4. UNDERWAY GEOPHYSICS[1]

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TRANSIT

The ship departed Lisbon, Portugal, at 0530 hr on 28 May 1993 (this and all subsequent times are in Universal Time Coordinated). Both 12- and 3.5-kHz echo-sounding profiles transmitted from hull-mounted transducers were recorded on Raytheon LSR-1807M Line Scan flatbed recorders beginning at 1250 hr on 28 May. A Geometrics proton precession magnetometer was deployed at 1230 hr, 28 May, towed 1300 m behind the ship, and recorded on a Hewlett-Packard 680 strip-channel recorder as well as on the header log and magnetic tape. Strong headwinds and adverse seas slowed westward progress for much of the transit and led to noisy echo-sounding profiles. Global Positioning Satellites (GPS) and Loran-C provided 24-hr coverage. To reduce the risk of getting tangled in commercial fishing gear, the magnetometer was retrieved when we began the first of three pre-site surveys on 10 June. Each survey was entirely within the Jurassic Quiet Zone (Larson and Pitman, 1972), so little was to be gained by collecting these magnetometer measurements. All transit data are archived at both ODP/TAMU and the JOIDES Data Bank, and will not be discussed further.

SEISMIC PROFILING

Despite an excellent set of pre-Leg 150 site survey data, much of it with GPS positioning, the small tolerances for error in site placement on the continental slope made additional surveying advisable. Hence, we conducted three separate water-gun and precision-depth-recorder (PDR) surveys during Leg 150, which we describe below. The source, receiver, and recording parameters were identical in each of the surveys.

The first survey (Fig. 1) preceded drilling and tied Site 905 to slope Sites 902 and 903. Proposed Sites MAT12, 13, 15, and 16 were crossed during this survey as well, but they were not drilled. The second survey (Fig. 2) followed our shipboard decision to move Site 904 from its proposed location at Site MAT12 to the preferred location of MAT12A (see "Background and Objectives" section in Chapter 8, this volume); these data were collected between our drilling Sites 903 and 904. The third survey (Fig. 3) immediately preceded drilling at Site 906, and tied this site to adjacent Sites 902, 903, and 904, and to the grid of previously acquired survey data linking these sites (see "Background and Objectives" section in Chapter 10, this volume, for additional discussion).

Recording Parameters

We began the first survey with two 200-in.[3] Hamco water guns fired every 10 s at 2000 psi. Ship speed was maintained between 6 and 6.25 kt through the water; ground speed differed slightly because of surface currents. Gun depths were monitored with transducers mounted on each towing frame. The port gun ranged between 10 and 13 m below sea level, depending on speed through the water; the starboard gun was nearly always 2 m shallower. The towing rig was the same for each gun and, despite deck calibration, these contrasting towing depths may not be accurate. After being test fired, the starboard gun was turned off but left pressurized and in the water as a spare. The port gun blast phone malfunctioned and created poorly timed recording pulses for a few minutes during the first survey. We then changed to recording based on an internal clock instead of the shot detection, and this arrangement remained in effect for the rest of seismic surveying on Leg 150. Digital data were recorded by HiRes software with 1–ms sampling after a bandpass of 10 to 250 Hz. Analog data were displayed on Raytheon LSR-1807M Line Scan flatbed recorders at 4- and 6-s displays after a 100-dB gain and a bandpass of 30 to 150 Hz were applied. A Teledyne 100-m streamer comprising 60 hydrophones was deployed off the port side of the stern to the full length of the tow cable. The arrival time of the D-wave determined that the shot-receiver offset was initially 352 m.

We shortened the initial shot-receiver offset for two reasons. First, we wished to minimize the effects of follow-on sea surface reflections (or "ghosting"). These effects cannot be eliminated, but they can be minimized by towing the source and the receiver at the same depth. Towing depths are much more difficult to adjust for the gun than for the streamer; hence, we trimmed the latter by winding its lead-in cable back onto the drum. An offset of 172 m (roughly half the original; Fig. 4) shortened the source pulse from 85 to 55 m (Fig. 5); the streamer was still apparently deeper than the gun, but we felt that shorter offsets would introduce too much noise. Second, survey water depths were as shallow as 300 m, and this meant that the condition of normal-incidence reflection would not be met. In such a case, a finite length receiver attenuates signals when the ratio of water depth to shot-receiver offset becomes too small (Fig. 6; Lorenzo and Vera, 1992). We there-

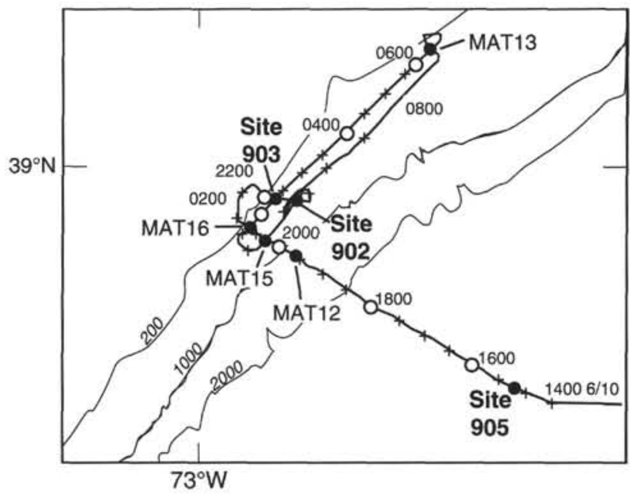

Figure 1. Ship's track and Universal Time Coordinated (UTC) notations for SCS survey 1, beginning as we crossed Site 905 on the continental rise and continuing landward to slope Sites 902 and 903. Proposed Sites MAT12, 13, 15, and 16 were also crossed but not drilled during Leg 150. Contour intervals in meters below seafloor.

