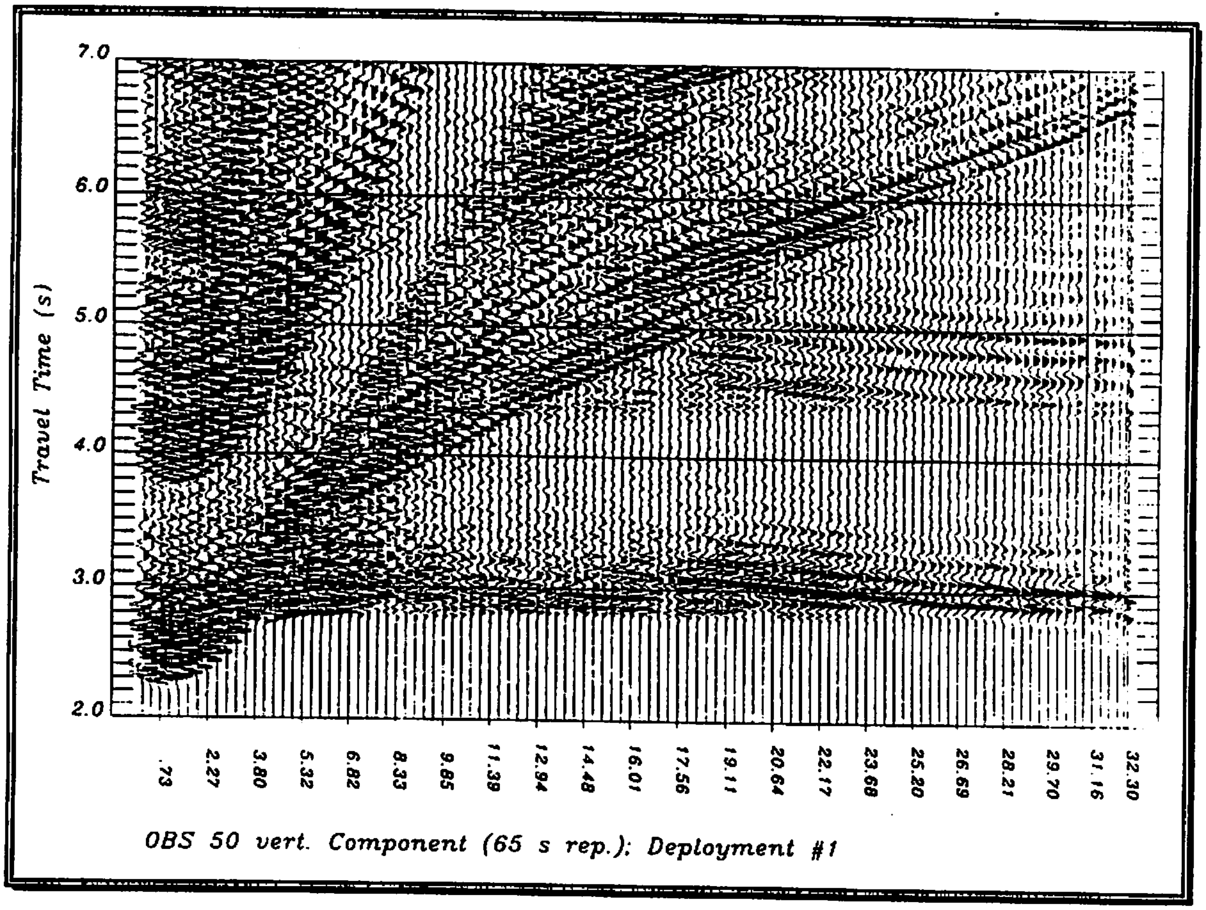
CRUISE REPORT

R/V *Maurice Ewing* Leg 94-16
San Diego, CA-to-Panama City, Panama
24 October 1994 - 26 November 1994

HOLE 504B OCEAN BOTTOM SEISMIC EXPERIMENT AND COSTA RICA RIFT SURVEY



OBS 50 vert. Component (65 s rep.): Deployment #1

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Summary

EW 94-16 carried out three major OBS seismic refraction experiments and very detailed MCS/SCS reflection profiling of the oceanic crust in and around Hole 504B in the Panama Basin (Figure 1). MCS and sonobuoy refraction data were also collected on a transect from Hole 504B to the Costa Rica Rift, 200 km to the north. This leg was successful in every major respect. This was the first time the WHOI ONR OBS have been used in a major, active-source seismic refraction experiment and the first time OBS and MCS operations have been combined on the *Ewing* in a single leg. The 38 OBS deployments and recoveries carried out over a two week period during this leg is unprecedented and represents a major operational achievement. This leg also demonstrated the feasibility of extensive at-sea processing of both seismic reflection and refraction data. Brute stacks of MCS profiles were produced in near-real time using a comparatively inexpensive HP 9000/700 series workstation running SIOSEIS. Over 800 km of SCS data were also plotted, fk migrated and interpreted at sea. OBS data were transcribed and reformatted into SEGY aboard-ship and complete record sections plotted for all of the geophone and hydrophone channels, ususally within 24 hours of instrument recovery.

The ONR OBS performed extremely well on all three Hole 504B experiments with over 94% recovery of high-quality hydrophone and three-component geophone data. Diving waves turning beneath the drillhole at depths near the layer 2/3 transition were recorded on several instruments and should provide excellent constraints on the depth to seismic layer 3. Excellent shear-wave conversion was observed in this area and several different S-wave phases were observed on both the geophone and hydrophone records that should provide good constraints on the shear wave velocity structure of the oceanic crust in this area. SCS and MCS reflection data acquired with the *Ewing's* 10-gun, 3005 cu. in. airgun array will provide detailed information on sediment thickness variations around Hole 504B and crustal reflectivity and structural variations from the 5.9 Ma crust around the drillsite to the Costa Rica Rift 200 km to the north. One unexpected result from the reflection profiling done on this leg is evidence for faulting within the sediment section near Hole 504B that suggests that basement faulting continues well out onto the flanks of the Costa Rica Rift. A 1-day Hydrosweep survey of the axial zone of the Costa Rica Rift will provide new information on the morphology and tectonics of this intermediate spreading ridge.

1.0 Scientific Objectives

The principle scientific objective of EW 94-16 was to obtain a better definition of the seismic properties of the crust in and around Hole 504B, the deepest hole drilled into oceanic crust, and to correlate these results with the *in situ* lithologic and physical properties measured in this hole. An additional objective of this leg (funded by ONR through a 5-day add-on to the original project) is to image seismic layer 2A at the Costa Rica Rift and trace its evolution off-axis to Hole 504B on approximately 5 Ma crust. The seismic studies conducted on this leg should lead to a better understanding of the origin and evolution of the fundamental seismic layering of the oceanic crust.

2.0 Operational Objectives

This leg has several unique and challenging operational objectives combining MCS and OBS operations on the same leg:

• During a 12-day period carry out 38 deployments and recoveries of the WHOI OBS for three active source refractions experiments at Hole 504B. This number of deployments of the ONR OBS in a single leg had never been attempted before.
• Use a modified 10-gun array and a single channel streamer to map sediment thickness and depth to basement around the drill hole. Previous airgun and water gun single channel studies in this area had limited success in defining basement structure.
• Use the 10-gun array and 160 channel MCS steamer to image crustal reflectivity beneath the 504B drill site
• Use a 1-day Hydrosweep survey of the Costa Rica Rift to determine the most favorable location for detection of layer 2A at the ridge axis
• Acquire MCS and sonobuoy refraction data along isochrons in crust of ~ 0-1 Ma, 2.2 Ma and 5 Ma, as well as a flow line profile bisecting each of the isochron profiles

3.0 Cruise Narrative

Monday, Oct. 24th (JD297) - The *Ewing* left the 10th Avenue dock in San Diego at about 1020L (1720Z) to begin EW 94-16. As we sailed out of San Diego harbor we had a very impressive view of the USN aircraft carrier Abraham Lincoln sailing into port. The pilot was taken off the ship at 1118L (1818Z), and we got underway at full speed for the Panama Basin. The lab watch was started at 1900L.

Tuesday, Oct. 25th (JD298) - Second day of transit south. Weather is fair with partly cloudy skies and a following wind and sea. We are making good time - about 11.6 kts over the last 24 hours. Experienced some minor problems with the 3.5 kHz recorder. Hallinan, Bailey and Collins work most of the day preparing the OBS instruments for an in-lab "100 Mbyte" test (writing 100 Mbyte of data to both disks on each instrument). This test, which will last ~47 hrs (170,000 s) begins at 2100L (0400Z). Dolan continues to work on the OBS data transcription program; Kent introduces everyone to PLTSEGY, and Greaves/Swift work on mapping sediment thickness around Hole 504B using the 1985 MCS data collected by Brocher & Collins.

Wednesday, Oct. 26th (JD299) - We continue to steam southeast along the west coast of Baja California, still visible off to port. Still making over 11 kts speed over the ground. Some problems with Hydrosweep freezing up this morning, but they were fixed after breakfast. Began some noise tests on the spare OBS acquisition unit. It does not show the same noise problems encountered back at Woods Hole.

Thursday, Oct. 27th (JD300) - Fourth day of transit. The log window on Moray froze up at 0000Z and the problem was not corrected until 1222Z. However, data (bathy, gravity, nav) were logged throughout this period. At 1510Z we stopped to do the first rosette release test. After a short delay to fix the Hydrowinch wireline counter, the rosette was sent down to 1000 m at 1539Z. All eight releases were successfully interrogated and released (#14744, 14748, 14152, 14160, 14156, 14737, 14153, 13652). A second rosette was sent down at 1659Z. All eight releases were successfully interrogated and released (#14164, 14113, 14165, 14147, 14118, 14734, 14127, 14738). By 1803Z the second rosette was on deck. About an hour was spent completing engine room cooling system repairs before resuming the transit. At about 1430L (2130Z) a life ring with a smoke bomb was accidentally launched by an ordinary painting on the bridge. The ship had to turn around to retrieve it before proceeding.

Friday, Oct. 28th (JD301) - Fifth day of transit. The "100 Mbyte" test was completed last evening. Ten of the thirteen instruments passed the test. One instrument lost power (SAIL loop problem?), a second appears to have had a problem with the serial link between the acquisition and recording packages; the third instrument recorded header information but no data. On Saturday we will try to track down these problems. John Bailey ran some additional noise tests on an acquisition package. The origin of the "1 sec spikes" is still a puzzle, although the latest tests show they are not present. Jim Dolan is working on the SEGY conversion program.

Saturday, Oct. 29th (JD302) - Sixth day of transit; beautiful weather continues. The two John's tracked down one of the instrument failures discovered yesterday to a bad "Rambo card" in one of the recording packages. All three instruments that failed the first test were rerun through a "50 Mbyte" test and passed. On Saturday night the ship's clocks were advanced 1 hour, leaving us +6 hours GMT.

Sunday, Oct. 30th (JD303) - Seventh day of transit. This afternoon we ran through the pre-deployment checklist for OBS 55, which will be deployed on Monday. The check-out went fine and in the process extensive modifications were made to the check-out form. It was programmed to turn on at 1100L (1700Z) and to shut off at 1530L (2130Z). By barbecue time OBS 55 was prepped and ready to be deployed.

