

# THIRD PARTY BOREHOLE SEISMIC EXPERIMENTS **DURING THE OCEAN DRILLING PROGRAM**

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## Abstract

sponding to Laver 3 which was consistent wit th structure at the site and showed that upper I at a depth of over 2km into the crust, did not consist of gabbros but rather consisted of the lower portions of the sheeted dykes. Both offset nd normal incidence VSP s were run on Leg 164 to study the seismic velocity structure of gas hydrates on the Blake Ridge. A new innovation on ODP was the deployment of broadband seismometers in boreholes Whereas the conventional VSP\_s and offset VSP\_s mentioned above operate in the frequency range from 1 to 100Hz, broadband seismomete used in earthquake seismology and operate in the frequency range rom 0.001 to 10Hz. The first broadband seismometer test was carried ou ermanent broadband borehole seismic observatories were installed in the Western Pacific and Japan Trench on Legs 186, 191 and 195. The ODP era o saw the development of systems for re-entering boreholes from entional research vessels after the drill ship left the site. Borehole logy were carried out in DSDP Holes 534 (Blake-Bahama Basi 396 (Mid-Atlantic Ridge at 23degrees north) and ODP Hole 843 south of Oahu). The latter experiment (the Ocean Seismic Network Pilo experiment) carried out a test of three configurations of broadband seafloor seismic installation in preparation for extending the Globa eismic Network to the deep ocean. The author would like to thank the arthquake Research Institute at the University of Tokyo for a six-mont Visiting Professorship during which this synthesis was carried out.

1.5km of the upper crust (Layer 2) adjacent to the borehole could be imaged ( fixed range from the borehole. The direct wave from the shot to the top of the borehole decays exponentially with depth (Figure 3) and is called the "Direct Wave Root".

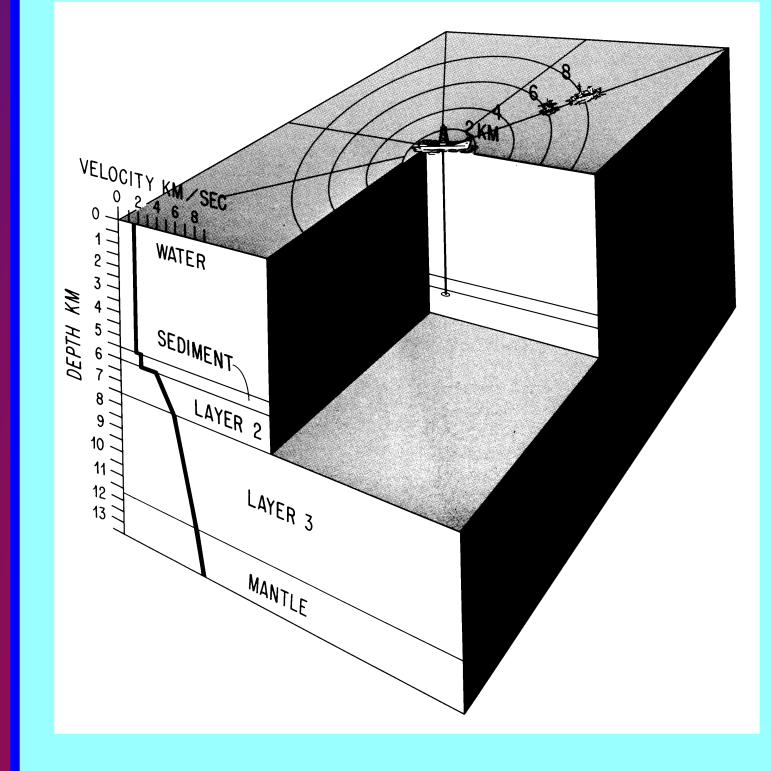
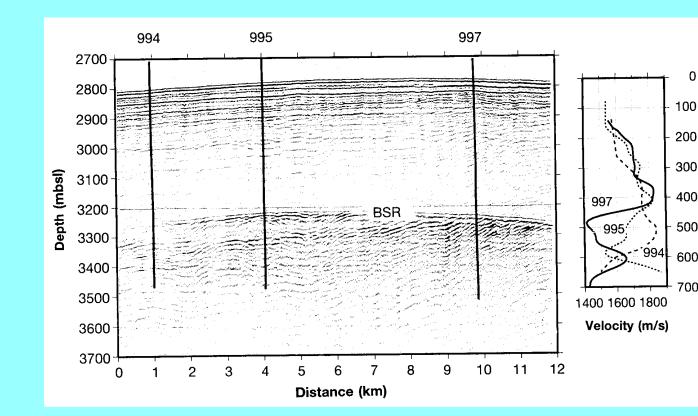
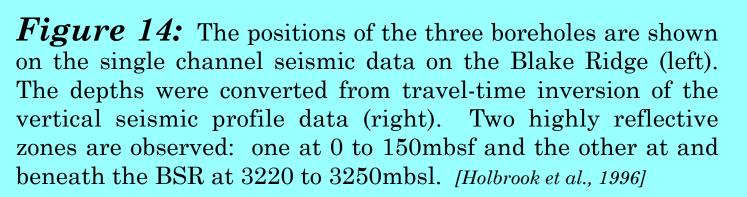