[1] Mountain, G.S., Miller, K.G., Blum, P., et al., 1994. *Proc. ODP, Initial Reports,* 150: College Station, TX (Ocean Drilling Program).

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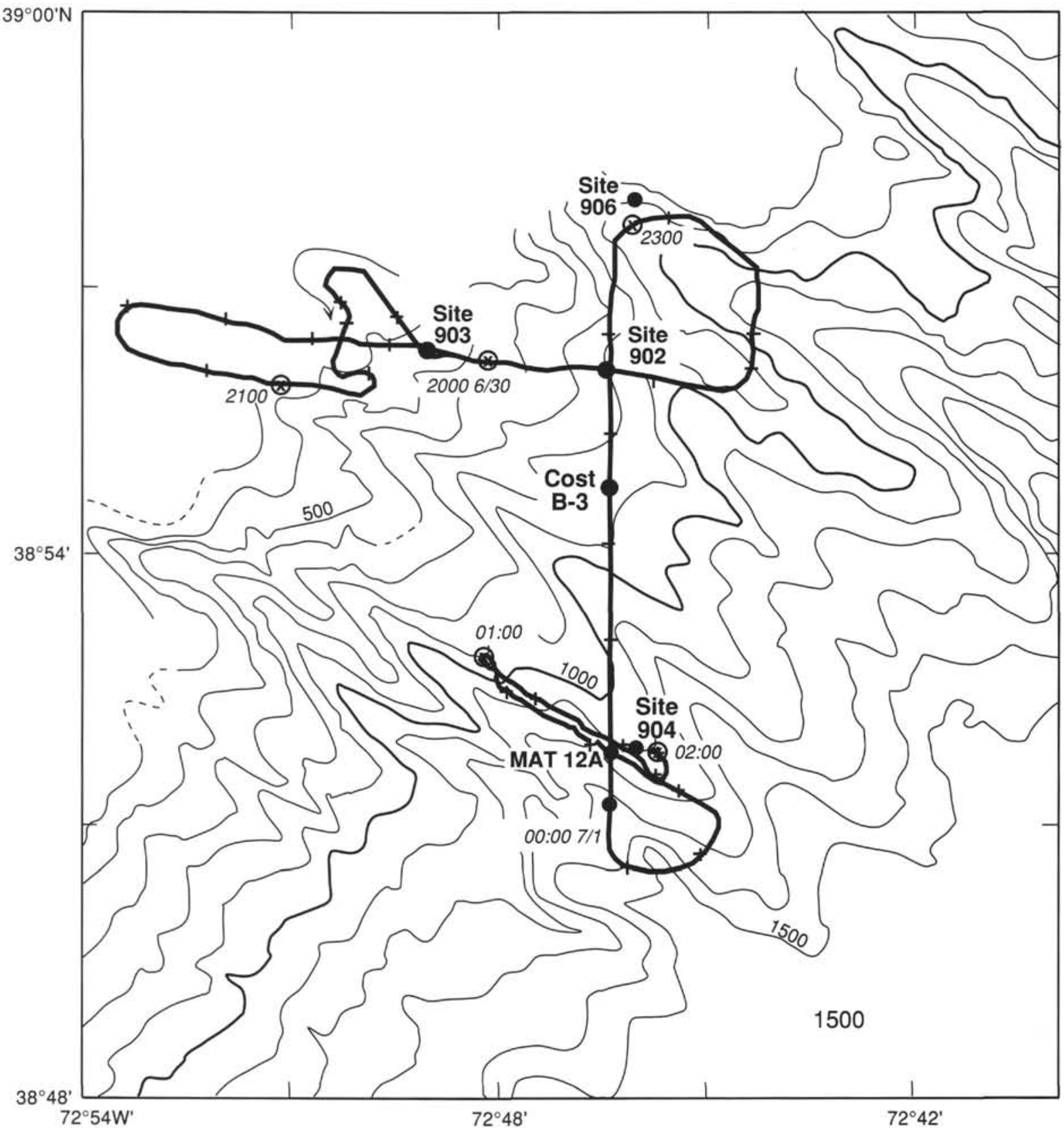

Figure 2. Ship's track and UTC notations for SCS survey 2, beginning at Site 903 and crossing Sites 902, COST B-3, MAT12A, and 904. The latter was moved east-southeast from the intended location (proposed Site MAT12A), as described in the text. SeaBeam bathymetry from W.B.F. Ryan and D.C. Twichell (unpubl. data, 1989). Contour intervals in meters below seafloor.

fore wished to reduce attenuation by reducing the shot-receiver offset. Real-time monitoring of the seafloor return on a Hewlett-Packard 3582A Spectrum Analyzer before and after the offset adjustment confirmed that we did indeed achieve a more uniform amplitude spectrum.

Survey Design

For the first of our three single-channel seismic (SCS) surveys we crossed 0.9 nmi south of Site 905 (proposed Site MAT14; Fig. 1) at 1525 hr on 10 June and continued without course change to the foot of the continental slope and across proposed Site MAT12. Intersecting dip and strike lines were then run across proposed Sites MAT15, 16, 11, and 10 (the latter two were drilled as Sites 903 and 902). We continued northeast to complete a pair of lines intersecting at proposed Site MAT13. Seismic gear was retrieved at 0720 hr on 11 June and we returned to Site 902 to complete the tie-in with a short bathymetric survey before we dropped the beacon (see "Background and Objectives" section in Chapter 6, this volume).

