers but only shallow penetration. The high-frequency (high-resolution) reflection profiling systems have been used extensively in studies of sediment accumulation in lakes and coastal waters and in investigations on continental shelves and slopes (Smith 1958, Moore 1960, van Andel and Sachs 1964). In these studies, sedimentary and structural features as well as areas of outcrop are clearly revealed on the profiler records. However, in deep water, the signal strength of most existing high-frequency systems is so greatly reduced by attenuation and absorption that sub-bottom echos are rarely recorded (Hersey 1963). Only under conditions of maximum output power and low ambient noise is even shallow penetration obtained.

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Thus, most deep-water reflection work has made use of the low-frequency systems. These systems often allow penetration to the acoustic "basement" but do not allow the resolution that is necessary to accurately locate areas of outcrop and define structures in near-surface sediments. The growing interest in deep-sea sedimentation and stratigraphy and in the sediments and structure of the lower continental slope and continental rise have accentuated the need for a high-resolution reflection profiling system that can be operated effectively at normal cruising speeds in the deep ocean.

Table I. The 3.5-kHz system—Edo Western Corporation Model 400 bottom-penetration system.

Acoustic power	8000 watts (max)
Pulse rate	4 per second (max)
Pulse length	0.2 milliseconds (min)
Beam width	Conical 30°
Receiver bandwidth	± 900 cycles
Weight	800 lb. (hull mounted)

The 3.5-kHz System. The basic characteristics of the new high-frequency (3.5-kHz) system (Edo Western Corporation, model 400) are given in Table I.

The transducer may be either towed or mounted on the hull. In the towed configuration, the record generally contains less noise than records obtained with a hull-mounted transducer. Attached to a nylon-polypropylene line (60,000-lb. breaking strength), the transducer may be towed at speeds in excess of 10 knots. If a towed transducer is used, the system may be moved from ship to ship. However, for overall ease of operation, the hull-mounted system is more desirable. On the R.V. Argo, the maximum speed of operation of the hull-mounted system is about 11 knots and seems to be limited by water noise around the hull mounting. Careful design and placement of the hull mounting might increase the maximum speed attainable.

The dominant frequency of this system is on the lower end of the high-frequency range used in previous profiling studies. The relatively low frequency of this system together with the high acoustic power output (up to 8000 watts) allows penetration in deep-water sediments of up to 0.15 seconds (two-way travel time). In theory, the minimum pulse length of 0.2 milliseconds and a frequency of 3.5 kHz should allow the resolution of layers 0.5 m thick.

Features that are usually hidden in the outgoing signal ("bubble") pulse of low-frequency profilers may be easily defined with this system. The relatively deep penetration of the 3.5-kHz signal often results in the detection of reflectors just before they merge into the surface echo of a low-frequency profiler. Thus, the combination of a low-frequency (deep-penetration) system with the 3.5-kHz profiler can provide a much more complete picture of sedimentary and structural features than either system by itself.

Results. On recent oceanographic expeditions, the 3.5-kHz system has been used in the towed configuration (aboard the R.V. Cayuse of Oregon