Monday, Oct. 31th (JD304) - Today we carried out a full dress rehearsal OBS deployment and wireline-tested the remainder of the acoustic releases. At 0845L we reversed course and stopped near 11°24.906N, 94° 42.044W for the OBS test deployment. OBS 55 was launched at 0919L (1519Z) in 4068 m of water. The OBS reached the bottom at 1619Z and the release transponder was disabled at 1620Z. The sink rate was 67.8 m/min. We then steamed ~5 n.m. northwest of the OBS site and completed tests of the remaining 12 release transponders (#13653, 14143, 14511, 14129, 14134, 14745, 14150, 14142, 14148, 14125, 14157, 14159). All of the transponders passed this test. We then turned back toward the OBS position steaming at ~4.5 kts and began firing a single 540 cu. in. airgun every minute. Shooting began at 1946Z and was completed at 2102Z. We then retrieved the airgun and turned back toward OBS 55. We began interrogating the OBS at 2145Z starting first with S/N14113 then switching to S/N14164 using both master units but without success. At 2206Z we pulled the transducer and moved the ship to ~750 m range. We also lengthened the transducer cable. At 2223Z we received a response and at 2224Z we got a confirmed release. The OBS was on the surface at 0005Z (1805L) with a computed rise rate of 40 m/min. The recovery went very quickly and the OBS was on the deck by 0015Z (1815L). We then resumed our transit to the Panama Basin. Post-recovery checks of OBS 55 showed that the instrument worked as programmed; a nice airgun record was plotted out. Inspection of the data from seismometer channel 3 showed that the geophone sensor released from its deployment arm at approximately 1744Z, i.e., 2 hours and 25 minutes after the OBS was deployed.

Tuesday, Nov. 1st (JD305) - Continued transit. Weather is cooler, cloudy with occasional rain squalls, and swells of ~4 ft. Dolan and Collins worked on finalizing the data transcription program and successfully transcribed the ~20 Mbytes recorded in the test experiment. Instrument preparation for deployment on Saturday continued.

Wednesday, Nov. 2nd (JD306) - Weather continues cool, cloudy with occasional rain squalls. The true time GPS clock that drives the data recording and shooting from the main lab has not been working for about the last 3 days. Bailey and Francis repaired the antenna system and now both the GPS and GOES lab clocks are working. Based on an analysis of the test OBS data we will reduce the gain on the hydrophone channel on the floated instrument by about a factor of forty to avoid clipping (this instrument is only being used to record far-field source signature information). During the afternoon, anchors were attached to 9 OBS frames. The ship's crane on C deck was used to place each anchor on the deck and then to place an OBS frame on top of the anchor.

Thursday, Nov. 3rd (JD307) - This morning tests showed that acquisition S/N 19 was not functioning even though it previously had passed the 100 Mbyte test. The problem appears to be with the A/D board. We replaced this acquisition package with acquisition S/N 15. We had intended to use acquisition S/N 15 for the OBS deployments. On checking it out prior to doing the 100 Mbyte tests, we recorded anomalously low counts on the hydrophone channel, and consequently put it aside in favor of another acquisition package (S/N 11). Bailey worked on acquisition S/N 15 during the 100 Mbyte test and it appeared to work satisfactorily. We checked it out again this morning, and, again, it appeared to be working well. Dave Dubois and Karen Reiner purged all of the acquisition and recorder pressure cases that we will use for the first OBS deployment.

At 1030L (1630Z) we reached the first way point for the one day Hydrosweep/ watergun SCS survey Carolyn Mutter planned to carry out at the Costa Rica rift axis. The watergun was deployed at 1047L but we experienced problems with getting the DSS 2000 to fire the watergun. These problems were fixed by 1155L. SCS line 01 was begun at 1500L (2100Z). Francis was unable to get the DS2000 to record only 2 channels of data; the only way he could get it to work was to record all 180 channels with the SCS data on channels 173 and 174. Obviously this is not ideal since we will consume vast amounts of tape recording SCS. We later realized that the Nav tape could be programmed to record channels 173 and 174 thus bypassing the need to record anything on the Data tape. We tried this, and after some messing around by Graham, were able to read the SCS data off of the Nav tape using SIOSEIS.

During the afternoon, ten of the thirteen OBS were loaded with acquisition and recorder pressure cases, geophones, and hydrophones. Beecher Wooding had previously loaded all 13 of the OBS frames with acoustic releases and recovery aids (flashers, radios, etc.). One of these 10 OBS will be deployed on a tether 1 km long. The anchor for this OBS will be attached to the Kevlar line immediately prior to deployment. John Hallinan took a small amount of data on each of the ten fully configured instruments and determined that they were all working satisfactorily. The remaining 3 OBS frames will be loaded after we begin deployments.

Friday, Nov. 4th (JD308) - Still continuing a Hydrosweep survey of the Costa Rica rift axis. The topography is surprisingly rugged with the ridge axis characterized by a narrow, deep valley on most crossings and flanking topography of up to 500m. The ridge axis is hard to recognize in the Hydrosweep data but can be clearly identified in 3.5 kHz and reflection records from the inward-facing direction of off-axis scarps. More firing problems with the DSS-2000. Apparently the 2nd mate inadvertently logged into the nav system to enter way points through a port also used by DSS-2000, freezing the system. Firing was interrupted from ~1740-2039Z.

Friday evening at about 1800L we received a FAX from Michael Rawson at Lamont telling us that Carolyn Mutter's program on the Costa Rica Rift, which we had been doing for the last day, was in Columbian territorial waters (about 175 mi from the tiny, uninhabited island of Malpelo which is itself almost 200 miles off of the coast of Columbia). We were advised that we could complete the present survey, however we were told "not to proceed any closer to Malpelo Island and further work should be in a direction which will return you to international waters". The Captain interpreted this message to mean that if we left the CRR we could not return. Thus if we followed our original cruise plan Carolyn Mutter would have lost most of her program since we would have been unable to return to the CRR later in the leg to complete her MCS work. Not wanting to do this, we decided to carry out the remainder of her program on the CRR despite the fact that this would entail a 4 day delay in the beginning of our refraction work at Hole 504B..

Saturday, Nov. 5th (JD309) - At 0111Z the CRR Hydrosweep survey was completed and we turned into the wind to retrieve the SCS gear and to prepare for MCS deployment. It took about an hour to clear OBS on the fantail so the MCS streamer could be deployed. The tail buoy was launched at 0238Z. The streamer deployment continued through the night and was not completed until just before breakfast (1347Z). The deployment went comparatively slowly, mainly because 1 lb lead ballast were put on the streamer at 25 m or 50 m intervals (over 200 lbs in total) to compensate for the 28°C water temperatures. We replaced one section damaged on the last leg, and exchanged two more to end up with 3 km of "new" Canto sections and 1 km of the old style with external cans. By 1603Z all 10 guns were in the water. The first CRR MCS line was begun at 1734Z. MCS data acquisition continued through the rest of Saturday.

John Hallinan recorded some data on all 13 of the OBS tied down on the fantail and determined that all were working satisfactorily. In the morning, John Bailey and the Bosun covered all of the OBS with tarps to try to prevent the electronics from overheating in the hot sun.

Sunday, Nov. 6th (JD310) - Continuing with Carolyn Mutter's CRR MCS survey. Late this morning we began working our way south of the ridge axis toward Hole 504B. The streamer is towing extremely well at about 10 m depth over its entire 4 km length with only the last bird or two running shallow. The 10-gun, 3005 cu. in. airgun array is working fine with the guns firing at about 7 m depth. We have been able to maintain shooting at a 13 s interval using just one compressor running at peak output. The DMS2000 recording system has behaved reasonably well, but is still experiencing occasional tape swapping errors and unexplained and frustrating altered processor states. This has been a particular problem at line changes. We therefore are letting the system record through turns and are just noting for the log the start and stop times and shot numbers of the lines.

John Hallinan recorded some data on all 13 of the OBS and determined that all were working satisfactorily.

Monday, Nov. 7th (JD311) - Continued working our way south toward Hole 504B doing Carolyn Mutter's CRR MCS survey completing flank surveys on 0.75 Ma and ~2.2 Ma crust. The MCS system is working flawlessly at the present time. John Bailey calibrated the OBS clock with the lab GPS clock and showed that they were reading the same time. Our daily testing of OBS on the fantail found one instrument (recorder S/N 38) whose hard disk failed to spin up. Hallinan brought the malfunctioning recorder into the lab; Disk #1 on the bottom of the two-disk stack had slipped forward out of the chassis, although the lock was engaged. The disk chassis is connected, via mounting blocks, to the two parallel rails that run lengthwise on the outside of the recorder package. It appears that tightening the chassis mounts to the rails pulls the chassis (and locking cylinder) away from the disks, allowing the disks to slip out of the chassis. The mounting blocks should be thicker. As a temporary measure we decide to wedge the disks in place with foam padding.

Tuesday, Nov. 8th (JD312) - Today we completed Carolyn Mutter's CRR MCS survey with a third flank survey on ~5 Ma old crust. Her final line was completed at 1600L (2100Z). We then transited about 90 minutes and began the first of 6 MCS lines to be shot in the Hole 504B area at 2228Z. These lines were shot at a nominal ship speed of 4 kts with the 10-gun, 3005 cu. in. airgun array, a shot interval of 15 s ($\pm$ 250 ms), and a record length of 10 s. At this speed the streamer towed well at about 10 m depth although the first and last few sections of the streamer were sometimes too shallow. The gun depth was about 7-10 m. Graham was able to generate brute stack sections and on-screen plots within a few minutes of the completion of each line... pretty amazing!

John Bailey checked the Seascan clocks in the OBS and found that one (acquisition S/N 23, Clock S/N 18) was not working correctly. On opening the acquisition package, Bailey discovered that the Seascan clock was not connected to its 18 V battery pack. The 18V battery is the "keep-alive" battery that powers the clock when the primary battery in the recorder package dies. (The 18V battery is also used to power the clocks while the instruments are being shipped.) In addition to the 18V battery, every clock has a 9V "switch-over" battery that powers the clock when the 18 V battery is being replaced. This battery is a backup to the 18 V backup battery. The OBS on the fantail are not powered up, and the clock in each acquisition package should be running from the 18 V battery. In the case of acquisition S/N 23, the 18V battery was never connected to the clock, and the clock was powered from the 9 V battery. This battery failed sometime since the acquisition package was loaded on the frame. Fortunately, the 3V battery which powers the oscillator in the event that all of the other batteries fail was still charged (2.8V). The loss of the 9V battery meant that the correction factors loaded in the clock's microprocessor were lost. Bailey has been tracking all of the clocks and was able to reload these factors.

In Hallinan's daily testing of the OBS, one of the hydrophone channels recorded what appeared to be "un-earth like" signals. Bailey replaced the hydrophone cable connecting the hydrophone and the hydrophone preamp. The data recorded after this fix appeared more reasonable. It is possible that the old cable did not marry sufficiently well to the hydrophone.

<u>Wednesday, Nov. 9th (JD313)</u> - Continued with MCS survey of Hole 504B area. In total we ran 5 N-S lines (called line Hole504B01, segments A-E) and 1 E-W line (line Hole504B02 segment B). There was a strong south flowing surface current (~0.9 kts) in this area which meant that we could manage 4 kts or less speed over the ground on the South-to-North lines (B and D) but generally 4.5-5 kts speed over ground on the North-to-South lines (A, C, E). We found that if the speed through the water was less than ~4-4.5 kts the guns towed too deep (>10-12 m). At 2353Z (1853L) we completed the MCS survey and began recovering the streamer. Even before the streamer was aboard, Graham had produced brute stack sections of all of the 6 line segments. The data look excellent with a clear Moho event on parts of all lines as well as several intriguing dipping events.