Figure 1: : In an Oblique Seismic Experiment the dril ship maintains its position over the borehole and monitors the downhole geophone while a shooting ship sails concentric circles and radial lines. A generalized oceanic crustal structure and velocity-depth function are shown. [Little and

### 6. Gas Hydrates on the Blake Ridge (Holes 994, 995 and 997, Leg 164)

smic velocity structure of gas hydrates on the Blake Ridge, offshore South arolina (Figure 13 and 14). Seismic velocities measured in three drill holes hrough the gas hydrate deposit indicate that substantial free gas exists to at east 250 meters beneath the bottom-simulating reflector (BSR) (Figure 15). oth methane hydrate and free gas exist even where a clear BSR is absent. The low reflectance, or blanking, above the BSR is caused by lithologic nogeneity of the sediments rather than by hydrate cementation. *(Holbrook et* 1996; Leg 164 Shipboard Scientific Party, 1996a; Leg 164 Shipboard Scientific Party, 1996b; Leg 4 Shipboard Scientific Party, 1996c; Leg 164 Shipboard Scientific Party, 1996d]





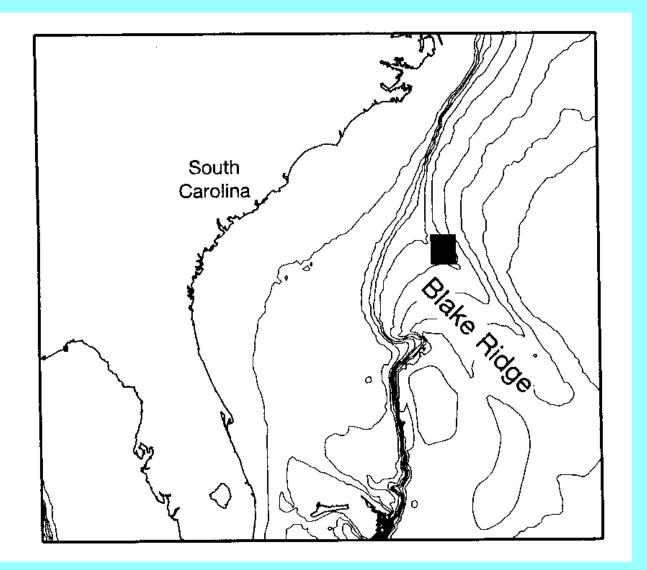
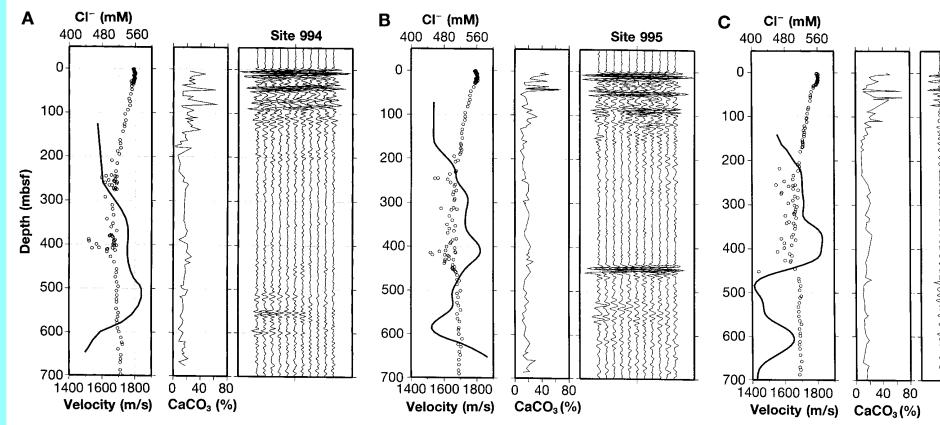


Figure 13: Location of ODP Leg 164 on the Blak Ridge. [Holbrook et al., 1996]



*Figure 15*: The seismic velocities from VSP's, the chlorinity, and the CaCO3 content are ompared with the vertical-incidence seismic reflection data from (A) Site 1994, (B) Site 995 and (C) Site 97. Anomalous chlorinity values indicate that methane hydrate is present between 220 and 450mbsf at all three sites. Seismic reflections correlate with vertical lithological changes in the upper 150mbsf and with low seismic velocities indicative of free gas (bright spots) beneath the hydrate stability zone. The low reflectance above the BSR is the expected response of lithologically uniform sediments. [Holbrook et al., 1996]