A second seismic tie was made across Sites 903, 902, and 904 (proposed Sites MAT11, 10, and 12A; Fig. 2) for two reasons. First, the latter site was a modification of planned Site MAT12 (see "Background and Objectives" section in Chapter 8, this volume) and the first survey had not crossed this new location. Second, the SCS line connecting Sites 903 and 902 during the first survey was of poor quality because of a malfunctioning blast phone, and the line needed to be reshot. Recording parameters and the shortened shot-receiver offset were identical to the first survey described above. Recording began at 2040 hr on 30 June, and ended at 0045 hr on 1 July. A third seismic survey was run from 2025 hr on 13 July to 0640 hr on 14 July, before spudding in at Site 906 (Fig. 3). As explained in the "Back-

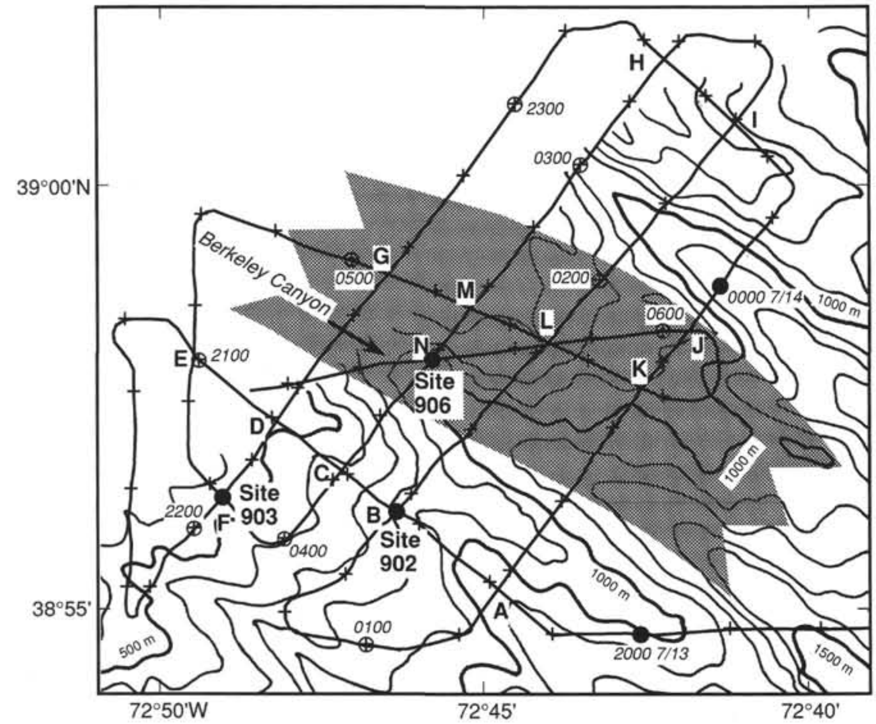

Figure 3. Ship's track and UTC notations for SCS survey 3, which began on the lower slope en route from Site 905, crossed Sites 902 and 903, and surveyed Site 906 in detail. The numerous crossings are keyed by letters to their locations on the profile in Figure 9. The modern Berkeley Canyon and the buried target canyon (shaded) are shown. Note that the upslope and downslope limits of the target canyon cannot be determined with the available data. SeaBeam bathymetry from W.B.F. Ryan and D.C. Twichell (unpubl. data, 1989).

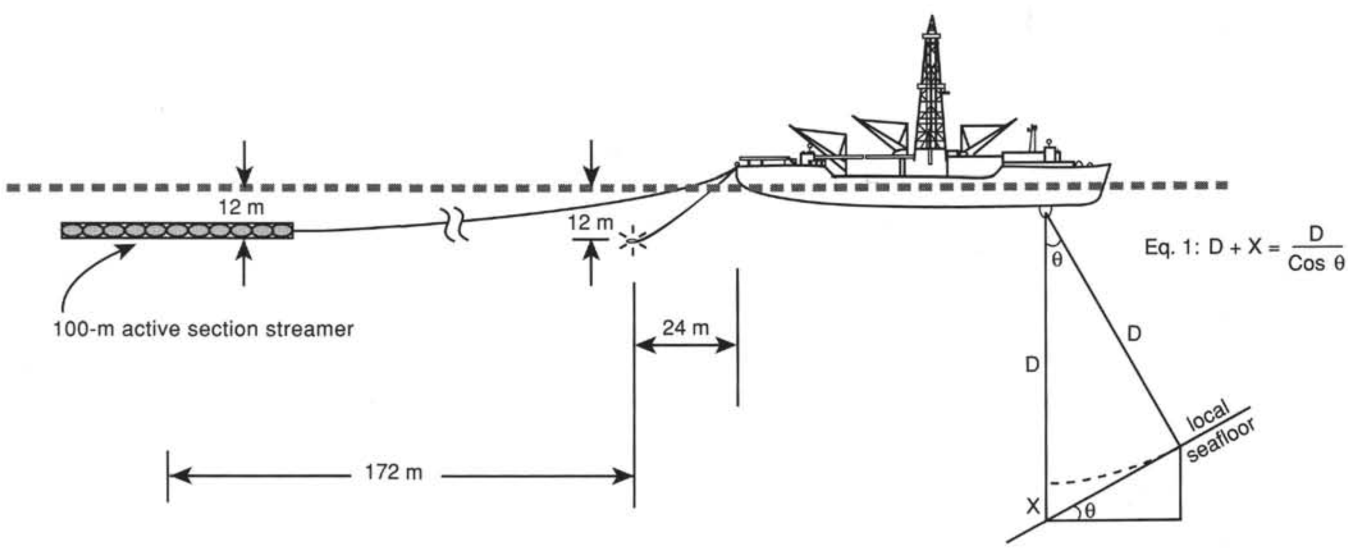

Figure 4. Diagram showing dimensions of the SCS deployment and the source of differences between PDR depth "D" and pipe depth "D + X" in areas of locally steep topography of slope "θ." These parameters are related by Equation 1.