<u>Thursday, Nov. 10th (JD314)</u> - The MCS streamer took about 4 1/2 hours to recover. We removed four compass sections and repaired two leaks. The streamer was aboard by 0430Z. We then commenced what was planned to be a 12 hour SCS survey. Line 504B03 segments A-E were planned as E-W lines beginning in the southern part of the study area and working north. The single channel streamer was deployed without a weighted section at the head. The SCS streamer is configured with a 188 m leader, a 25 m stretch section, and four active sections totaling 137.5 m (12.5 m, 25 m, 50m and 50 m). The data are recorded on DMS2000 data tapes on channels 4 (raw data) and channel 5 (attenuated by a factor of 20 across the entire frequency band of 0-160 Hz (note: a total of 8 channels are recorded on the data tape; channels 1-3 and 6-8 are dummy channels). We acquired the SCS data using the 10-gun, 3005 cu. in. array fired every 13 s. We used a 2 ms sampling rate and recorded 6 s records. During the first segment we experimented with different towing speeds and settled on ~5-5.5 kts as the best speed. At this speed the guns tow at 5-6 m depth. The first segment was begun at 0714Z. Two segments were completed before breaking off segment 3 at 1313Z to head north for an hour while the OBS frames were repositioned on the fantail. We resumed the SCS survey at 1425Z and ran two E-W profiles (D and E), completing them at 1914Z. The airguns and SCS gear were recovered and we headed for the first OBS deployment site.

The first OBS (#54) was put over the side at 2034Z. All of the instruments were deployed using the ship's crane through the main A-frame. When we were within ~100-200 m of the drop site, the frame was lifted over the side into a "launch" position. When the ship was <50 m from the site the instrument was released. For all but the last three deployments we waited on-site until the instrument hit bottom before disabling the release transponders. The deployments went quite smoothly. Only two problems were encountered. The cable connector on the geophone orb for OBS 63 had been over-tightened. The orb had to be replaced, and the instrument reprogrammed, before launch.

The deployment of OBS 58 took longer than usual since ~1000 m of Kevlar line had to be let out in order to tether the instrument 1000 m above the bottom.

Friday, Nov. 11th (JD315) - The last OBS was deployed at 1314Z. In total, deployment of the 13 instruments took ~17 hours or about 7 hours less than we had budgeted. A summary of instrument positions, water depths and deployment and recovery times is given in Appendix 8. Since the instruments are programmed not to turn on until 2300Z, we took advantage of the extra time to complete the two E-W SCS profiles that were not done yesterday before beginning shooting for the OBS refraction line. These lines were called Hole504B04 segments A, B and C. The last of these lines was completed at 2008Z. We then headed to the western end of the first refraction line while rigging the 20-gun array for deployment.

Saturday, Nov. 12th (JD316) - The first airgun shots were fired at the western end of the first refraction line at 0018Z as we maneuvered into position. This line (Hole 504B05 -A and B) will be shot twice, once with the 20-gun, 8420 cu. in. array firing at a 65 s rep rate (~150 m shot spacing at 4.5 kts) and a second time with a 43 s rep rate (~100 m shot spacing). We recorded both lines on the SCS streamer (2 ms sampling rate, 6 s records). The first line segment (Hole504B05-A) was begun at 0109Z and completed at 0719Z. There were several problems with the guns during this line. At 0520Z guns 1-5 were turned off due to an air hose leak. By 0533Z, guns 1 and 3-5 were back on. At 0612Z gun 17 was pulled to replace the shuttle. During the second segment, which began at 0818Z and was completed at 1414Z, the guns performed flawlessly. With some time still remaining until the OBS turn off (1900Z), we decide to shoot SCS along the refraction profile. The gun array was changed back to the 10-gun configuration. This line, called Hole504B06, was begun at 1528Z and shot from west to east ending at 2054Z. During this line at 1735Z the SCS monitor display showed at sudden drop in amplitude. A check of the SCS streamer revealed that channels 1 and 3 had no signal, although channels 2 and 4 appear to be working properly. The digital recording was adjusted to sum channels 2 and 4 only. Bruce will work on the SCS while we recover the OBS.

At 2100Z we turned back toward OBS 59 and began retrieving the guns and SCS streamer. The OBS will be recovered from east to west in the opposite order they were deployed.

Sunday, Nov. 13th (JD317) - Retrieval of the OBS's from the first deployment began at 2246Z, Nov.12 when OBS # 59 was released from the bottom. The entire operation, involving the recovery of 12 instruments took approximately 27 hours. We broke into two teams of four people each to conduct the retrieval operations. The teams were on duty for ~6-7 hours at a time. A check list was developed for the teams to follow with each instrument. This strategy worked very well, giving people sufficient rest during this long operation while at the same time keeping track of the status of the check-out, data transcription, and turn-around operations.

The amount of time it took to retrieve the OBS's from release to retrieval varied between one hour forty-four minutes and one hour fifty-eight minutes. We experienced no serious problems with the release transponders. Rise rates were well approximated by the 40 m/min estimate derived from our test deployment. Recoveries were done off the starboard waste deck and were usually done within 15-20 min of the instrument surfacing. The recording packages were then debriefed, afterwhich the frames were "J-bared" to the fantail. At that point the recording packages were removed from the frame into the lab. They were allowed to thermally equilibrate for ~3 hours before they were opened, and the disks removed for data transcription. While this was going on we steamed to the next OBS site and recalled that instrument.

Only a few problems were discovered during our preliminary assessment of instrument performance (Appendix 8). The geophone package on OBS 61 did not deploy (the sugar had not been drilled) and on OBS 64 the geophone package appeared to deploy sometime during the experiment (two rust marks on the RSLI). OBS 57 appeared to stop writing to disk during the second shooting line. Further data evaluation is planned prior to the next deployment.

While we were recovering the OBS, Bruce Francis looked at the SCS to track down the problem with channels 1 and 3 identified on Saturday. He found and repaired two bent connector pins that appear to have been the source of the problem.

Shortly after dinner the Captain and Chief Engineer reported to me that one of the four propulsion motors on the Ewing had failed earlier in the day. They are not optimistic it can be repaired but would need ~6 hours during which we would have no propulsion to try to fix it. It will not affect current operations but might reduce our transit speed to Panama at the end of the leg. I asked that the repairs be deferred until later in the leg and the Captain agreed.

<u>Monday, Nov. 14th (JD318)</u> - At 0308Z, the last OBS had been retrieved and we began a 1-day SCS survey. This set of profiles (called Hole 504B07) consists of 7 E-W lines to be shot over the northern half of the study area. This line started at 0231Z and was completed at 2213Z. At the beginning of the last profile (G) the SCS signal disappeared. Bruce traced the problem to a shorted cable from the wet staging area to the main lab.

While these lines were being run anchors were being places on the frames, and the frames were loaded with the data recording units in preparation for tomorrow's deployment. Jim Dolan reformatted all of the OBS data from the first deployment to SEGY and Graham produced record section plots using PLTSEGY. The data quality from nearly all of the OBS is excellent (the only exceptions were OBS 61, 64 and 57 noted above, plus the geophone channels on OBS 53 which were ringy probably due to poor coupling). The S/N on the 65 s rep rate data is noticeably lower with the 43 s rep rate due to prior shot noise.

Beginning at 2300Z we stopped all science operations while the ship's engineers repaired the broken propulsion motor. These repairs were completed by 0430Z. At this point we re-deployed the SCS gear and 10-gun array and shot the N-S refraction line (this SCS line is called 504B08).

<u>Tuesday, Nov. 15th (JD319)</u> - Line 504B08 was completed at 1110Z. The airguns and SCS gear were recovered and we steamed to the southernmost OBS position on the N-S refraction line. The first OBS was over the side at 1340Z. Unlike the first deployment, we disabled the transponder when the instrument reached 500 m depth rather than waiting for it to reach the sea floor. This resulted in a considerable time savings. All twelve OBS were deployed in only 6 hours. The only incident during the deployment occurred when a geophone package (S/N 28) fell to the deck when a frame was being moved on the fantail just prior to deployment (the arm had not been secured to the bale). The geophone package was badly damaged and had to be replaced. At 2023 we began ~9 hours of SCS on N-S trending profiles (504B09) until the instruments turn on at 0800Z on the 16th.

<u>Wednesday, Nov. 16th (JD320)</u> - SCS profile 504B09-C was completed at 0421Z. From the end of this line we steamed to the southernmost point of the 50-km, N-S refraction line. While doing this the 10-gun array was swapped out for the 20-gun array. Three shooting lines are planned, one using the 20-gun array fired at 65 s rep rate, a second at 84 s rep rate, and a third using the 10-gun array and a 65 s rep rate. These shooting profiles will be called 504B10-A, B and C, respectively. We began shooting profile A at 0755Z and completed it at 1412Z. Segment B began at 1506Z and was completed at 2236Z.

<u>Thursday, Nov. 17th (JD321)</u> - After swapping out the 20-gun array, shooting profile C was begun at 0019Z and completed at 0612Z. We then steamed south collecting another

N-S SCS reflection profile (504B11-A) before beginning to recover the OBS from the second deployment at 1230Z. These recoveries continued through the rest of the day.

Friday, Nov. 18th (JD322) - The thirteenth, and final OBS was brought aboard at 1543Z. The entire recovery operation took a little over 28 hours. The recoveries generally went quite smoothly. Both transponders on the tethered instrument (OBS 58) had to be released and one instrument (OBS 54) had a radio beacon that did not work. Within 4 hours of the last OBS recovery all of the instruments had been debriefed, all of the data transcribed to Exabyte tape, and all the OBS (except two with recording problems) rebatteried and readied for redeployment. We were plotting record sections by evening. Three instruments had disk data abnormalities that we are investigating further (OBS 59, 57 and 64). Comparison of record sections produced using the 20-gun array fired at 65 and 84 sec, and the 10-gun array fired at 65 sec, indicated that the 20-gun/84 sec rep rate is the best combination - especially for longer range P-wave arrivals and S-wave arrivals.

After recovering the OBS we began a 36-hour SCS profiling survey, focusing primarily on N-S profiles (Line 504B12 profiles A-I).

Saturday, Nov. 19th (JD323) - We continued with SCS profiling most of the day. Line 504B12 was completed at 1457Z, after which we began a series of E-W profiles that fill in the gaps in our previous survey (Line 504B13A-F). This morning anchors were placed on all of the OBS frames and right after lunch recording packages were mounted on all of the OBS frames. We began programming the instruments in the early evening in preparation for deployment #3 which began at 1031L and continued through the night.

Sunday, Nov. 20th (JD324) - We completed the third OBS deployment at 1021Z. Only one significant problem was encountered with OBS 58. The acquisition package on this frame would not pass pre-deployment tests. The problem was eventually traced to a by-pass put in acquisition circuitry when the instrument was configured for source monitoring (hydrophone only) during deployment #1. This was corrected and the instrument passed all pre-deployment tests. The entire deployment operation took about 7 hours.

We began streaming gear about 1400Z and shortly after 1500Z began shooting and maneuvering for the first of two circle shots. These experiments ("line" 504B14) were navigated by keeping a constant range (at 4.5 km and 7.5 km, respectively) from OBS 60 which was located at Hole 504B. A laptop computer display of the ship track and range to this position helped the helmsman steer this unusual tack. The better helmsmen could keep the ship within 20 m of the desired range; usually the ship was within 50-75 m of the target range. However, in a few cases the ship wandered ~200 m off course.