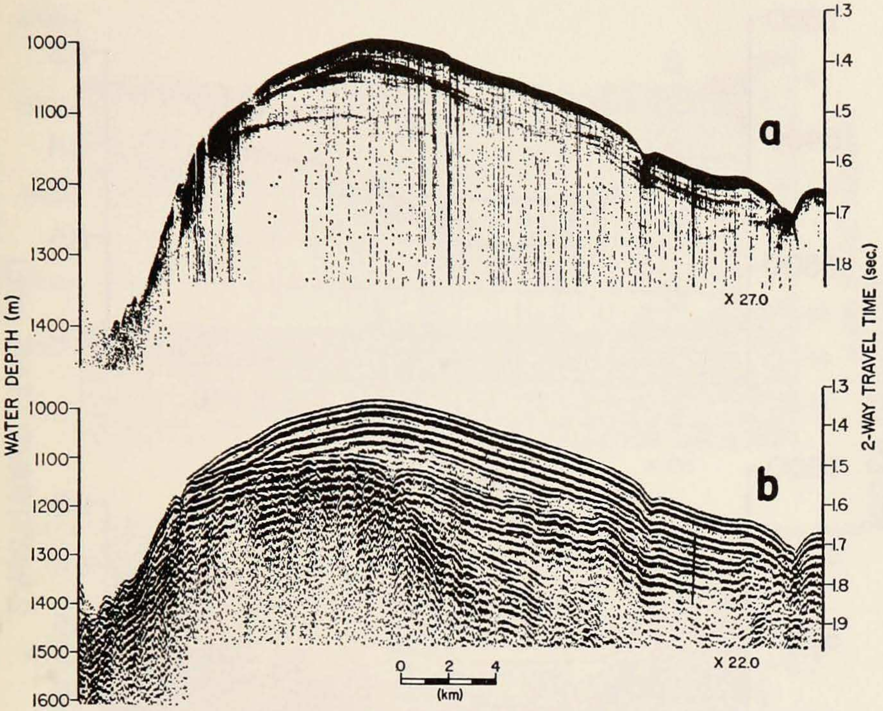

Figure 1. Outcropping sediments on the Walvis Ridge (26.5°S, 6°E). Records taken aboard R. V. ARGO. a, 3.5-kHz record; b, air-gun record.

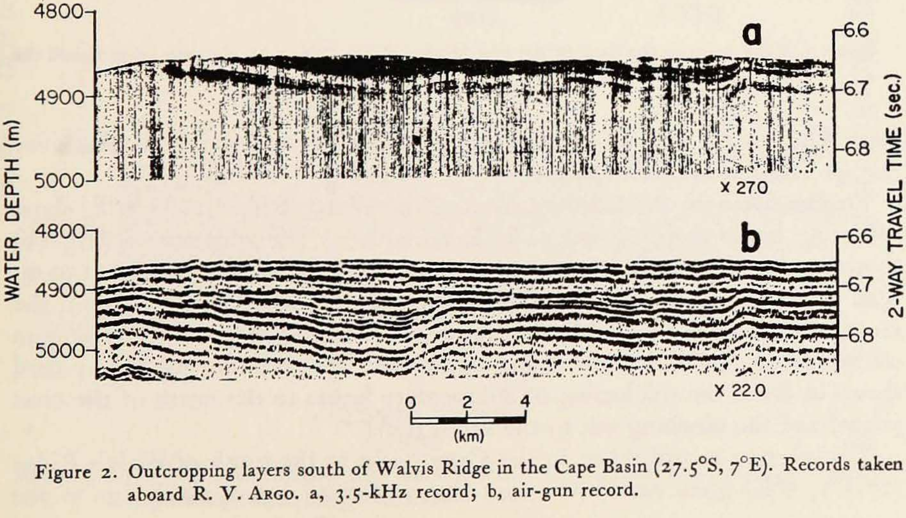

Figure 2. Outcropping layers south of Walvis Ridge in the Cape Basin (27.5°S, 7°E). Records taken aboard R. V. ARGO. a, 3.5-kHz record; b, air-gun record.