### 1. Introduction

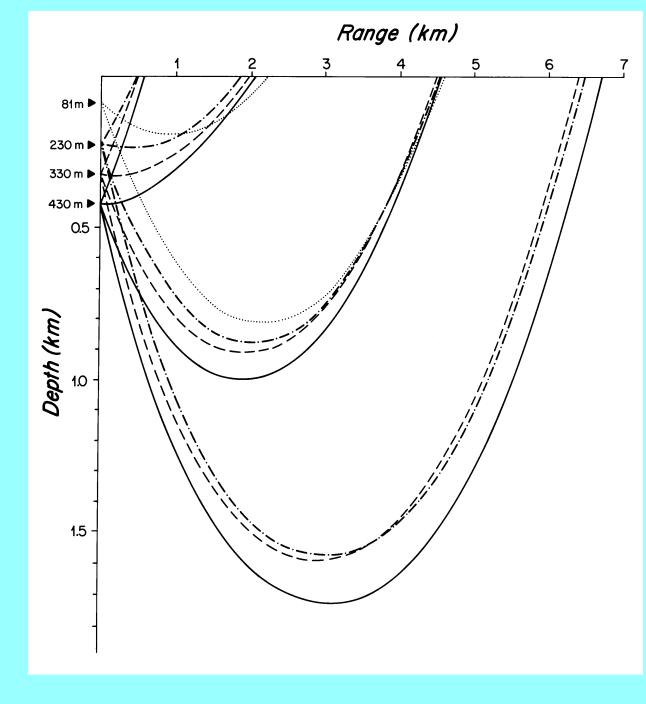


Figure 2: Rays traced through a typical velocity model for the upper oceanic crust are shown for just below the seafloor. The sources of the ray paths are near the sea surface in a 5.6km deep ocean at ranges of 2, 4, 6, and 8km. [Swift et al., 1988]

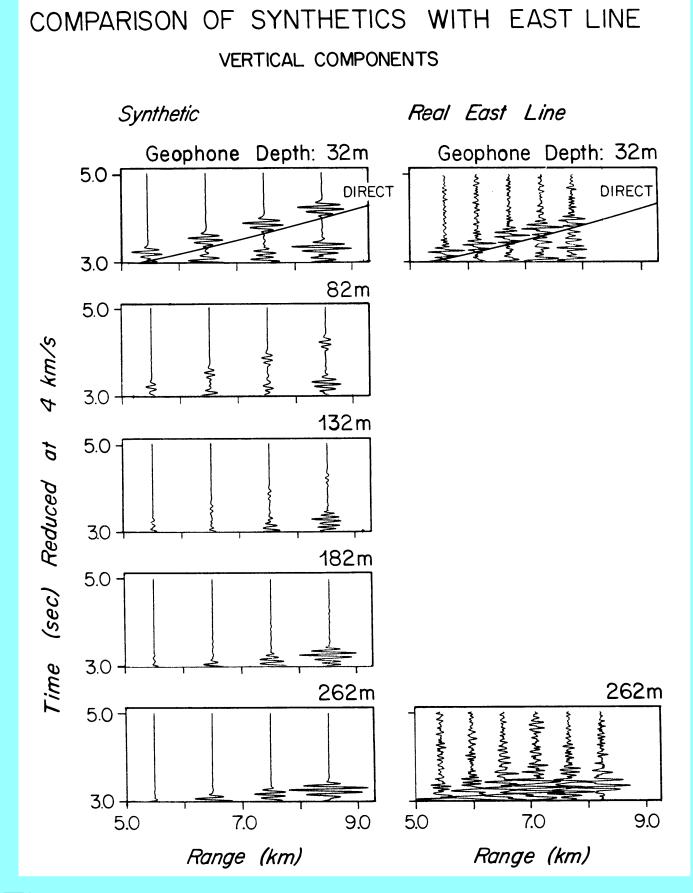
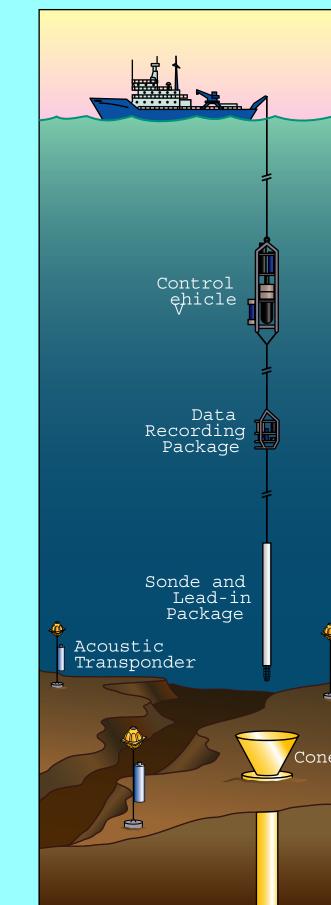