Monday, Nov. 21st (JD325) - The second, larger radius circle shots were completed at 0150Z. We then began shooting a pattern of straight lines in a grid pattern over the OBS array. These profiles will have the line number 504B15. Segments A-D (working from north to south) were run without incident. However, at ~1100Z the DSS-2000 CSRU crashed stopping SCS data acquisition; at 1120Z the guns stopped firing about 2 miles short of the eastern end of segment E. At 1153Z the guns were restarted just before reaching the end of segment E. Bruce Francis traced the DSS-2000 recording problem to a bad "holo board" in the digital acquisition system. However, when this board was replaced and the system was rebooted, the guns began to fire only intermittently from 1229Z on. Rebooting the DSS-2000 repeatedly failed to solve the problem. For the next six hours this intermittent shooting continued until the guns were finally shut down at 1845Z. Bruce called both Lamont and Digicon for advice but none of the suggested fixes worked. Finally, it was decided to fire the guns on internal trigger and bypass the digital acquisition system. This required changing the maximum allowed shot interval in the

TAGS system to 65s. With advice from a former Digicon programmer, Buddy was able to make this modification.

The system was rebooted at 2017Z and the guns began firing regularly (although we are no longer collecting SCS data). At 2037Z we began reshooting segment F from east to west. This arrangement work fine until ~2153Z when the guns stopped firing again. The TAGS console was hung up in "fire" mode. The TAGS was rebooted and shooting resumed at 2203Z. We finished segment F and turned onto segment G. However, the system crashed again at 2346Z. It was rebooted and firing again by 2351Z; segment G was competed at 0018Z. These crashes appear to have been caused by a counter in the TAGS module which limits the number of internally triggered shots to ~100. Working on this theory we decided to shoot the remainder of the profiles by rebooting the TAGS module just before the segment begins and speeding up to ~5 kts. This would allow us to collect an entire profile without having to reboot the system. Using this procedure, we began to shoot the N-S profiles (segments H-L).

Tuesday, Nov. 22nd (JD326) - Segments H-L (N-S profiles) were run without incident through the early hours and morning on Tuesday followed by diagonal segment M. We then reshot parts of segments E and F with missing shots (eastern and western parts of these profiles, respectively). Following this we ran the second diagonal profile (segment N) then had time for a sixth N-S profile bordering the eastern side of the area (segment O). Shooting operations were concluded at 1949Z, the airguns and SCS were recovered, and we commenced OBS recovery operations. The first OBS was released at 2116Z.

Wednesday, Nov. 23nd (JD327) - Continued with recovery operations throughout today. After each recovery the acquisition and recording packages were moved into the lab, the OBS frame was stripped, and the gear was prepared for shipment back to Woods Hole. While these recoveries were going on Bruce Francis and Chuck Donaldson troubleshot the DSS-2000 system and found a bad chip in the system interface box. Once this chip was replaced the gun firing system appeared to work normally.

Thursday, Nov. 24nd (JD328) - Thanksgiving. The last OBS was on deck at 0142Z. This is the 39th successful deployment and recovery on this leg - a new record! After completing the recoveries we spent the next 6 hours collecting SCS reflection data along some of the shooting lines used in deployment #3. This line (504B16) consisted of three E-W profiles. Shooting began at 0232Z and was completed at 0831Z. The gear was recovered and at 0911Z we got underway for Panama. At 0903Z as we approached Columbian territorial waters, logging of Hydrosweep, magnetics, ADCP and CO_2 was suspended and the lab watch was terminated.

Friday, Nov. 25th (JD329) - Continued transit to Panama. Everyone began packing up the lab and writing their cruise report sections. Left-over turkey sandwiches for lunch.

Saturday, Nov. 26nd (JD330) - At 0800L arrived off Panama City. However, a docking berth was not immediately available and we spent about 3 hours anchored offshore. A pilot boarded about 1100L and the first line was over the side at 1203L. End of the saga of EW 94-16.

4.0 Preliminary Cruise Assessment

4.1 Hole 504B Experiment

OBS operations and data quality

The Hole 504B cruise was the first time the WHOI ONR OBS were used in a major seismic refraction experiment. All previous experiments using these instruments consisted of either ambient noise or microearthquake monitoring studies, and typically involved deploying all of the OBS once only on a leg and recovering them later on a second cruise. For the 504B experiment, 13 OBS were deployed and recovered three times, a total of 38 deployments and 38 recoveries over the course of a two week period. Including the test deployment of one OBS, a total of 39 deployments and recoveries were successfully carried out on EW 94-16. This represented a substantial challenge, not only to carry out the deployments and recoveries, but also to rapidly diagnose and fix instrumentation problems, and to assess data quality. Instrument check-out and preparation began back at WHOI at least 3 months prior to the cruise. The extensive shore-side and shipboard OBS tests are described in Appendix 4.

The gains of the geophone and hydrophone channels were chosen on the basis of the test deployment of one OBS prior to arriving at Hole 504B. The test deployment was carried out on Oct. 31st near 11°24.9'N, 94°42.0'W. OBS #55 was deployed in 4068 m of water and a short (maximum shot/receiver range was ~6.5 km) refraction line was shot using a single 540 cu. in. airgun. The test deployment was very encouraging in that the OBS worked satisfactorily (Appendix 6). Using the A/D counts generated by the 540 cu. in. airgun as a reference, we estimated the A/D counts that would be generated by the full 20-gun array using John Diebold's (L-DEO) airgun array signature program.

The operational goals of the seismic refraction program were to carry out three independent experiments in the immediate vicinity of Hole 504B. Two of the three experiments consisted of conventional refraction lines whereby the 13 OBS were deployed in a linear array centered at the Hole and the shooting pattern was a line extending along the OBS array (Figure 2). These experiments were designed to measure the seismic velocity structure at Hole 504B. For the third experiment, 13 OBS were deployed in a rectangular grid centered south of the drill site (Figure 3). This experiment was designed to measure the variation in the shallow velocity structure in the vicinity of 504B.

For the first experiment, the 13 OBS were deployed along an azimuth of 095°-275°, at ranges of 2, 3, 4, 6, 8 and 9 km on both sides of the drillsite (Figure 2). This azimuth is parallel to the strike of the magnetic anomalies and of the basement topography in the region of Hole 504B (north of the 504B area, the strike of the topography and the magnetic anomalies is E-W, parallel to the Cost Rica Rift). By deploying the array along the topographic strike, we hoped to minimize the effect of along-profile topography. The shooting line for this experiment extended 25 km on both sides of the drill site. One OBS was modified to record the hydrophone channel only, and was deployed on a 1 km long tether at the drillsite. This instrument was used to measure the source signature of the *Ewing* airgun arrays (Appendix 2). Because of the requirement to record the direct arrival without clipping, the gain on the hydrophone channel was reduced from x10^3 to x2. The line was shot with the 20-gun array at shot intervals of 65 and 43 seconds. At a nominal ship speed of 4.5 knots, these shot intervals corresponded to shot spacing of 150 and 100 m, respectively. Much of the line was also shot with the 10-gun array at a shot interval of 13 s at a ship speed of 5 knots.

The locations of the OBS relative to Hole 504B were carefully chosen to sample energy turning in the crust below the drillsite. These locations were determined by ray tracing through the upper crustal velocity model of Little and Stephen (1985) and the whole crustal model of Collins et al. (1989). Pending the analysis of the data collected on this cruise, these models are currently the best available for Hole 504B. Ray tracing through the former model demonstrated that an OBS located ~3 km from the borehole (i.e. at a shot-receiver range of ~6 km) would sample P-wave energy turning beneath the drillsite at a depth of ~1.6 km. Assuming that the layer 2/layer 3 boundary lies within 1 km of this depth, OBS located at 2, 3, and 4 km from the Hole 504B should allow us to record diving-wave arrivals turning at this seismological boundary beneath the drill site. A similar analysis for the S-wave velocity-depth model showed that OBS located at 2 and 3 km from the drillsite should sample S-wave energy turning at the layer 2/ layer 3 boundary below the drill site. Ray tracing through the whole-crustal model showed that OBS positioned 8-9 km from Hole 504B would record wide-angle reflections from the Moho directly beneath the drill site. The OBS located ~6 km from the drill site was positioned to sample energy turning with layer 3 beneath the borehole.

For the second experiment, the OBS were deployed along an azimuth of 005°-185°, at the same ranges from the drill site as for the first experiment (Figure 2). This azimuth is parallel to the lithospheric flow lines at the time the crust in the vicinity of 504B was accreted. As for the first experiment, the shooting line for this experiment extended 25 km on both sides of the drill site. The source-monitoring instrument was not recovered at the end of the first experiment and remained deployed throughout the second experiment. This OBS was recovered at the end of the second experiment and reconfigured to its normal state. This line was shot with both the 20-gun and 10-gun airgun arrays. For the former array, the shot intervals used were 65 s and 84 s. At ship speeds of 4.5 knots and 3.5 knots, respectively, both of these shot intervals correspond to shot spacing of 150 m. The line was also shot with the 10-gun array at a shot interval of 65 s and a ship's speed of 4.5 knots. A comparison of noise levels on record sections constructed for these various airgun sources and firing intervals is given in Appendix 3.

For the third experiment, 13 OBS were deployed in a rectangular grid of dimension 11 x 7 km with the long axis oriented 005°-185° and with a midpoint located ~3 km south of the drillsite (Figure 3). This experiment had three components, comprising a number of conventional 2-D refraction profiles, a tomography study, and two circular shooting lines. By shooting along circles of radii 4.5 and 7.5 km from the borehole to an OBS deployed at the drill site, we aimed to determine the degree and scale of lateral heterogeneity of the upper crust in the vicinity of the drill site. If the crust is laterally homogeneous and isotropic then arrivals from a circle of shots at a constant range from the receiver should be identical. The second component to this experiment comprised 12 x 15 km lines, each shot directly over 2-3 OBS. Data from these short lines will provide a set of 1-D velocity models that will provide a starting model for the tomography study. All of the shots recorded during this experiment, will be used for the tomographic study. The OBS were located so as to allow the comparison of the velocity structure beneath the drill site with the velocity structure of an uplifted fault block to the south of the hole. This experiment was shot with the 20-gun array at a ship's speed of 4.5 knots, corresponding to a nominal shot spacing of 150 m.

Within 5-10 minutes of recovery, every OBS was debriefed to determine clock drift and the amount of data recorded. About 20 seconds of data collected mid-way through the experiment were plotted as a crude check on data quality. Three hours after recovery, the recording package having warmed to near ambient temperature, the disk(s) were removed. The first task was to write a byte-for-byte copy of the data onto Exabyte tape. This step, which was done twice, was carried out with the program "obs_transcribe.c" (Appendix 14) Next, the data on each disk was read with the program "obs_disktest.c". This program checks that each data header is in the correct location and that the time in each data header has the appropriate value. It does not check data quality per se. Finally, some of the transcribed data were read from tape and plotted to check that the data was written correctly to tape and as an additional check on data quality. After recovery of the last OBS, and before the next deployment, data from selected OBS were reformatted to SEGY and complete record sections for all the geophone and hydrophone channels were plotted with the SIO program "pltsegy.c". The reformatting step was carried out with the program "obs2segy.c" (Appendix 14).