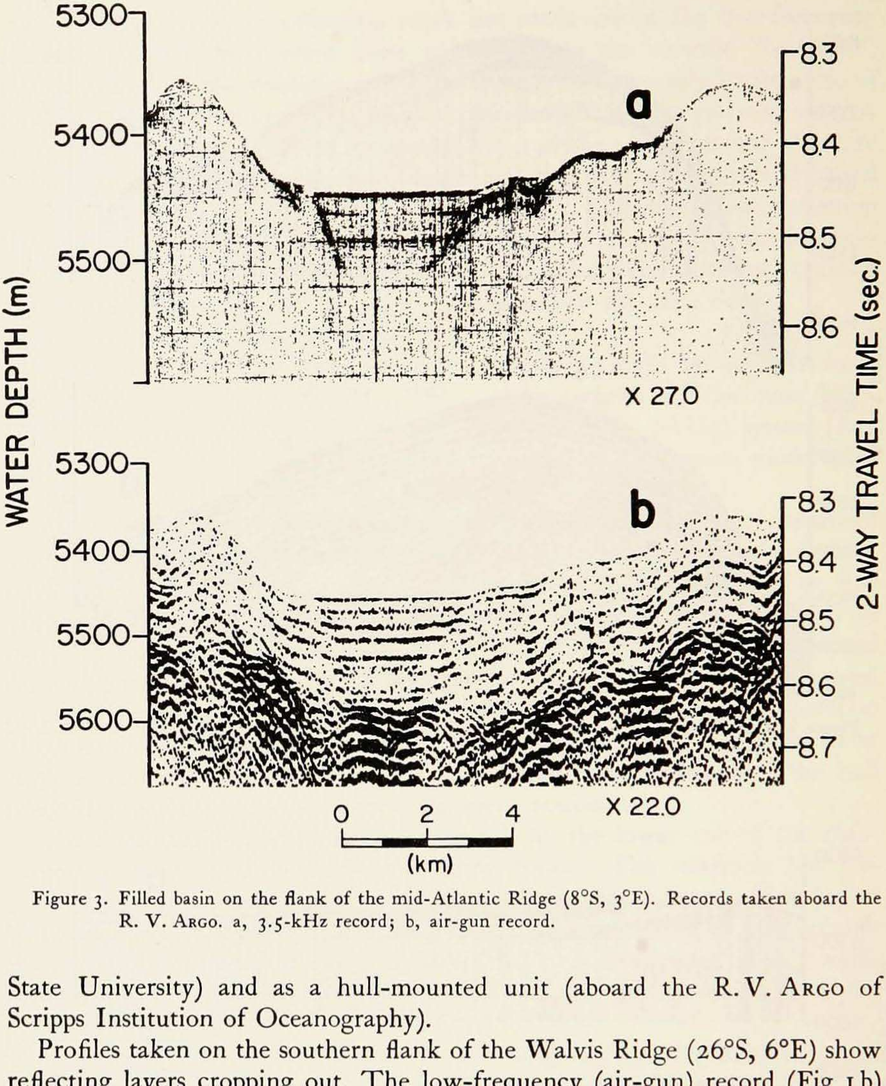

Figure 3. Filled basin on the flank of the mid-Atlantic Ridge (8°S, 3°E). Records taken aboard the R. V. Argo. a, 3.5-kHz record; b, air-gun record.

State University) and as a hull-mounted unit (aboard the R. V. Argo of Scripps Institution of Oceanography).

Profiles taken on the southern flank of the Walvis Ridge (26°S, 6°E) show reflecting layers cropping out. The low-frequency (air-gun) record (Fig. 1 b) shows one probable area of outcrop at a water depth of approximately 1150 m. The 3.5-kHz record (Fig. 1 a) also shows this reflector; but in addition, the record shows above it several other reflectors that may crop out. The air-gun record shows few reflectors in the upper part whereas the 3.5-kHz record shows in detail the thickening of sedimentary layers to the north of the crest (right) and the pinching out to the south (left).

The air-gun record taken in the Cape Basin to the south of Walvis Ridge (27.5°S, 7°E) gives some indication that reflecting layers pinch out to the