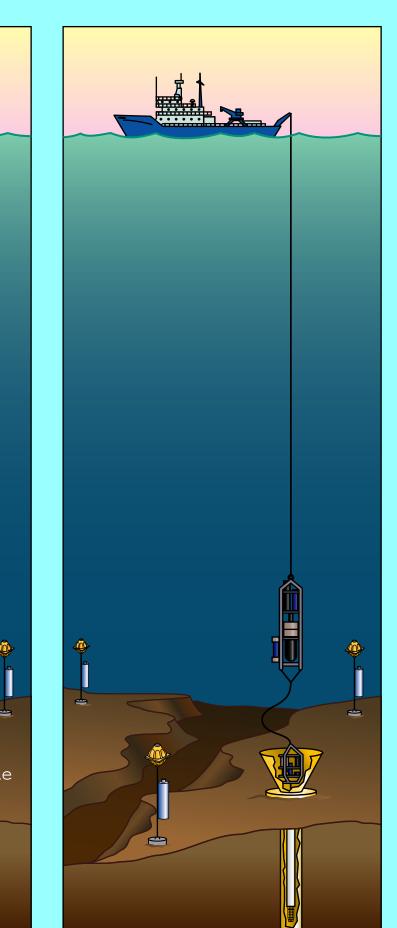
Figure 3: The evanescent behavior of the "direct wave root is shown here on field data (at 32 and 262m into basement) and on synthetic seismograms. [Stephen and Bolmer, 1985]



System

The ODP era also saw the development of systems for re-entering boreholes from conventional research vessels (Figure 16) and submersibles after the drill ship left the site (Legrand et al., 1989: Montagner et al *Spiess et al.*, 1992]. Borehole seismic experiments and installations that used this wireline re-entry technolog were carried out in DSDP Holes 534 (Blake-Bahama Basin) [Bradley et al., 1997: Stephen et al., 1994] and 396 (Mid Atlantic Ridge at 23degrees north) [Montagner et al., 1994a] and ODP Hole 843B (south of Oahu [Collins et al., 2001: Dziewonski et al., 1992: Stephen et al., 2003: Sutherland et al., submitted]. The latter experimen (the Ocean Seismic Network Pilot Experiment) carried out a test of three configurations of broadband seafloor seismic installation in preparation for extending the Global Seismic Network to the deep ocean.





*Figure 16:* In the Wireline Reentry System a borehole sonde, data recording package and control vehicle are suspended from a conventional research vessel on co-axial or fibreoptic cable (left). The control vehicle, navigated within a network of acoustic ransponders, is used to guide the sonde into the borehole. The sonde is lowered into the borehole until the data recording package lands in the re-entry cone (right). When the seafloor and subseafloor systems are operating properly the control vehicle s disconnected from the data recording package and is recovered back onboard the ship. The borehole system acquires data autonomously for up to a year until the system recovered by grappling. [Spiess et al.,