In general, the OBS performed very well (Appendices 7-9). Every OBS recorded at least one useful channel (geophone or hydrophone) and most instruments recorded good three-component geophone data on all three deployments. In total we recorded 182 channels of data during the three experiments (38 OBS x 5 channels/OBS - 8) and achieved 94% recovery of high quality data. Some of the remaining 6% of the data is still usable (e.g. at least one geophone channel is usable on the two OBS whose geophone sensor package failed to deploy). Figure 4 shows the geophone and hydrophone data recorded by OBS #50 on the first OBS experiment, plotted with a reduction velocity of 6.5 km/s. P-wave arrivals make up the first-arriving phase on the vertical geophone component and in the data recorded by the hydrophone. Note the change in curvature of the diving wave arrivals at ranges of 3-8 km. These arrivals represent energy turning in the layer 2/layer 3 transition. Both record sections show a PmP phase at ranges greater than 18 km. The slow arrivals on the vertical and hydrophone channels are converted S-wave phases, generated by the conversion of P-wave energy to S-wave energy at the sediment/basement interface. The second arriving phase on the vertical component with a phase velocity of 6.5 km/s is generated by P-wave energy traveling in the igneous crust converting to S-wave energy at the sediment/basement interface. The two horizontal components show the P-wave to S-wave converted phase described above. Figure 5 shows the P-wave arrivals recorded by the OBS located at Hole 504B for the two circle "lines". Data for both circles show considerable travel time and amplitude variations. The degree to which basement topography contributes to these variations remains to be determined.

MCS operations and data quality

A modest (1-day) MCS survey of the area surrounding Hole 504B was carried out to constrain patterns of crustal reflectivity beneath the drill hole, and to image any fault-like features within the crust which might be indicative of crustal thinning near the drill hole. The layout of our MCS survey as shown in Figure 6 placed importance on imaging in-plane structure along flow-lines (5 CMP dip lines), but also attempted to test the veracity of a notable dipping reflector seen on a quasi-strike line from a 1985 MCS survey of the area. The combination of a purely strike profile along this enigmatic feature, along with 5 intersecting dip profiles, should enable us to obtain an accurate subsurface picture of the "interpreted fault", as well as sub-basement structure as evidenced through patterns of crustal reflectivity.

MCS shot records were produced every 15 s +/- 250 ms with a record length of 10 s during the Hole 504B phase of our MCS operations. The streamer was towed at a nominal speed of 4 knots over the ground, although a local current trending N-S resulted in slower tow-speeds (~3.5 knots) on the S-to-N lines, and faster tow-speeds (~4.5 knots) on the N-to-S lines. The streamer appeared to ride well (~10 m depth) during the slow tow-rate with the exception of the streamer head and tail sections which should be weighted more heavily in the future. At these speeds, the guns were also slightly deeper than desired (10-12 m) and probably should be floated in future experiments. These slow tow-speeds should minimize aliasing in the common-offset domain which is crucial to any scheme of suppression of diffracted energy emanating from the seafloor. The Digicon streamer included 160 active groups separated by 25 m thereby giving rise to a nominal fold of approximately 70 traces within each 12.5 m CMP bin. The DMS-2000 acquisition package wrote shot records to IBM 3480 cartridge tapes in SEGD format with a 2 ms sampling rate. Recent additions to SIOSEIS enable the reading of SEGD, rev. 1, 20-bit seismic tape records and places navigation, "aka L-DEO trace 0 header", within channel set #1 of the SEGD structure as required! The general header, channel set #1, and two traces of the users choice were also written to the navigation tape, or NAV tape. The SEGD structure within the NAV tape, however, is not adhered to, with incorrect values for the number of traces expected in channel set #2 (180 expected, 2 written), and no EOF mark recorded after channel set #2...AS REQUIRED BY SEGD! Modifications were made to SIOSEIS to help debug the single channel system, but most likely will be stripped from SIOSEIS since its such a total kludge, and promotes non-standard usage of SEGD.

Quasi-real time processing of both MCS and SCS data was achieved using SIOSEIS, a seismic processing package developed at Scripps Institution of Oceanography, and PLTSEGY, a versatile SEGY-based X-Window and PostScript based plotting package developed at SIO with modifications added at WHOI. Both of these programs were run on two HP 9000/700 series workstations which were connected to one another via the shipboard Ethernet backbone (Appendix 14). Seismic processing included: SEGD tape I/O, geometry, gather, surgical muting, trace killing, NMO using velocity-depth function from a previous sonobuoy experiment, stack, filtering, and stolt migration. These nominal processes were applied to each profile during the first go-around. Other processes including finite-difference migration and DMO were applied to subsets of the data subsequent to MCS acquisition. The data were decimated to 4 ms and windowed between 4 and 8 sec to reduce the size of the gather sortfile (< 100 MBytes). In this mode, we were able to gather and process the data in real time with about a 40% duty cycle when compared to the acquisition write and processing time to tape. This capability ensured that brute stacks were available minutes after the completion of each MCS and SCS profile. We owe this real time capability, in part, to the fast floating point and I/O capabilities of our Hewlett-Packard workstations which nominally run 10-15 times faster than a Sparc 2, or 3-4 times faster than a Sparc 10. Each of these machines would have fallen hopelessly behind acquisition data rates delaying the final brute stack well into the next line(s). Minor bugs were fixed in SIOSEIS process SEGD with respect to delay and GMT time which caused only minor inconveniences. Future real-time processing should vary velocity in a prescribed way which is a function of seafloor depth which is passed within channel set #1 (center-beam depth) in the SEGD record. Thus stacking velocity could vary in a 2-D sense during real-time acquisition based on velocity constraints from previous lines, experiments, or one's own preconceptions. This addition should help modify track line locations in real time and would be based on contributions from all 160 + channels—and not a single trace display!

Data quality from the streamer is good, but many of the channels are plagued with transient "glitches". This "noise" is especially abundant near the streamer's head and tail sections, and in some sections near the middle of the streamer. On the whole, it probably appears on roughly 20% of all channels, and can be quite annoying, and obvious, during pre-stack migration processes like DMO. These transients (although sometimes not so transient) do not seem to be tied to anyone shot, but occur during noisy periods of 50 shots or more (but not always on every shot trace). This noise may be electronic-related...loose cabling? While most of these noise spikes tend to cancel out through stacking or prestack migration, these transients reduce the over all data quality by a significant amount.

Nonetheless, the MCS data shot in the vicinity of 504B are quite promising and should enable a suite of interesting problems to be addressed. Figure 7 shows a single trace display (#155) of Line 504B01C within the sedimentary section centered on a small fault located near Hole 504B. This fault is associated with a distinct offset in basaltic basement. It can be traced upward through most of the sedimentary section by offsets in intra-sediment reflectors, and may extend to the sea floor. This unexpected observation suggest that basement faulting may continue well out on to the ridge flanks (5-6 Ma crust) in this area.

As alluded to earlier, the CMP reflection lines were laid out to constrain better the origin of the fault-like feature seen on the quasi-strike line from the 1985 MCS survey. Unlike the 1985 cruise, multiple dip lines intersect the strike line which should allow a discrimination between an in- or out-of-plane origin for this feature. On the basis of magnetic and topographic data, the lines were oriented approximately 5° east of north to align with the structural grain of the region. This geometry should "flatten" any "fault-like" event which is side-swiped from small, out-of-plane, faulted features (like that seen in Figure 7). A preliminary stack of Line 504B02B (Figure 8) shows the expected flattening of the event previously interpreted as a fault, suggesting instead that it is a scattering artifact! The are many of these flat lying events seen throughout this section which undoubtedly originate at the sediment/basaltic basement boundary. This example demonstrates the importance of scattering from basement, even in regions with significant sediment coverage.

High quality images of Moho and other dipping events were observed in the flow-line profiles obtained in this survey that should enable a map of crustal reflectivity beneath Hole 504B to be produced. Among the nearly flat-lying Moho reflections are dipping events which lie above and below the Moho boundary. Examples of these reflections are shown in Figure 9 from MCS lines 504B01D&01E. In the bottom panel, a reflector can be seen curving upward from the Moho, and is similar in appearance to other lower crustal events seen in the North Atlantic Transect dataset! The upper panel shows an example of typical Moho in the area, with a weak event seen dipping from left to right beneath the Moho horizon. Remember, all these events shown within this report were derived from our real-time, ship-board processing, and undoubtedly can be enhanced by more thorough, shore-based processing schemes.

SCS operations and data quality

The primary objective of single-channel seismic (SCS) profiling on EW 94-16 was to determine the travel time correction for sediment thickness to be applied to the OBS refraction data. Secondary objectives were to map basement relief and determine the nature and lateral extent of seismic units within the sediments. These data will be used with the borehole stratigraphy to interpret tectonic and geologic history of the local region.

Most SCS data on this leg were collected using the L-DEO 10 gun array (described in Appendix 2) and the L-DEO "single-channel" streamer. The SCS streamer begins with a 188 m header section (attached to the ship midway across the fantail) followed by a 25 m stretch section. There are four active hydrophone sections with lengths of 12.5 m, 25 m, 50 m, and 50 m. The center of the active section is 137.5 m long and is located 217 m aft of the center of the gun array. The reflection point between gun and the center of the active section is 196 m aft of the navigation mast. The location of the reflection point for each shot can be determined by shifting shot navigation backwards by the number of shots equivalent to the separation between the mast and reflection point. During the survey the speed-over-ground ranged from ~4.1 to ~6.0 knots giving shot spacing ranging from 27.3 m to 40.0 m (at a 13 sec rep rate) or shot shifts of 7 to 5 shots, respectively. Using the median shift of 6 shots will add a maximum uncertainty of +-30 m to the GPS navigation.

Hydrophones in each section are summed constructively to provide four data channels that pass through a broad-passband, analog pre-amplifier on deck. The pre-amplifier applied 60 dB of gain and summed all four channels. Within the main lab, the single channel of data from the streamer was split into two, and one of these channels was attenuated by 20 dB. These two channels were then digitized at 500 Hz with no anti-alias analog filter beforehand. This digital data stream was low-pass filtered at 160 Hz and recorded using the Digicon seismic system in two of eight channel SEGD files on half inch cartridge tape (ch 5: no attenuation; ch 6: -20 dB). Both channels were also recorded in a modified SEGD format on a two-channel "navigation" tape. Each shot was recorded for six seconds with no deep-water delay. In addition to the digital tape, an analog split of the data stream from the pre-amp was displayed on a 20 inch EPC flatbed continuos roll graphic recorder at 4 sec sweep with a 4 sec delay.

SCS data collection was done both alone and in combination with the shooting of the OBS refraction lines. The simple reflection profiles were shot at a 13 sec rep rate to avoid interference between the arrival of the seafloor and basement reflections and the primary water, sediment, and Moho multiples. At the beginning of the SCS survey we compared the seafloor reflection signature with source signatures computed for the L-DEO 10-gun array by a program (written by John Diebold) that allows variable source and receiver depths. The observed sea floor reflection is ~47 msec long with a small dip in the crest of the primary pulse. To reproduce this dip with the gun array at 6 m depth required the streamer to be near 13-14 m depth - well below its designed tow depth. We decided on a tow speed through water of 5-5.5 knots as a compromise between the need to go slower to keep the guns closer to their optimum depth of 7-10 m and the need to go faster to raise the streamer to eliminate the dip in the primary pulse. Gun depths throughout the survey varied between 3 and 9 m and averaged about 6 m.

The SCS grid shot at a 13 sec rep rate covered a 22x22 km square centered on Hole 504B and included 40 straight line segments totaling about 842 km (Figure 10). These lines are supplemented by 226 km of reflection profiles obtained during refraction shooting at rep rates of 43 sec (1 line for 48 km), 65 sec (10 lines for 314 km), and 84 sec (1 line for 26 km) (shot spacing of 100 m, 150 m and 150 m [3.5 km/s], respectively). SCS 13 sec lines and MCS lines are spaced at 1 km intervals across 11 km E-W and 15 km N-S. Extending outward toward the edge of the survey, the nominal spacing between lines decreases to about 2 km. Including turns and approaches, we collected 29,094 shots on 48 cartridge tapes at 13 sec and 3100 shots on 12 tapes during refraction shooting at various rep rates (Appendix 15). Smoothed shot navigation were provided by the L-DEO system manager on a daily basis. These data were reformatted to be compatible with GMT and plotted every 3-4 days during the cruise.