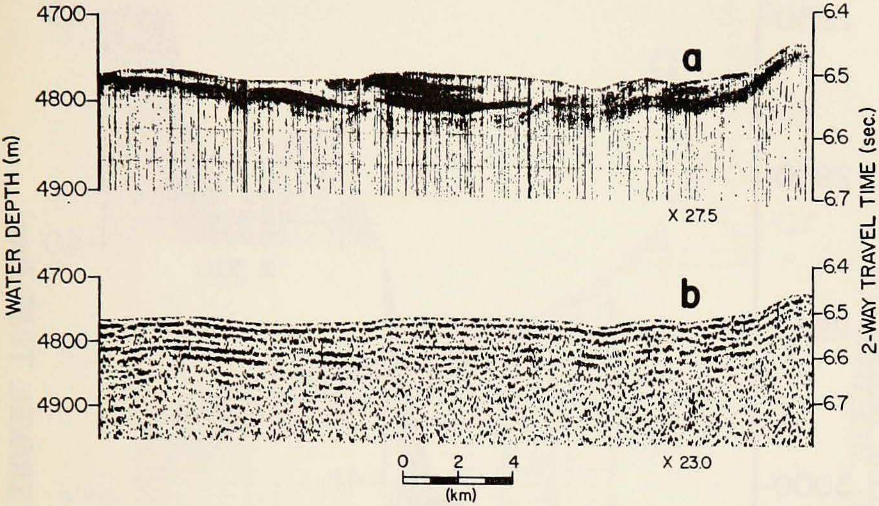

Figure 4. Small filled basin (or channel) in the Cape Basin (29.6°S, 9.5°E). Records taken aboard R. V. ARGO. a, 3.5-kHz record; b, air-gun record.

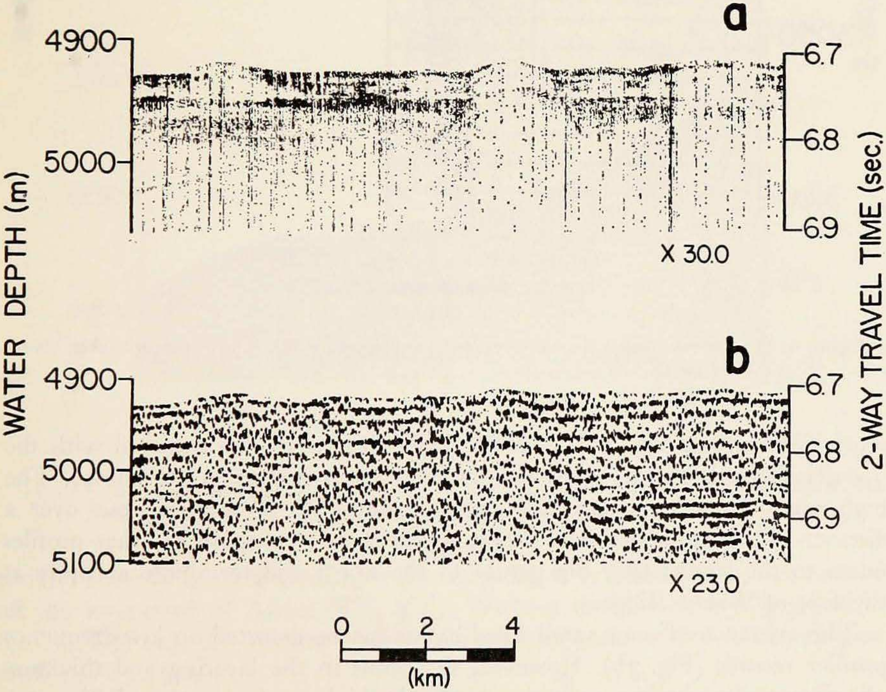

Figure 5. Mounds of sediment in the Cape Basin (28.6°S, 7.7°E). Records taken aboard R. V. ARGO. a, 3.5-kHz record; b, air-gun record.