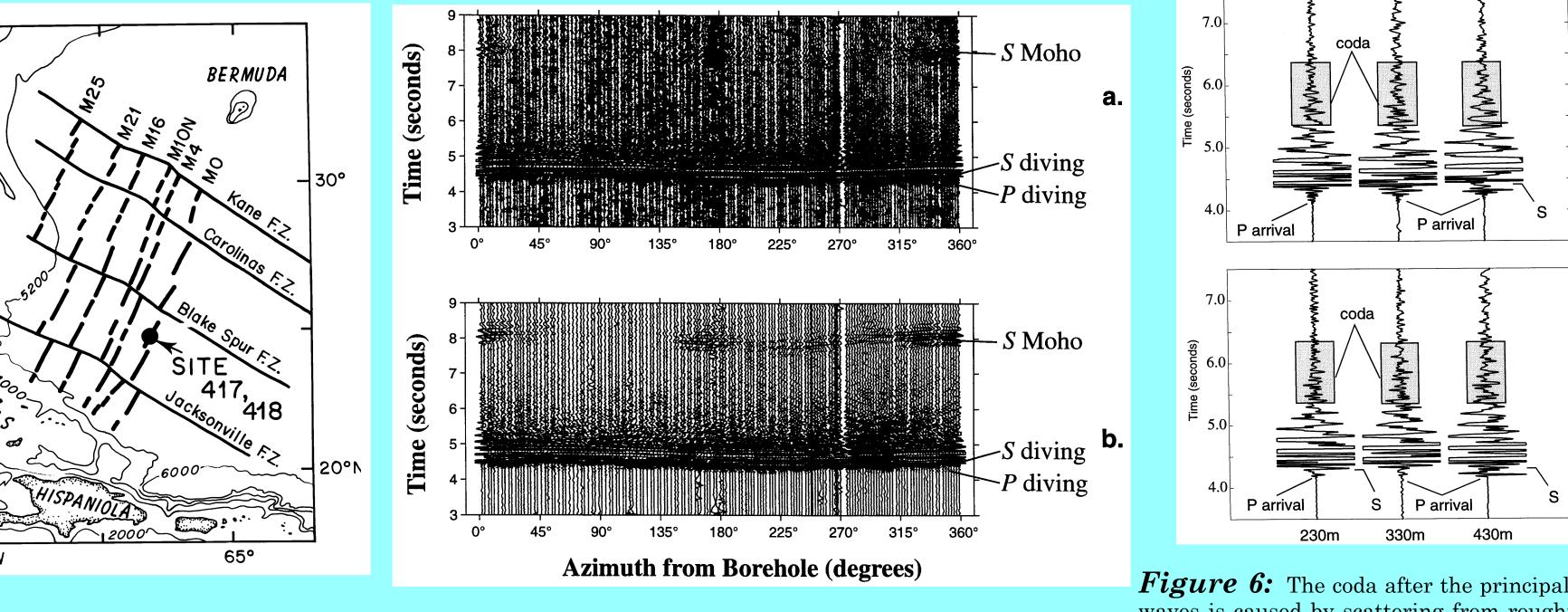
# Swift and Stephen, 1989

*Figure 10:* This is an example of the spectral ratio method used VI.01-gabbro, troctolite **Figure 8:** VSP seismograms collected at Hole 735B using a to infer Q from the data in Figure 8. (a) Solid lines are five traces 1000 cubic inch airgun and a vertical component geophon Figure 9: Interval velocities from one-way obtained at 149mbsf; dashed lines are four traces obtained at 434m Depths in the borehole are given in meters below the seafloor no sediments were found at Site 735. The seismograms were iltered to pass energy less than 250Hz; signal-to-noise ratios are 5-15dB in the 5-90Hz band. The small, upward deflection 180ms. (b) Spectra of the nine traces in (a) using the same line at about 25ms after the first arrival is an out-of-plane reflection ective errors in the selection of seismic styles. Spectra at each depth are stacked before computing the - possibly from the hull of the drilling ship. The data have been arrivals. The solid line connecting the circles amplitude ratios. (c) The dashed line is the linear regression fit to corrected for gain changes and spherical attenuation, so the ndicates velocities after smoothing by a five- the amplitude ratios between 10 and 75Hz. Q is determined from decay in amplitude with borehole depth is due solely to point moving average and is a more reliable the slope of the amplitude ratios as a function of frequency (Hauge, attenuation. The loss of high frequency energy in the initial ndication of seismic velocity. The numbered 1981]. The regression gives a Q of 46. (d) The stack of the spectral 50ms over just 350m (less than a wavelength at 10Hz) can annotations are the lithologic units drilled. ratios obtained from 13 receiver pairs has a linear regression fit clearly be seen. [Swift et al., 1991; Swift and Stephen, 1992] [Swift et al., 1991] corresponding to a Q of 26. [Swift and Stephen, 1992]

carried out on the Mid-Atlantic Ridge [Montagner et al., 1994a; Montagner et al., 1994b]. On the Ocean Seismic Network Pilot Experiment a broadband borehole sensor in ODP Hole 843B [Dziewonski et al., 1992] was compared with a shallow buried and a seafloor seismometer for a period of over three months (Figure 17) [Collins et al., 2001; Stephen et al., 2003; Sutherland et al., submitted] Subsequently four permanent broadband borehole seismic observatories were installed in the Western Pacific and Japan Trench [Araki, 1999; Suyehiro et al., Three other boreholes have been drilled specifically for seismic installations: at the Ninety-east Ridge (Leg Observatory (Leg 200). and in the equatori Pacific (Leg 203).