ground and Objectives" section of Chapter 10 (this volume), this was an unexpected addition to Leg 150 drilling following the premature end of operations at Site 905. Adequate survey data were on hand for site location, but it was clear that additional good-quality profiles would be useful for two reasons: (1) they would greatly enhance the value of the core and log data from this site, and (2) the objective was a narrow target that required an unusually precise site location.

Calm weather, moderate ship speed, shortened shot-receiver offset, and a vigilant underway watch by the shipboard technical staff resulted in useful profiles of good quality. The relatively shallow water depths throughout most of the surveying minimized spherical spreading loss of acoustic energy, and contributed to records with 1.25 to nearly 2.0 s of penetration. Data from the second of our three surveys were processed aboard ship using SioSeis software; we present and describe briefly the analog records of each survey. More detailed interpretations of these and the pre-Leg 150 multichannel seismic (MCS) data are found in the "Seismic Stratigraphy" sections of each site chapter of this volume.

Survey 1

Profiles comprising the first survey (Fig. 1) connecting Site 905 to Sites 903 and 902 are shown in Figure 7. Data quality was compromised at the very beginning (and the crossing of Site 905) by three factors: (1) relatively deep water (~2800 m); (2) the standard offset, meaning that at this speed the streamer was relatively deep; and (3) a

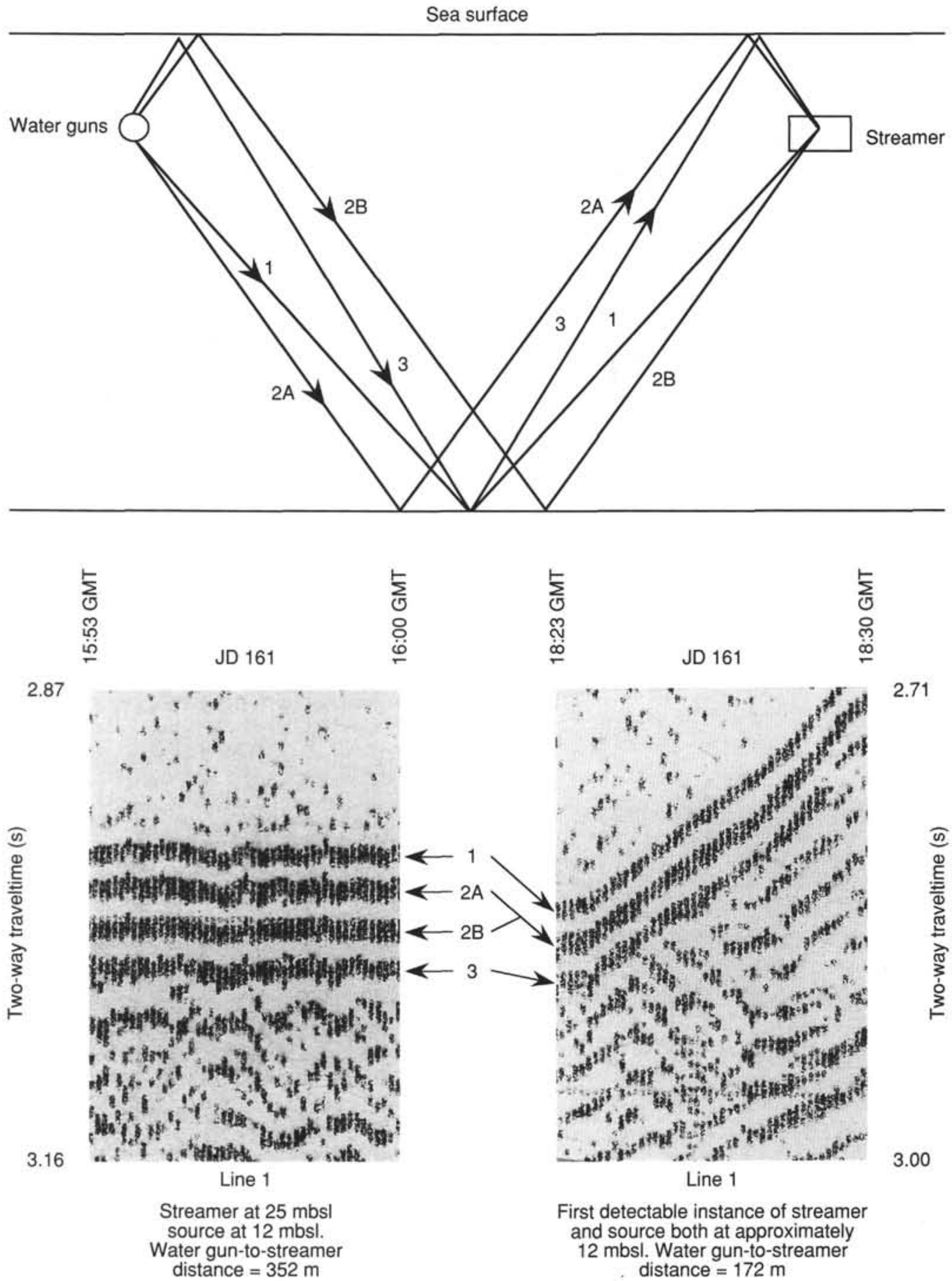

Figure 5. Interfering sea-surface reflections (schematic rays 1–3, top) combine to produce observed reflection trains on single-channel seismic records. By towing the streamer at the same depth as the water guns (bottom), rays 2A and 2B travel an equal distance and arrive simultaneously, thus shortening the observed reflected pulse and improving seismic definition.