Single-channel data were processed with SIOSEIS and PLTSEGY software running on an HP 712/60 workstation networked to a Fujitsu M2485H cartridge tape reader. SEGD data files were reformatted to SEGY disk files and data quality checks were made by plotting data and by using disk file utility programs. Profiles of all lines were plotted at-sea after band-pass filtering (5-80 Hz @ 24 dB/octave), trace amplitude equalization (where needed due to variable gain), and fk migration using a 1.5 km/sec velocity and shot spacing determined by the average speed made good along the line obtained from the watchkeeper's log book. Figure 11 illustrates how well the SCS collected with the 10-gun, 3005 cu. in. airgun array used in this survey was able to resolve basement structure. Figure 12 shows a sample from Line 8 across Hole 504B showing how well the fk migration collapses the hyperbolae produced by scattering off basement topography. The top of basement can be clearly distinguished at about 4.9 sec beneath the borehole and several sedimentary reflections can be observed. The projected positions of Holes 677A and 678B/896A are indicated. A fault offsetting recent sediment reflectors is marked with an F in the lower panel.

During the cruise, travel times to the seafloor and basement were picked on the fk migrated profiles for all 13 sec SCS data using an interactive picking software module that is related to PLTSEGY. Seafloor depths were determined for all basement picks by linear interpolation and sediment thickness was computed. These data were merged with the shot navigation and contoured using GMT. Preliminary maps of the travel time to seafloor and basement and the sediment thickness in msec were produced at-sea.

The primary problem to affect data quality (other than the crash of the DSS-2000 seismic system during the shooting of refraction line 15E on November 21 described in the Cruise Narrative) was an intermittent variation in gain in the analog signal coming into the main lab that occurred over about 15 hours during November 14 that affected data collected on lines 7B-G (tapes 95-100). Repairs to the system produced 86 null shots in two groups (4846-4878 and 4911-4963) on line 7G (tape 100). Gain losses exceeding 20 dB were observed. The problem was eventually traced to a short in the cable leading between the pre-amplifier on deck and the main lab and fixed at 2008Z (JD 318). Smaller problems included losses of 1-3 traces at irregular intervals and clipping of the un-attenuated data in channel 5.

4.2 Costa Rica Rift Survey

This study was aimed at determining the structure and evolution of the uppermost crust (Layer 2A) formed at the intermediate spreading (35 mm/yr) Costa Rica Rift (Figure 1). Layer 2A has already been well resolved in seismic studies of crust formed at fast spreading rates at the East Pacific Rise and in crust formed at intermediate spreading rates at the Juan de Fuca Ridge. The layer consists of crust having a characteristic low velocity (2-3 km/s) and a rapid velocity increase to about 5.0 km/s at the base. This velocity gradient is so strong that the returns form a post-critical reflection-like arrival that can be moved-out and stacked for detailed analysis of the layer. Studies to date indicate that seismic Layer 2A forms a 100-150 m thick layer at the ridge axis, thickens to 400-700 m within a km or so of the axis, and then appears to remain relatively constant in thickness, at least out to ranges of 10 km or so from the axis. It is likely formed of extrusive igneous rocks at the surface overlying intercalated intrusive and extrusive rocks grading into an entirely intruded dike complex at the base of the layer. The evolution of the layer beyond a few million years age has not been determined. Seismic Layer 2A is known not to occur in crust of 50 my or greater.

A determination of the seismic character of the uppermost crust provides key information of constructional processes at the ridge axis and subsequent modification of the structure by tectonism and hydrothermal alteration. An understanding of the seismic character of the uppermost crust is particularly important for the accurate resolution of seismic structures at greater depth. Downhole geological and geophysical studies at ODP Hole 504B, located in crust formed at the intermediate spreading Costa Rica Rift 5.8 my ago, would indicate that the layer thins as it ages, largely though a reduction in porosity (and increase in velocity) due to hydrothermal alteration. However a seismic Layer 2A event was not resolved in the earlier 1985 MCS survey of this site. This is likely due to the combined effects of a limited seismic source and the presence of a chert layer of higher than Layer 2A velocity, which effectively masks the uppermost seismic structure at the site. Chert formation in this area is spotty and is also likely restricted to crust of age 4 my or greater, however, so resolution of seismic Layer 2A at the and it's evolution remains a reasonable objective for crust formed at the Costa Rica Rift.

In order to determine the most favorable setting for resolution of upper crustal seismic characteristics at the relatively unknown Costa Rica Rift axis, a Hydrosweep survey was conducted along N-S corridors spaced at approximately 8 km range over the shallower western 70 km of the approximately 140 km spreading segment (Figure 13). Magnetic data acquired simultaneously ensured that the survey was centered between the Bruhnes/ Matuyama and Jaramillo magnetic lineations. The survey revealed the major features of the rift and the fabric of northern flank of the rift out to about .5 my and the southern flank of the rift out to about 1 my. The spreading center is characterized by a series of en echelon rift valleys that step to the north from west to east. The axial asymmetry observed for the western region of the Costa Rica Rift is not unlike that observed at the adjacent Ecuador Rift; both rift systems show a shoaling of the axial rift valley at toward the western limit of each segment. However, the morphology of the Costa Rica Rift appears somewhat more tectonized, with strongly lineated topography reminiscent of that observed on the slower spreading Mid Atlantic Ridge.

Based on the results of this survey, a seismic investigation utilizing a 3005 cu in air gun source array, a 4 km 160 channel digital streamer and sonobuoys was designed to investigate the most robust-looking part of the spreading segment, and the crust formed along a flow line south from this segment toward the Hole 504B area. The airgun array was fired at a 13 sec shot interval (randomized at ± 250 msec) at a ship speed of approximately 4.5 kts (over the ground), giving an optimal shot spacing of 30 m for the 10 s seismic records sampled at 2 msec. This shot spacing was chosen so that subsequent processing to reduce the influence of rough, diffractive topography could be accomplished with minimal spatial aliasing.

Multichannel seismic (MCS) and sonobuoy profiles were acquired in isochron orientations along flanks and rift of a valley of about 3000 m depth centered at about 3°20'N, 83°50'W (Figure 14). Three MCS profiles were also acquired across the axis of this feature. The object of these profiles was to image the axial and near-axis character of the uppermost crust so that the evolution of the features resolved in this crust could be studied along a flow line extending to the south. Additional MCS and sonobuoy profiles were acquired along isochron line intersections of the flow line in crust of .75 my, 2.2 my, and 5.5 my age to ensure the best possible resolution of intra-crustal features (Figures 14). In three days, 33 (of 59) sonobuoy records of reasonably good quality and 600 km of MCS data were acquired (Appendices 16 and 17). CDP gathers show good signal to noise (and a variable abundance of diffracted arrivals). An isochron section centered on the southern rift flank was stacked with velocities appropriate for imaging of Layer 2A at the East Pacific Rise and revealed a profile with strong Layer 2A-like intra-crustal arrival at about 0.3 s twtt beneath the seafloor. Out-of-plane scattering on this topographically high feature do not appear to be a great problem but are likely to be of considerable influence in topographically low areas like the rift valley proper. However, with the relatively dense shot spacing accomplished in this study, potentially detrimental effects of topography are likely to be effectively treated in subsequent processing efforts.

The acquisition of this data benefited greatly from enthusiastic participation by my co-chief scientists Bob Detrick and John Collins, and their considerable scientific and technical support staff from Woods Hole Oceanographic Institution, and by the excellent working conditions provided by Captain O'Laughlin, his crew, and the scientific and technical support staff of the R/V *Maurice Ewing*.

Figure Captions

Figure 1 - Map showing the location of the Costa Rica Rift and Hole 504B where operations on EW 94-16 were concentrated.

Figure 2 - OBS and shooting lines for OBS Deployment #1 (504B05) and OBS Deployment #2 (504B10). The circle at the intersection of the two lines shows the location of Hole 504B.

Figure 3 - OBS and shooting lines for OBS Deployment #3. Hole 504B is located at the position of OBS 60.

Figure 4 - Record sections (plotted with a reduction velocity of 6.5 km/s) for OBS 50 from Deployment #1: (a) vertical geophone component, (b) & (c) horizontal geophone components, (d) hydrophone.

Figure 5 - Vertical geophone component for a number of shots from each of the two circle shots designed to investigate the degree and scale of crustal heterogeneity around the drill site.

Figure 6 - Track line for MCS profiles shot around Hole 504B on EW 94-16.

Figure 7 - Example of reflection profile constructed from near-offset trace of MCS streamer showing basement fault that appears to extend upward into the sediment section. Top - time section. Bottom - fk migrated section.

Figure 8 - Stacked section for a portion of 504B02-B showing an event near 6 sec TWTT that was interpreted as a fault in an earlier MCS survey of this area but can be shown to be a scattering artifact from the scarp shown in Fig. 7.

Figure 9 - Examples of (top) a Moho reflection from around Hole 504B, and (bottom) a lower crustal dipping event that appears to sole out near the Moho.

Figure 10 - Track line for SCS profiles shot around Hole 504B on EW 94-16.

Figure 11 - Example of SCS data collected with the 10-gun, 3005 cu. in. airgun array showing the resolution of basement topography beneath ~300 m of sediment in the Hole 504B area.

Figure 12 - Example of (top) unmigrated, and (bottom) fk migrated SCS profile showing a basement fault which extends up into the sediment section and offsets several intra-sediment reflectors.

Figure 13 - Track line for Hydrosweep and SCS survey of Costa Rica Rift.

Figure 14 a, b - Track lines showing MCS profiles collected over Costa Rica Rift and southern ridge flank.

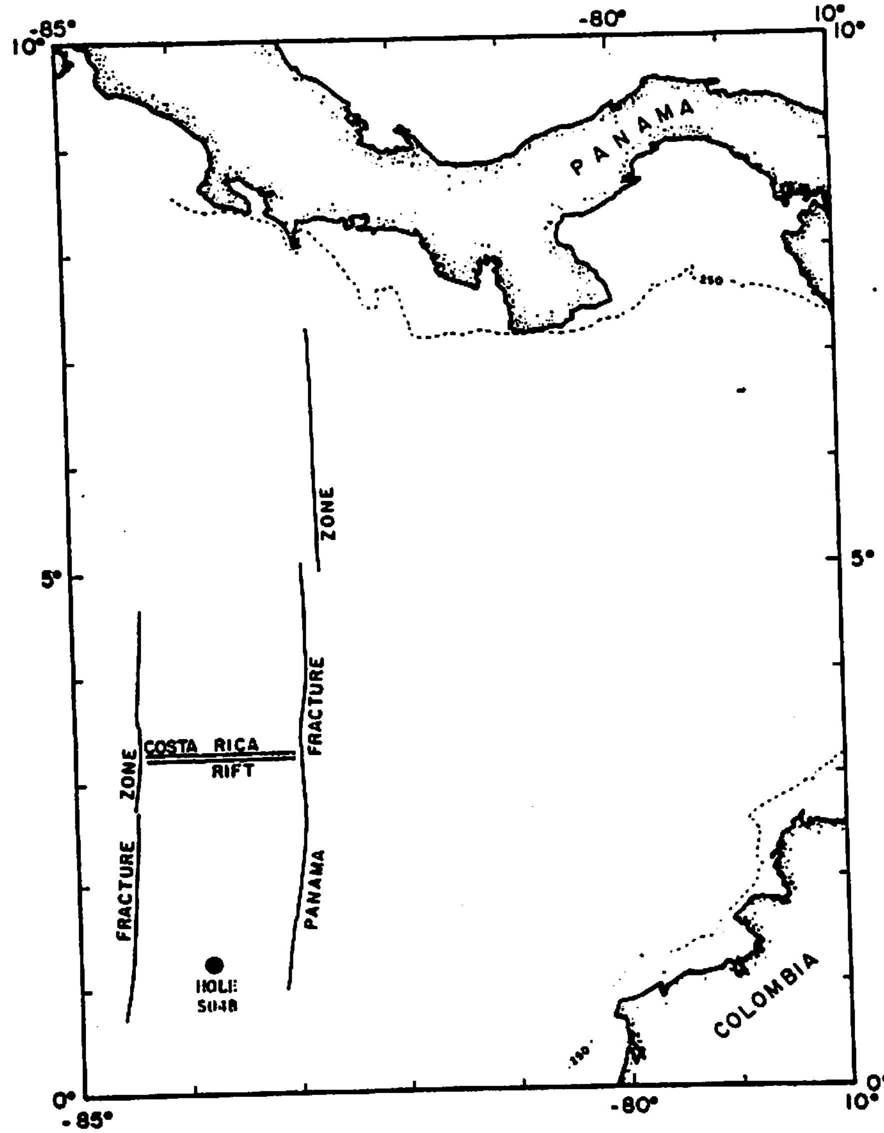

-85°
-80°
10°
10°
10°
5°
5°
0°
0°
-85°
-80°
10°
PANAMA
250
ZONE
FRACTURE
PANAMA
COSTA RICA
RIFT
ZONE
FRACTURE
HOLE
504B
COLOMBIA
250