### 2. Western Atlantic South of Bermuda (DSDP Hole 418, Leg 102)

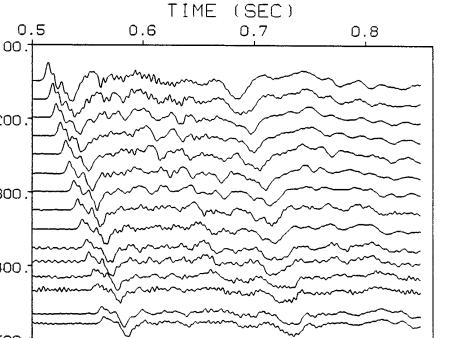
irmed the velocity structure of upper Laver 2 including Azimuthal anisotropy and azimuth dependent scattering (Figures 4 to 7). It is interesting to note that ravel-time and amplitude data from two Oblique Seismic Experiments on 110ma crust in the slow-spreading western North Atlantic and fast-spreading Northwestern Pacific shows that compressional velocities within layer 2 are, within experimental error, identical *[Kong et al., 1985*]

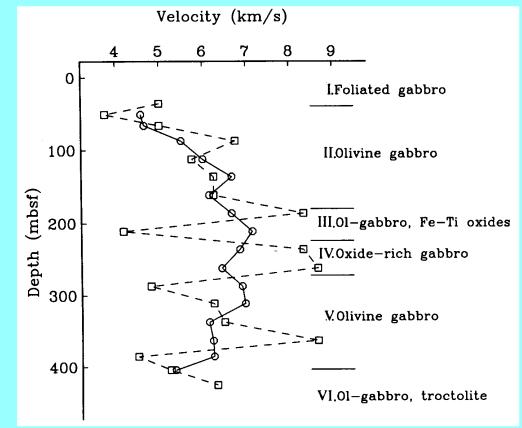


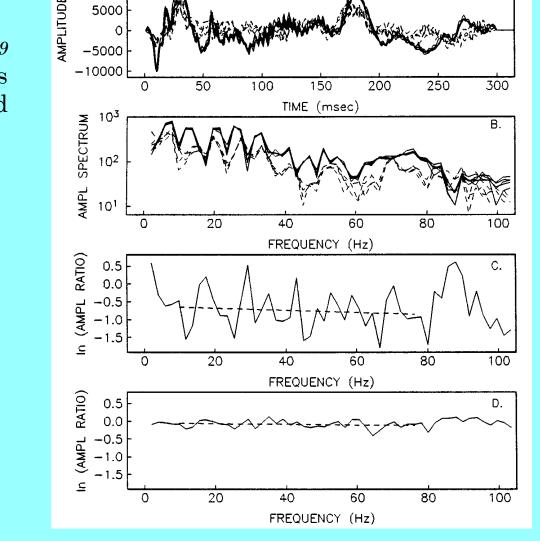
recording intervals, and/or debris falling down the borehole. Bandpass summary of the Azimuthal de filtered data (b) have been processed using a Butterworth filter at 2 and amplitude is given in Figure 7. [Dougherty et al., 1995] 20Hz. [Dougherty et al., 1995]

### 3. Southwest Indian Ridge (Hole 735B, Leg 118)

ientific Party, 1988/ before the VSP at Hole 735B on Leg 118 on the Southwest Indian Ridge. This experiment measured velocities corresponding to Layer 3 which was consistent with the gabbroic petrology of the cores. Anomalously high attenuation was also observed which prompted the hypothesis that the gabbro cored may not actually represent the bulk of Layer 3 material (Figures 8 to 10).







### 8. Broadband Borehole Seismology

of broadband seismometers in boreholes. Whereas the conventional VSPs and offset VSPs mentioned above operate in the frequency range from 1 to 100Hz (similar to the band used for reflection and refraction seismology), broadband seismometers are used earthquake seismology and operate in the frequency range from 0.001 to 10Hz. The first broadband borehole seismometer test was carried out from the dr ship on Leg 128 in the Japan Sea in the 1989 [Kanazawa et al., 1992; Suyehiro et al., 1992]. The first submersible assisted broadband borehole seismometer test was