locally irregular seafloor that scattered acoustic energy and reduced the amplitudes of vertical reflections. Regarding the second factor, the reduced arrival time of the D-wave signal along the top of the profile indicates when the streamer was twice partially rewound after crossing Site 905. The clarity of the seafloor reflection improves with each reduction of shot-receiver offset, as described previously (Fig. 5). The irregular seafloor in the vicinity of Site 905 is caused by Pleistocene debris flows, some of which contain ?Eocene blocks several meters across that lie exposed on the seafloor (see "Operations" section in Chapter 9, this volume).

The uppermost ~225 ms at Site 905 is relatively reflection free (Fig. 7). Drilling proved this correlates with poorly stratified debris flows comprising the uppermost 212 m at this site. Stacks of wavelike reflectors occur at roughly 600–800 ms below the seafloor, and are interpreted to be the result of current-controlled deposition. The intended total depth at this site was Reflector A^u, which is faintly detected at about 1400 ms below the seafloor. This dip line profile shows clearly that none of the strata recovered at Site 905 can be traced seismically to the Leg 150 slope sites because of the broad Eocene outcrop on the lowermost slope.

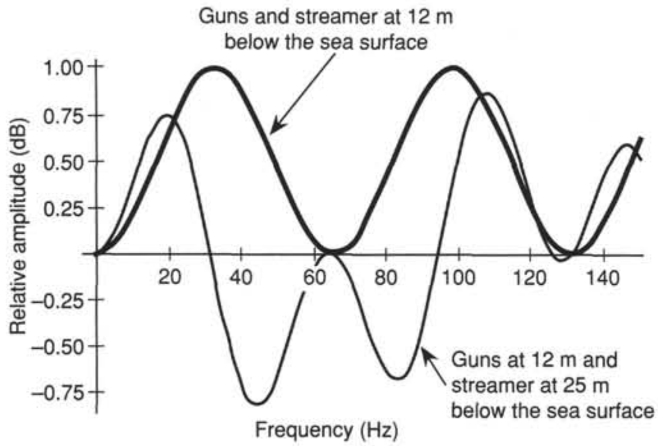

Figure 6. The frequency response for a source and receiver at a common depth of 12 m provides a window of nonfiltered data at a peak frequency of about 40 Hz and covers the useful range of frequencies received from the water guns.

Blast phone detection malfunctions began at 2152 on Julian Day (JD) 161 and continued until we switched permanently to internal synchronization at 2317 hr. Consequently, the profile across Site 903 was poor, and this prompted us to reshoot part of this line during our second survey. Note that internal synchronization introduced a 110-ms delay relative to triggering off the blast phone detection, so from this point onwards for all surveys on Leg 150 reflections appear deeper than they actually are.

Alternate Sites MAT12, 13, 15, and 16 were crossed during this survey but not drilled. The latter three were unnecessary because objectives were met at the primary slope sites. Site MAT12 is located on the southwest flank of Carteret Canyon, and it was realized that seismic ties to primary Sites 902 and 903 (and eventually to Site 906) for all strata above the middle Miocene would be difficult to determine because of this intervening canyon. Hence, we requested and received permission from ODP to select Site MAT12A at cdp 920 of Ew9009 Line 1027, 3.4 km northeast of Site MAT12. This location is on the northeast side of the canyon thalweg and closer to Sites 902, 903, and 906. Final site location was adjusted further after our second shipboard survey, described below.

Survey 2

Seismic recording during the second survey (Fig. 2) began at 2040 hr on JD 181 (30 June). Sites 903 and 902 were successfully tied with a good-quality line (Fig. 8) that shows clearly the contrasts between these sites and why they were chosen: the upslope Site 903 has a more nearly complete section between reflectors p6 and m1, as well as a thick section immediately below m2; Site 902 has an expanded interval between m1 and m2 (see "Seismic Stratigraphy" sections of respective site chapters, this volume). Though not yet chosen even as an alternate, the future location of Site 906 was about 200 m north of the track at 2256 hr on JD 181. The buried Miocene canyon that was the objective at this site can be seen beneath reflector m3. The profile across Site 902 shows clearly how the Pleistocene rests unconformably on the Miocene, separated by the erosional reflector p4. Alternate Site MAT12A was crossed twice at the end of this survey, but it was realized that 120 ms of additional Pleistocene above reflector p4 could be recovered by moving 360 m east-southeast. This was the location drilled as Site 904, as shown in Figure 8.

Survey 3

Unexpectedly complete and datable Pleistocene sections at Sites 902, 903, and 904 prompted us to bypass drilling Site MAT13 in favor of a new site selected when operations were halted prematurely at Site 905. A buried ?Miocene canyon had been recognized in pre-Leg 150 survey data, and this feature had been observed during our second Leg 150 survey described above (Fig. 8). The challenge was to minimize the overburden by locating Site 906 as close to the thalweg of the modern Berkeley Canyon as possible while still enabling us to drill into our target: the oldest sediment filling the buried ?Miocene canyon.