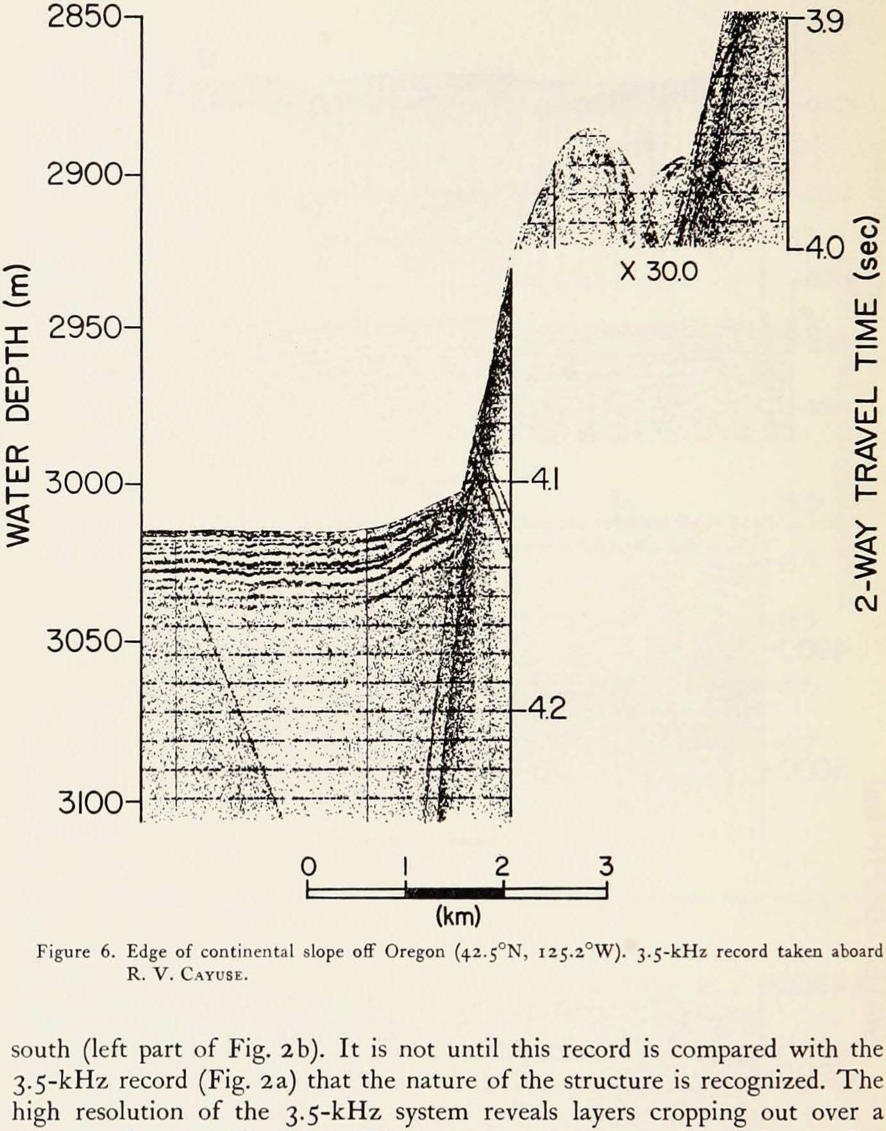

Figure 6. Edge of continental slope off Oregon (42.5°N, 125.2°W). 3.5-kHz record taken aboard R. V. CAYUSE.

south (left part of Fig. 2b). It is not until this record is compared with the 3.5-kHz record (Fig. 2a) that the nature of the structure is recognized. The high resolution of the 3.5-kHz system reveals layers cropping out over a distance of several kilometers. These layers do not reappear in other profiles taken to the south; they dip gently to the north and terminate abruptly at the foot of Walvis Ridge.

The existence of some small filled basins can be detected on low-frequency profiler records (Fig. 3b). However, variations in the layering and thickness of sediments in a basin are shown only in the high-resolution record (Fig. 3a). Other shallow basins or channels may be completely missed on low-frequency