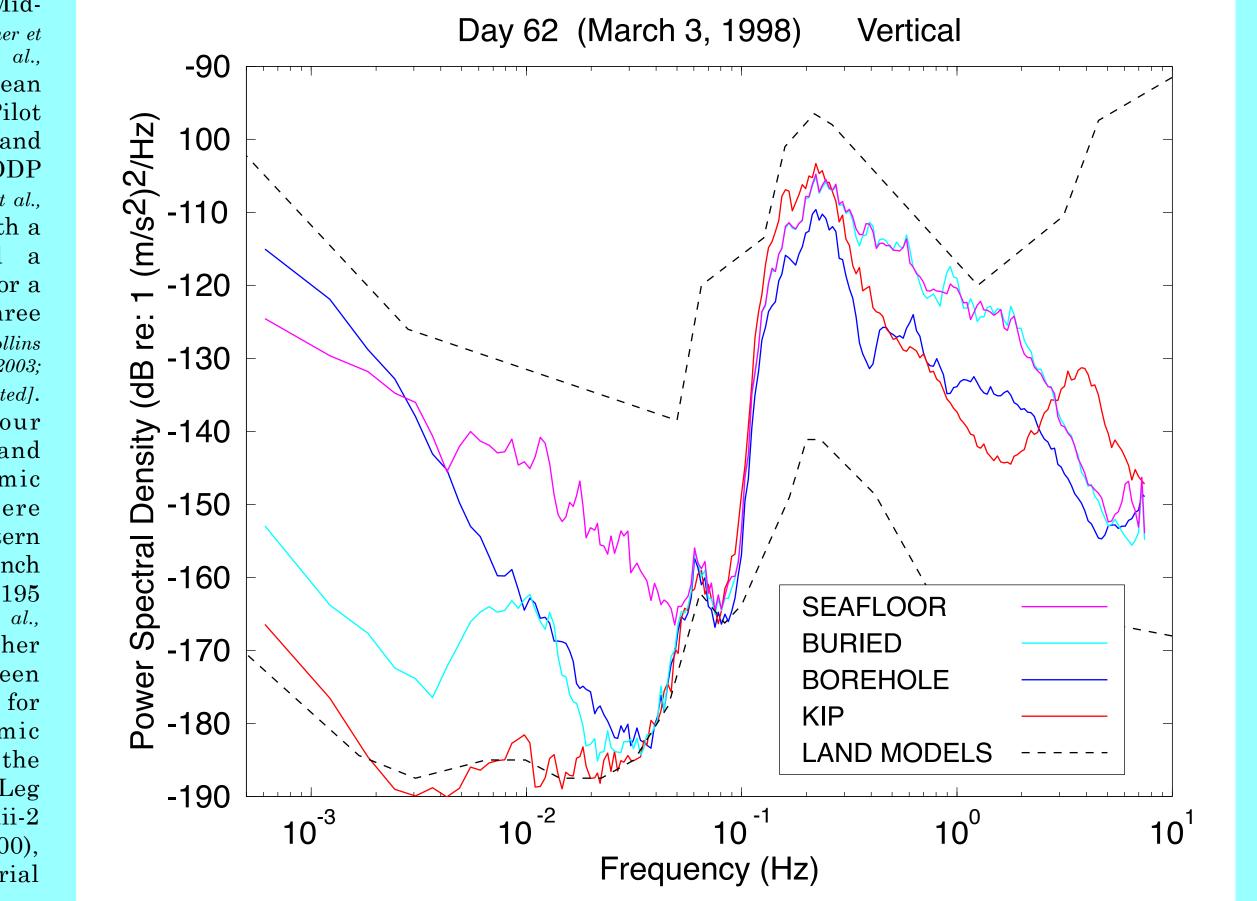


Figure 17: ertical component pectra for the three broadband seismometer configurations leployed on the OSNPE (seafloor, and Kipapa GSN station on Oahu are compared with igh and low noise pectral models pased on land observations. From 20mHz to 00mHz the orehole and buried sensors in the ocean are as quiet as any land

### References ormance of the marine seismic system during the Ngendie

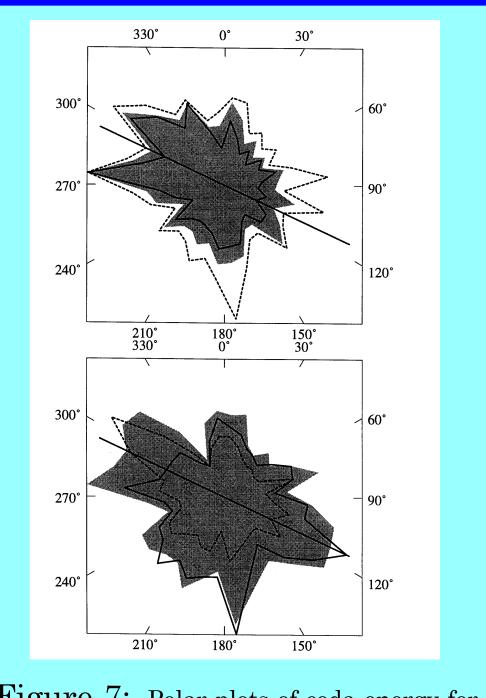
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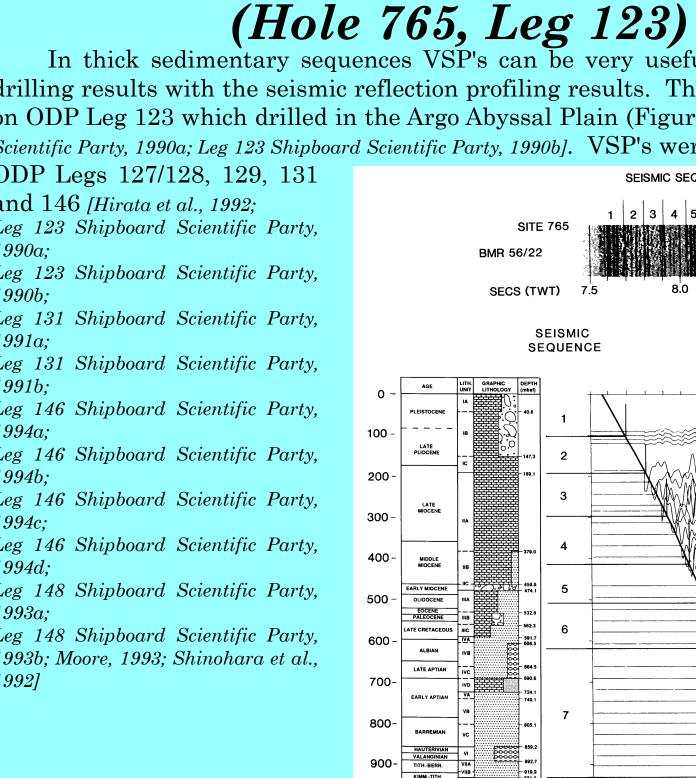
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4. Argo Abyssal Plain