We departed Site 905 and began recording at 2018 hr on JD 194 (13 July) while heading up the continental slope. An excellent quality dip line profile (Fig. 9) was collected across Site 902, and after turning, a strike line profile of similar quality was collected across Site 903. The numerous crossings of this third survey grid are marked by letters in Figures 3 and 9.

Although Ew9009 MCS Line 1027 provides clearer resolution of the Site 906 buried target, the Leg 150 SCS and PDR survey provided necessary geographic constraints on the optimal drilling location defined by both surface and buried morphology (Fig. 3). The buried canyon is defined by the deepest intact reflector m6 (Fig. 9), the shallowest incised reflector m3, and the oldest capping reflector m2. These reflectors and their geometric relationships were defined with pre-Leg 150 site survey profiles (see "Seismic Stratigraphy" section in Chapter 10, this volume). This profile (Fig. 9) shows the degree to which the middle slope is incised by Pleistocene canyons. Furthermore, it emphasizes the need for careful mapping to locate sites between canyons and achieve as complete an upper Pleistocene section as was recovered at Sites 902, 903, and 904.

BATHYMETRY

Three sets of bottom topography were available to us: a gridded and contoured Sea Beam swath map (W.B.F. Ryan and D.C. Twichell, unpubl. data, 1989), single-beam PDR records from the Ew9009 pre-Leg 150 site survey (G.S. Mountain and K.G. Miller, unpubl. data, 1990), and our own underway surveying. Occasionally, it was difficult to find bathymetric agreement between any two of these data sets. For example, the two crossings of Site 902 completed during the first Leg 150 survey on 10 June revealed bottom topography similar but not identical to the Sea Beam map. Compounding our uncertainty during this survey, we could not reconcile the Ew9009 depths with those of either the Sea Beam survey or our own Leg 150 data. Disagreements throughout this and subsequent surveys ranged from several to as much as 40 m water depth, with each value corrected for hull-mounted transducer depth but uncorrected for water velocity. There was no systematic offset between the three data sets.

The Sea Beam data were navigated by LORAN-C, the other two by GPS, and we suspected that perhaps one navigational system was better than another. This was dismissed, however, when we compared Leg 150 GPS and LORAN-C positions every 2 min during the first survey and found negligible differences. We concluded that the problem derived, in part, during preparation of the Sea Beam map. This procedure involved gridding discrete Sea Beam depth measurements, fitting a surface to these values, and recontouring the result. One can expect that small inaccuracies developed in this process; furthermore, because of the steepness of the terrain (regionally 2.5° to 4°, but locally up to 20° and more), positions mislocated by only 100 m can produce bathymetry that is several to a few tens of meters in error.

Disagreement between the Ew9009 and Leg 150 depths is probably the result of errors in navigation of the *Ewing* track. These data were collected in 1990 with 10 to 15 hr of GPS coverage per day. At those times without GPS, dead reckoning between transit satellite fixes determined the ship's position. The proposed location of Site 902 at cdp 1532 of *Ewing* Line 1027 by chance falls within one of these non-GPS segments and probably explains why it was especially difficult to identify this position with Leg 150 bathymetry. The 24-hr GPS coverage available during Leg 150 provided a much more precisely located data set. This is confirmed by the fact that we crossed our own track seven times during the pre-Site 902 and pre-Site 906 surveys, and we noted excellent agreement in water depths at every intersection.