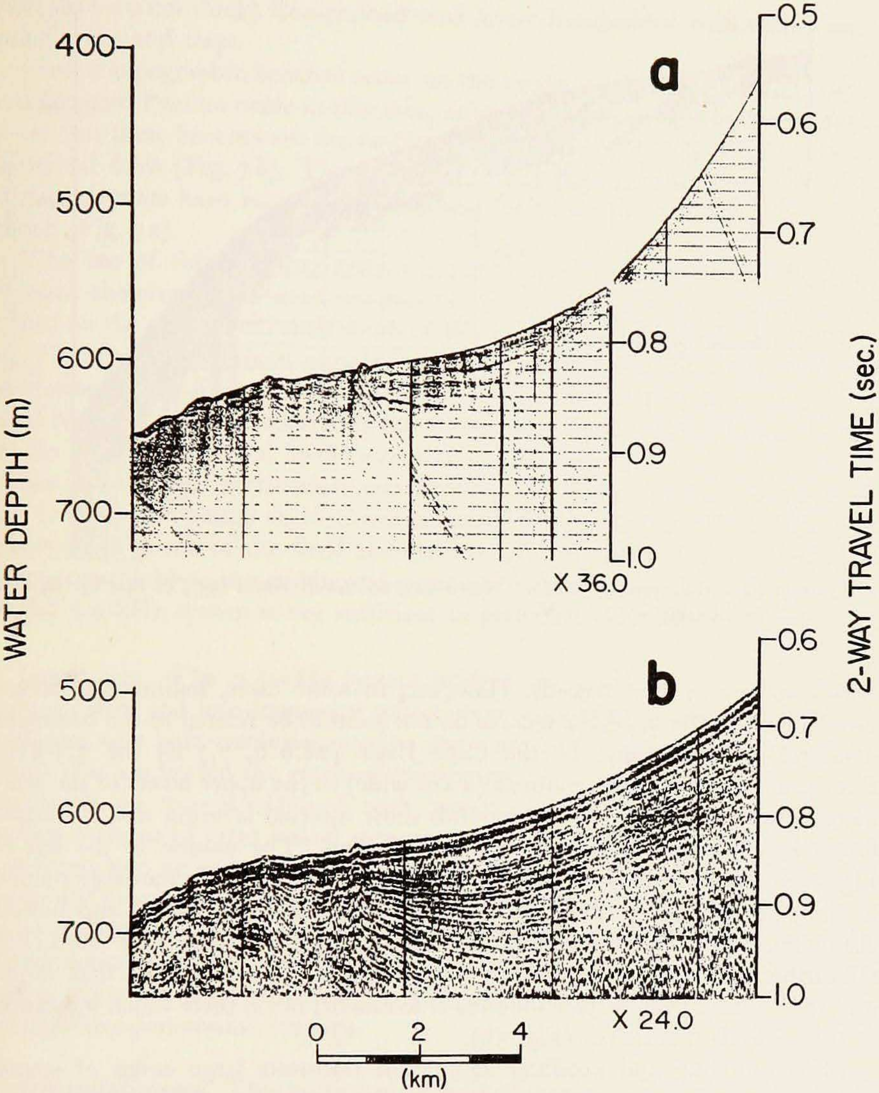

Figure 7. Bench on the upper continental slope off Oregon (42°N, 125.5°W). Records taken aboard the R. V. CAYUSE. a, 3.5-kHz record; b, sparker record.

profiler records. Such a filled basin (or channel), over 20 km wide, was crossed off the west coast of Africa (8°S, 3°E). Without the accompanying 3.5-kHz record (Fig. 4a), this feature would have remained undetected in the air-gun profile (Fig. 4b).

The near-surface layering seen in the 3.5-kHz records is commonly related to the gross structural or topographic features that are revealed in accompanying