### 5. Costa Rica Rift (Hole 504B, Legs 111 and 148)

The VSP data acquired at Hole 504B in the eastern equatorial Pacific on Leg 148 helped to constrain the velocity structure at the site ILeg 109 Shipboard Scientific Party 1988: Leg 148 Shipboard Scientific Party 1993a: Leg 148 Shipboard Scientific Party 1993b. 1996: Swift et al., 1998a: Swift et al., 1998b] and showed that upper Layer 3 at this site, at a depth of over 2km into the crust, did no consist of gabbros but rather consisted of the lower portions of the sheeted dykes (Figure 12) [Detrick et al., 1993]. VSP's were also carried out on Leg 156 [Leg 156 Shipboard Scientific Party, 1995a; Leg 156 Shipboard Scientific Party, 1995b; Leg 156 Shipboard Scientific Party, 1995a

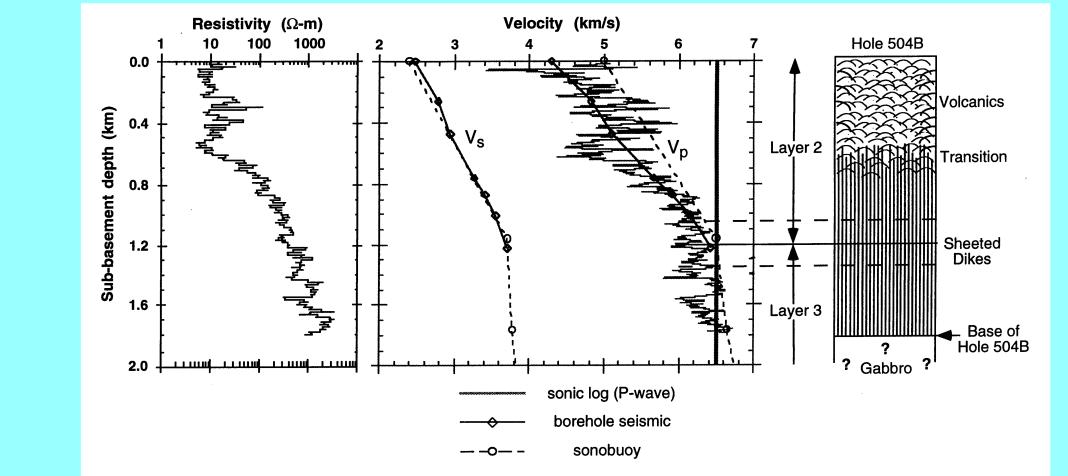


Figure 12: The variation in bulk resistivity downhole derived from logging in Hole 504B, the crustal velocity structure at the site, and the lithostratigraphy. The crustal velocity model is based on a Layer 3 velocity of 6.5km/sac derived from sonobuoy studies around Hole 504B (vertical bar) and a linear regression of the shallow crustal velocity gradient determined from travel-time and plitude modeling of the borehole seismic experiment (thick solid line). For comparison, the thin grey line shows the s locity log and the dashed line shows the sonobuoy velocity model. The change in the vertical velocity gradient that defines th eismic layer 2/3 boundary at 1.2+/-0.2km sub-basement, occurs within the sheeted-dyke section, about 660m above the base of the hole. At least the upper 400-800m of seismic layer 3 consists of dolerites and metadolerites rather than gabbro. [Detrick et al., 1993]

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