Figure 1

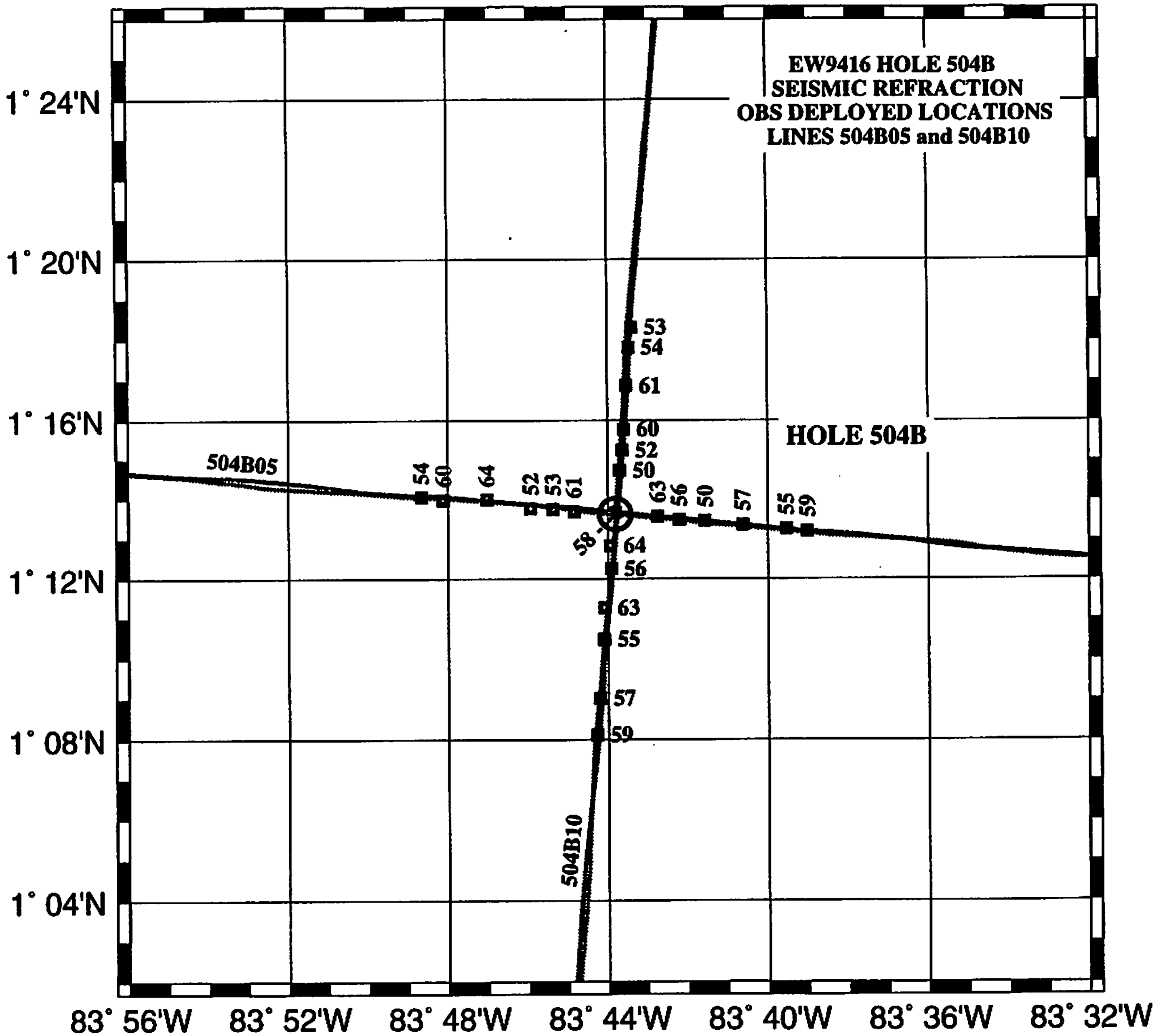

EW9416 HOLE 504B
SEISMIC REFRACTION
OBS DEPLOYED LOCATIONS
LINES 504B05 and 504B10
HOLE 504B
504B05
504B10
1° 24'N
1° 20'N
1° 16'N
1° 12'N
1° 08'N
1° 04'N
83° 56'W
83° 52'W
83° 48'W
83° 44'W
83° 40'W
83° 36'W
83° 32'W
53
54
61
60
52
50
64
56
63
55
57
59
58

Figure 2

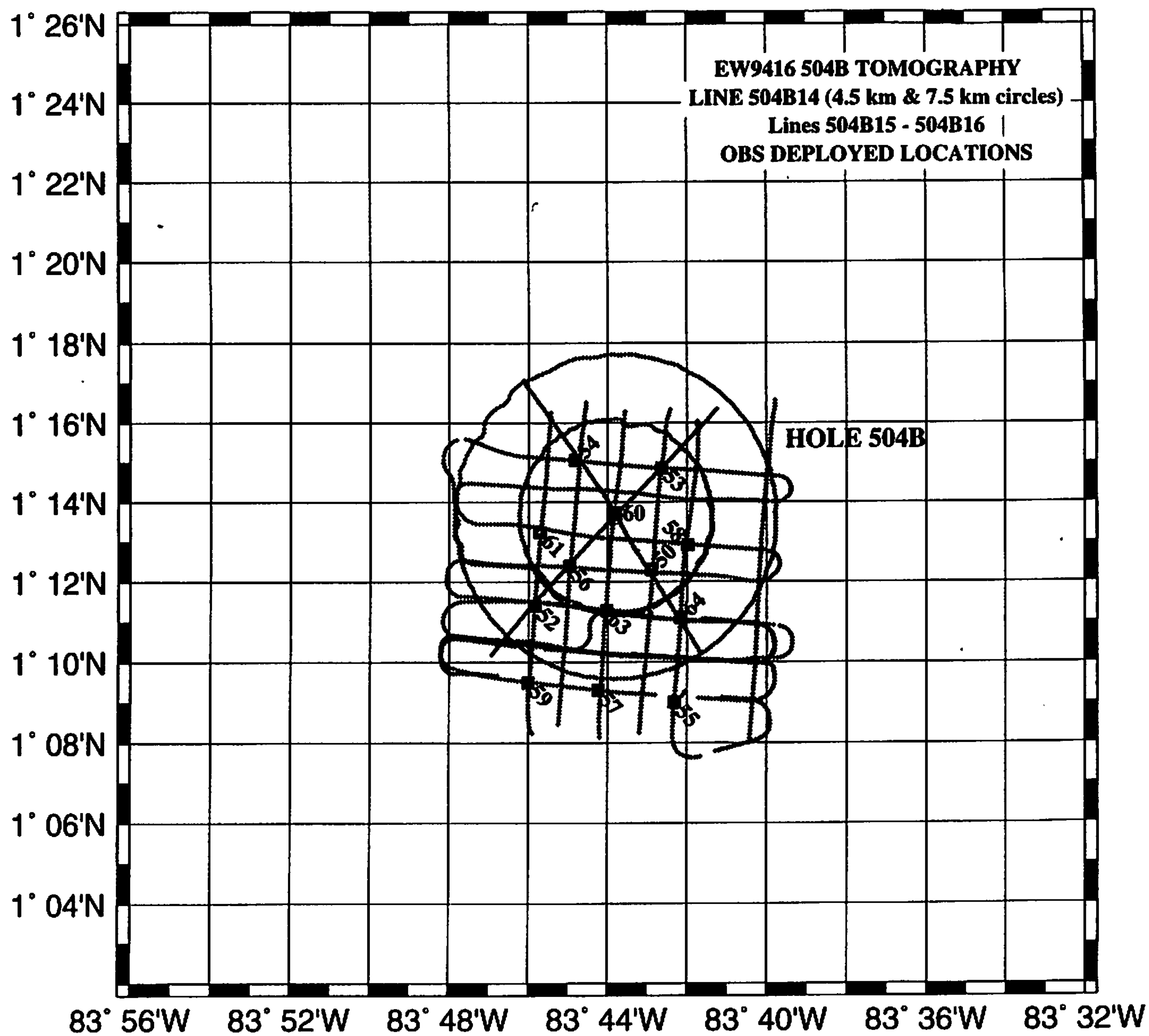

EW9416 504B TOMOGRAPHY
LINE 504B14 (4.5 km & 7.5 km circles)
Lines 504B15 - 504B16
OBS DEPLOYED LOCATIONS
HOLE 504B
1° 26'N
1° 24'N
1° 22'N
1° 20'N
1° 18'N
1° 16'N
1° 14'N
1° 12'N
1° 10'N
1° 08'N
1° 06'N
1° 04'N
83° 56'W
83° 52'W
83° 48'W
83° 44'W
83° 40'W
83° 36'W
83° 32'W