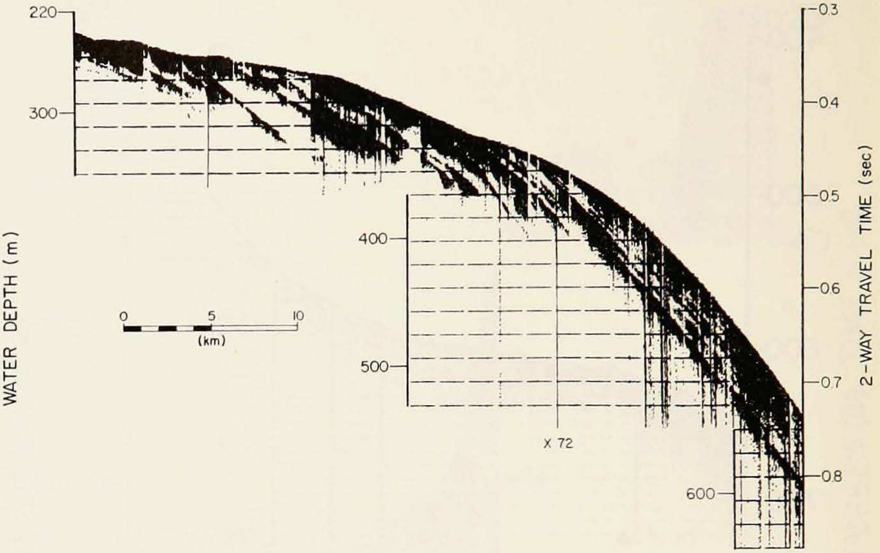

Figure 8. Edge of continental shelf off Walvis Bay, Southwest Africa (25.5°S, 14.3°E). 3.5-kHz record taken aboard R. V. Argo.

low-frequency profiler records. However, in some cases, sedimentary structures shown in the 3.5-kHz records do not seem to be related to the basement structure or topography. In the Cape Basin (28.6°S, 7.7°E) the 3.5-kHz record shows several large mounds (2 km wide) in the upper layers of the sediments (Fig. 5a). Some of these mounds show internal layering that is unconformable with the adjacent horizontal reflectors. The mound to the left in Fig. 5a has been formed on top of a flat-lying reflector while the large mound to the right appears to have gone through two "growth" stages and has no visible horizontal reflectors beneath it. In the air-gun record, there is no clear indication of a basement high or sub-bottom structural feature that might give rise to these near-surface mounds of sediment; nor is there much indication of the mounds themselves (Fig. 5b).

Most sounding and profiling equipment transmits large cones of sound. Consequently, angular interfaces, such as those often found between the continental slope and the abyssal plain, are usually masked by hyperbolic echos and are difficult to examine acoustically. A profile made across the continental slope and abyssal plain off southern Oregon (42.5°N, 125.2°W), using a towed transducer, shows the good resolution of the 3.5-kHz system (Fig. 6). The abyssal deposits are horizontally bedded except where they are slightly upturned at the base of the slope. Virtually no useful sub-bottom information was obtained from the adjacent steep slope. Sediment cores (up to 8 m long) taken on the plain in the vicinity of the 3.5-kHz profile (Fig. 6) contain thin (less than 10 cm thick) fine-grained sand layers interbedded with thick hemipelagic silts and clays.

Several topographic benches occur on the upper continental slope off southern Oregon. Profiles made in this area, using a low-frequency (sparker) system, show that these benches are the surface expressions of sediment ponding behind anticlinal folds (Fig. 7b). The 3.5-kHz record suggests that even the near-surface deposits have become distorted and folded on the seaward edge of the bench (Fig. 7a).

The use of this profiling system is not limited to deep water. Excellent records, showing up to 0.12 seconds of penetration (Fig. 8), have been obtained on the continental shelf south of Walvis Bay, Southwest Africa (25.5°S, 14.3°E). Surface sediment samples taken in this area contain sandy mud and shell fragments. From the 3.5-kHz record it appears that the continental shelf has been extended several kilometers seaward by depositional outbuilding, in the manner described by Moore and Curray (1963).

No sub-bottom information was obtained with the 3.5-kHz profiler on the Oregon continental shelf. Cores taken off Oregon indicate that thick sand layers cover much of the shelf and are overlain by only a thin layer of mud (a few cm thick) on the middle and outer shelf. Apparently, the signal strength of the 3.5-kHz system is not sufficient to penetrate these sandy deposits.

Conclusions. The 3.5-kHz system bridges the gap between conventional echo-sounder and low-frequency reflection profiler systems. Records obtained with this new high-resolution profiler show areas of outcrop and layered sediments that are within the reach of existing sampling devices but are not easily discernible in records obtained with low-frequency profiler systems. Near-surface features of great lateral extent, which are often completely masked in low-frequency records, are clearly revealed by the 3.5-kHz profiler. The capability to accurately define near-surface features will undoubtedly prove to be a valuable asset in mapping and sampling sedimentary units and in the study of sedimentation in the oceans. Information obtained from this high-resolution system provides a worthwhile supplement to data obtained with low-frequency deep-penetration systems.

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