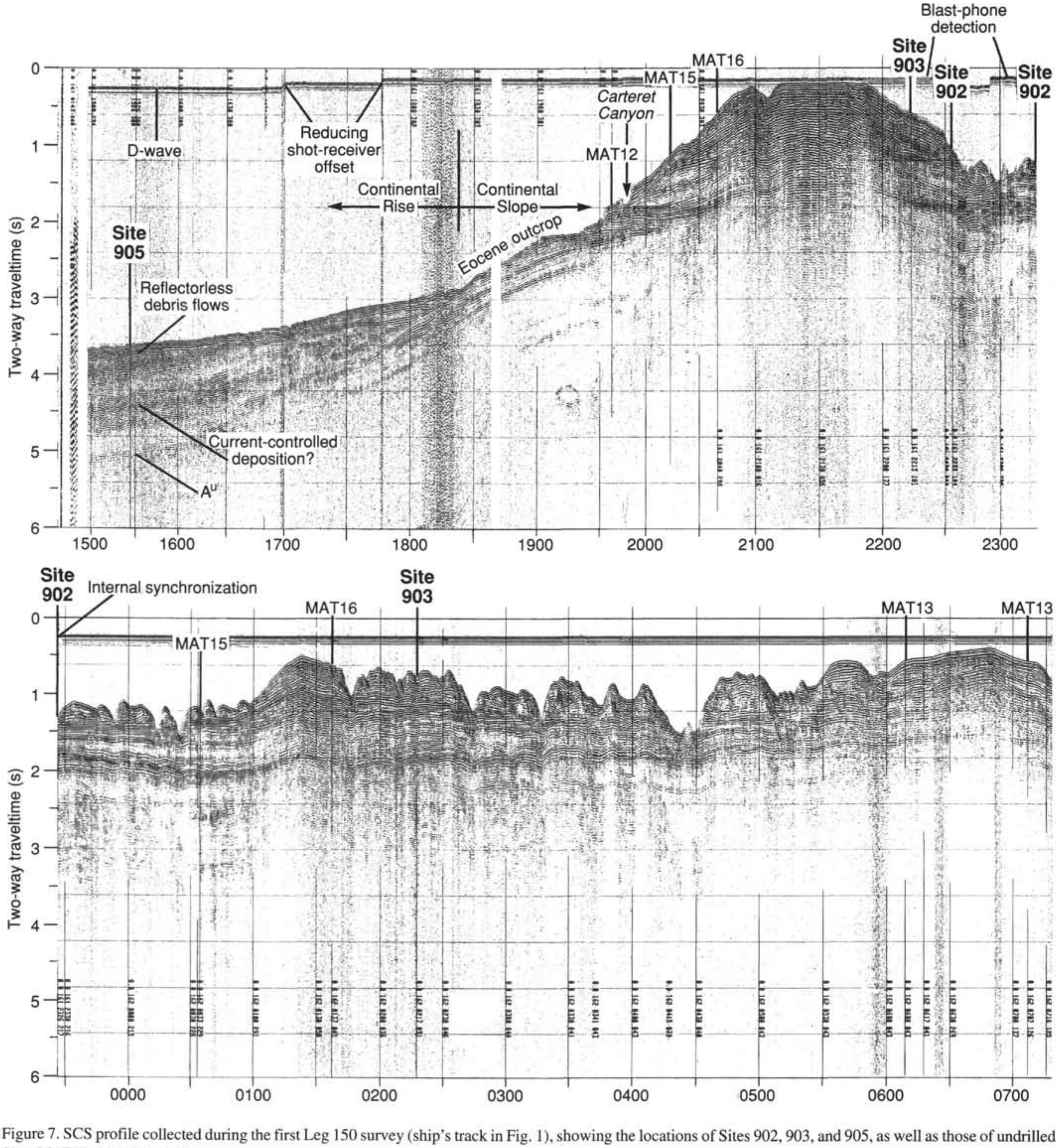

Figure 7. SCS profile collected during the first Leg 150 survey (ship's track in Fig. 1), showing the locations of Sites 902, 903, and 905, as well as those of undrilled Sites MAT12, 13, 15, and 16.

PDR Depths vs. Mud-line Depths

PDR depths corrected to sea level were consistently shallower than mud line depths adjusted to this same datum at all five sites drilled on Leg 150. Discrepancies between these two types of measurements are expected because the echo-sounder beam has a two-dimensional "foot print" that in steep terrain can receive a side echo as a "first return" (Fig. 4). Equation 1 shows the relationship between the PDR depth "D," the local seafloor slope "θ," and the true depth "D + X" detected by the pipe directly beneath the drill ship. Table 1 shows PDR and mud-line depths at each site and the local (but undetected) gradient that would account for the difference between the two depths. All calculated gradients are consistent with the known topographic relief in these areas. Though inaccurately measured pipe lengths could have been a factor, we conclude that the differences between PDR and mud-line depths were largely the result of the locally rugged terrain drilled on Leg 150.

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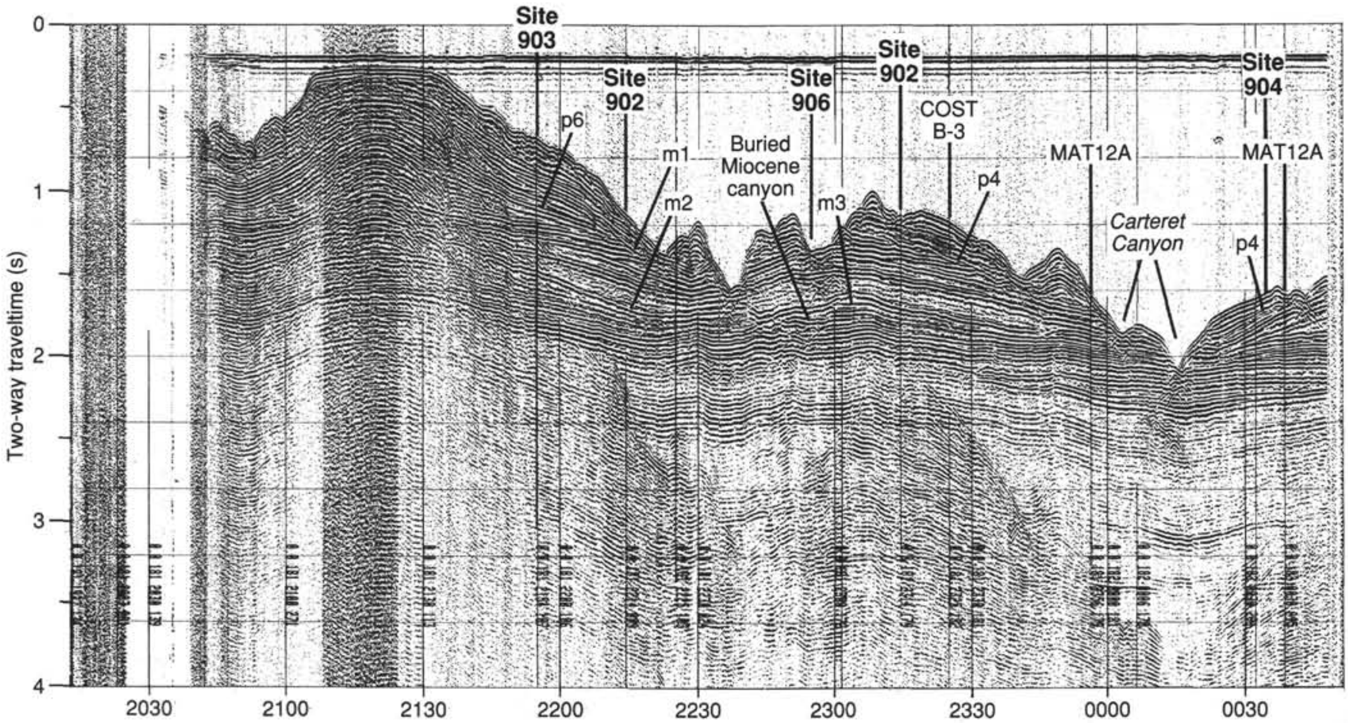

Figure 8. SCS profile collected during the second Leg 150 survey (ship's track in Fig. 2), showing the locations of Sites 902, 903, 904, and 906 plus the existing COST B-3 well. Undrilled Site MAT12A is shown (see text for detail).

Table 1. Precision depth recorder vs. mud-line depths to seafloor.

Site	PDR depth (mbsl)	Mud-line depth (mbsl)	Slope (degrees)	Gradient
902	792	815	13.6	1:4.1
903	443	456	13.7	1:4.1
904	1090	1134	16.0	1:3.5
905	2693	2709	6.2	1:9.2
906	918	925	7.1	1:8.0

Notes: PDR depths at each site have been corrected to meters below sea level by accounting for local seawater sound velocity and transducer depth. The depth to the mud-line below sea level was determined by the measured length of the drill pipe. The slope shown as degrees and as gradient was calculated according to Equation 1 (see Fig. 4) relating "first return" acoustic depth to true depth (i.e., PDR vs. mud-line depths). This calculated slope represents the local slope of seafloor required to justify the disagreement between the PDR and the drill-pipe measurements.

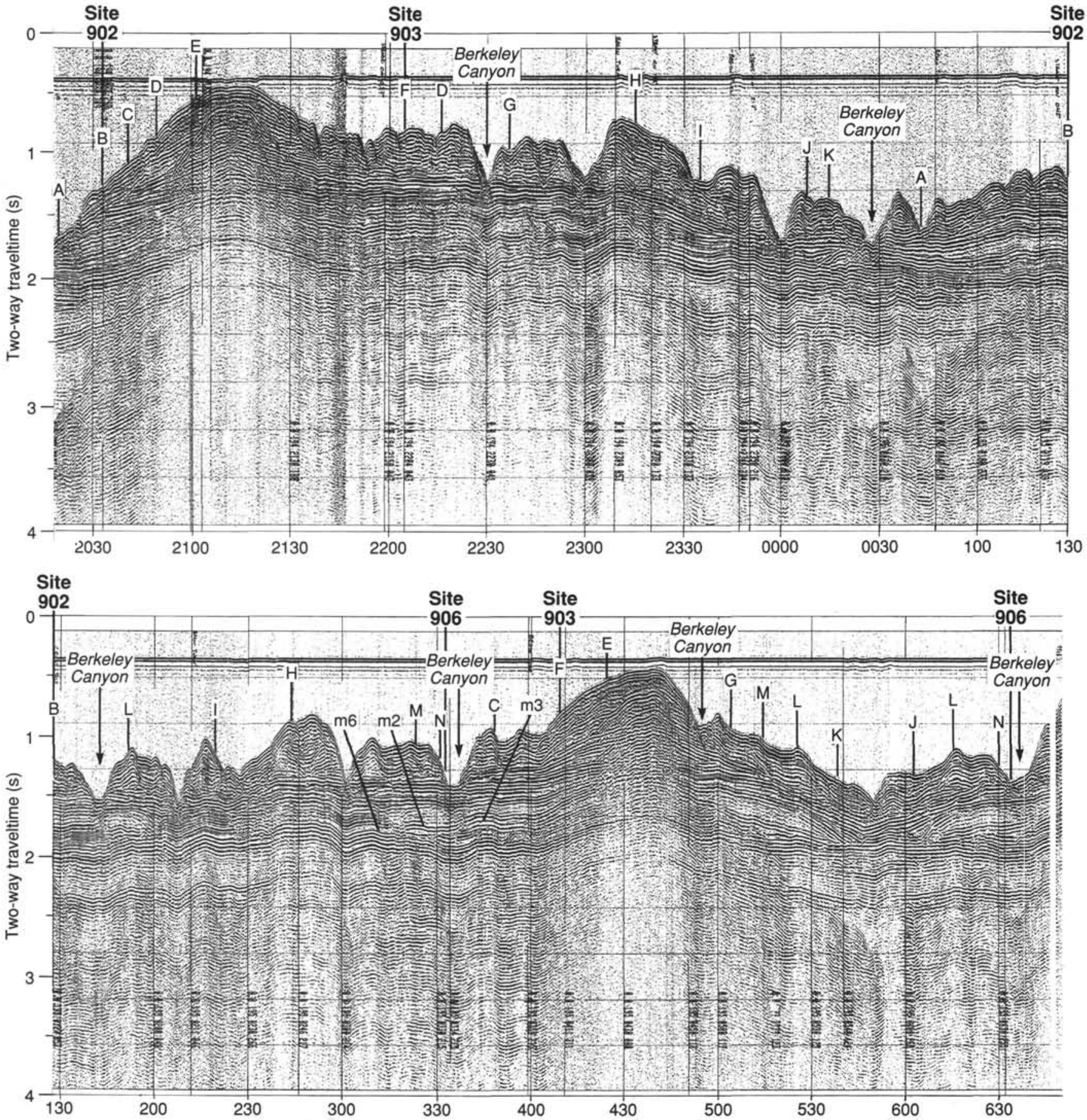

Figure 9. SCS profile collected during the third Leg 150 survey (ship's track in Fig. 3), showing the locations of Sites 902, 903, and 906. Capital letters refer to crossings within this survey grid.