Figure 3

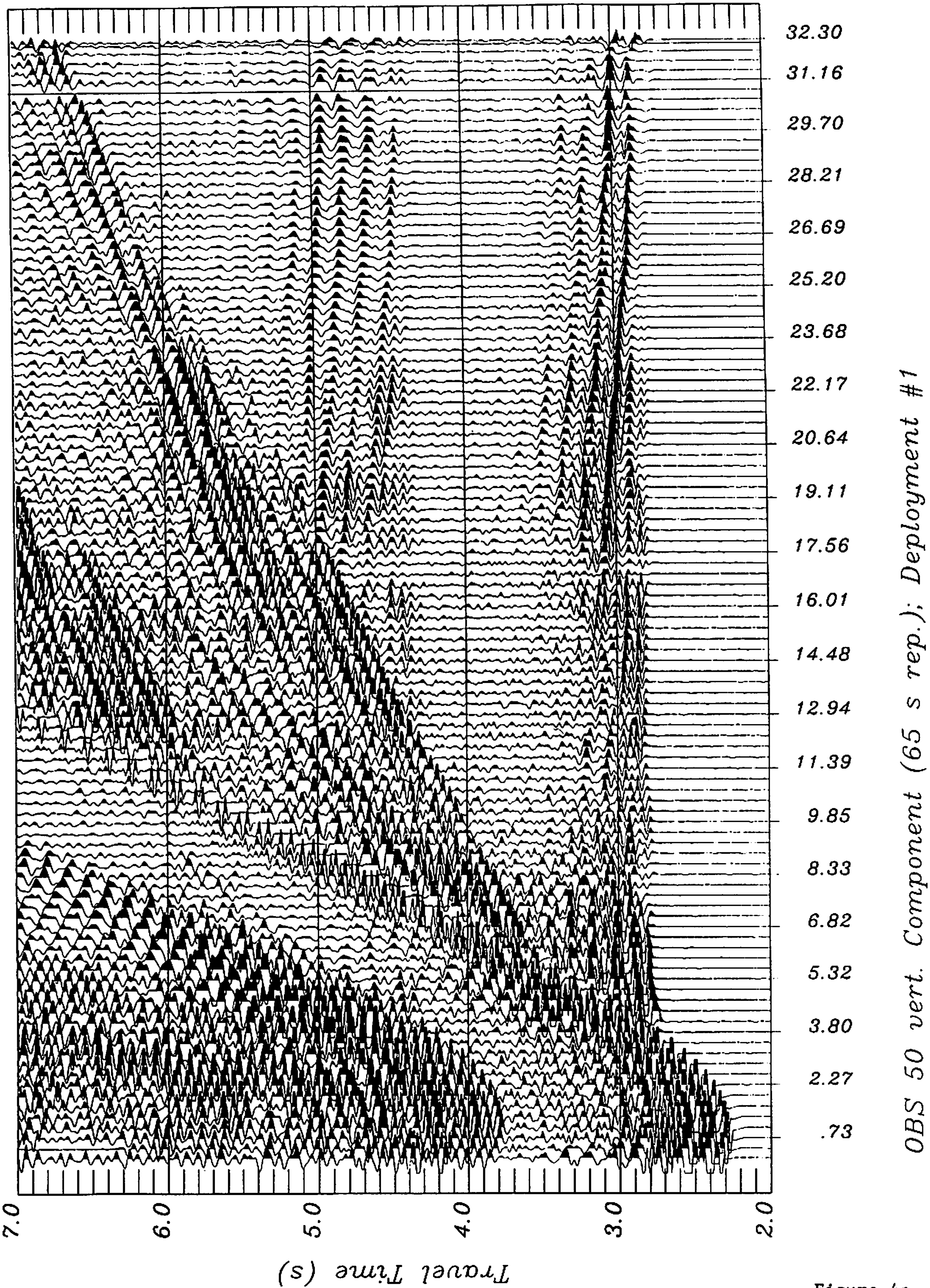

OBS 50 vert. Component (65 s rep.); Deployment #1
32.30
31.16
29.70
28.21
26.69
25.20
23.68
22.17
20.64
19.11
17.56
16.01
14.48
12.94
11.39
9.85
8.33
6.82
5.32
3.80
2.27
.73
7.0
6.0
5.0
4.0
3.0
2.0
Travel Time (s)

Figure 4a

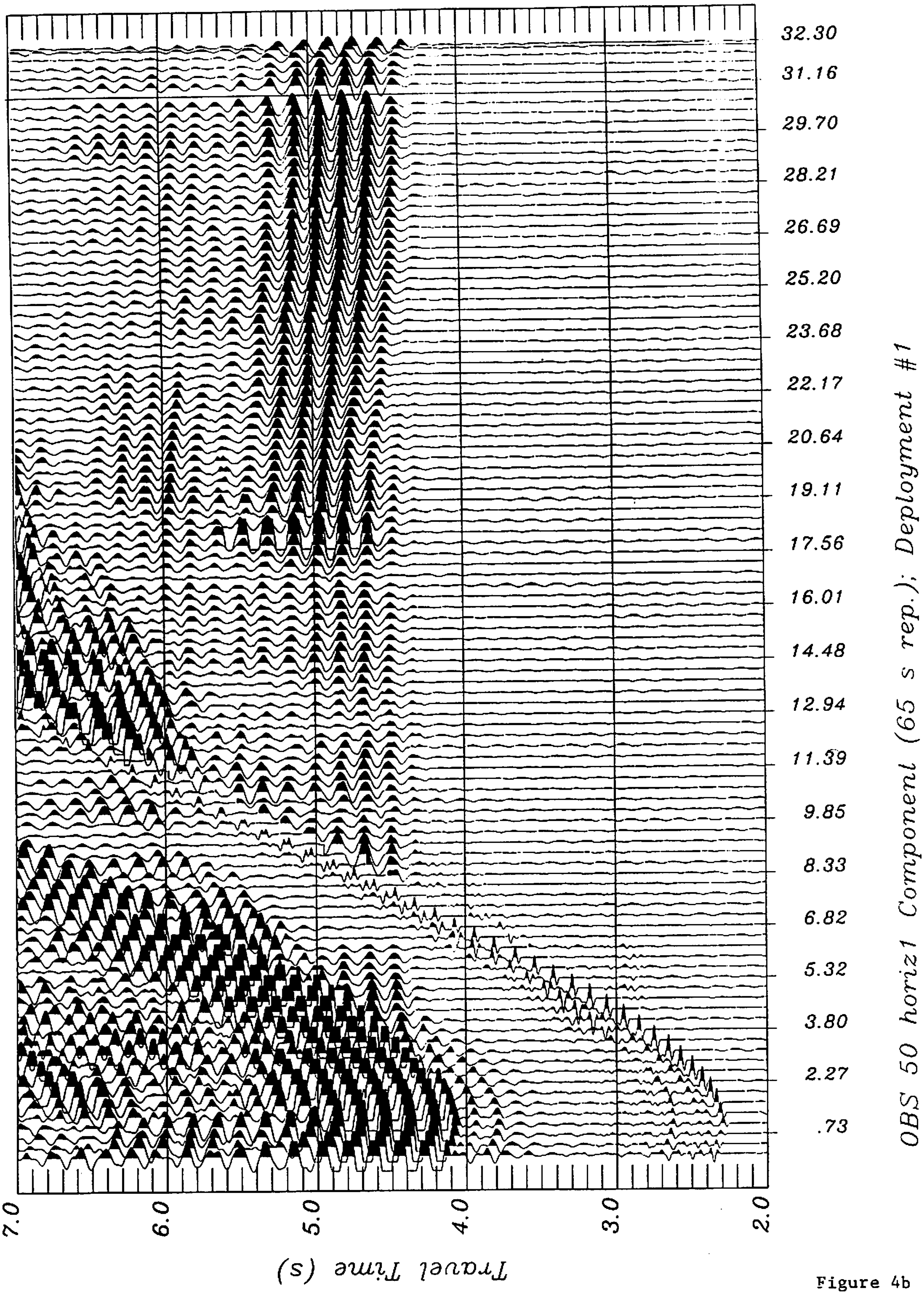

OBS 50 horiz1 Component (65 s rep.); Deployment #1
Travel Time (s)
7.0
6.0
5.0
4.0
3.0
2.0
32.30
31.16
29.70
28.21
26.69
25.20
23.68
22.17
20.64
19.11
17.56
16.01
14.48
12.94
11.39
9.85
8.33
6.82
5.32
3.80
2.27
.73

Figure 4b

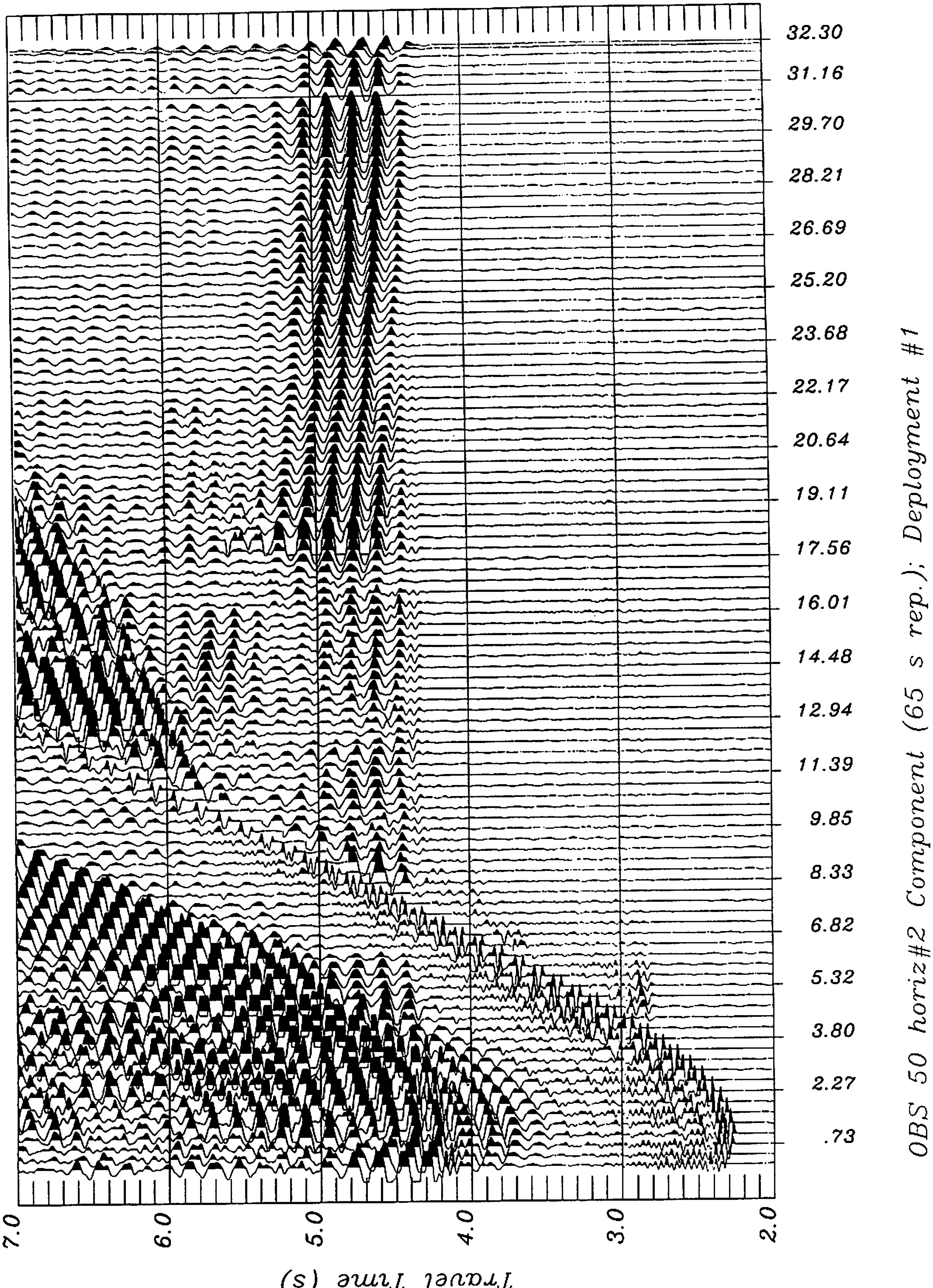

32.30
31.16
29.70
28.21
26.69
25.20
23.68
22.17
20.64
19.11
17.56
16.01
14.48
12.94
11.39
9.85
8.33
6.82
5.32
3.80
2.27
.73
OBS 50 horiz#2 Component (65 s rep.); Deployment #1
7.0
6.0
5.0
4.0
3.0
2.0
Travel Time (s)

Figure 4c

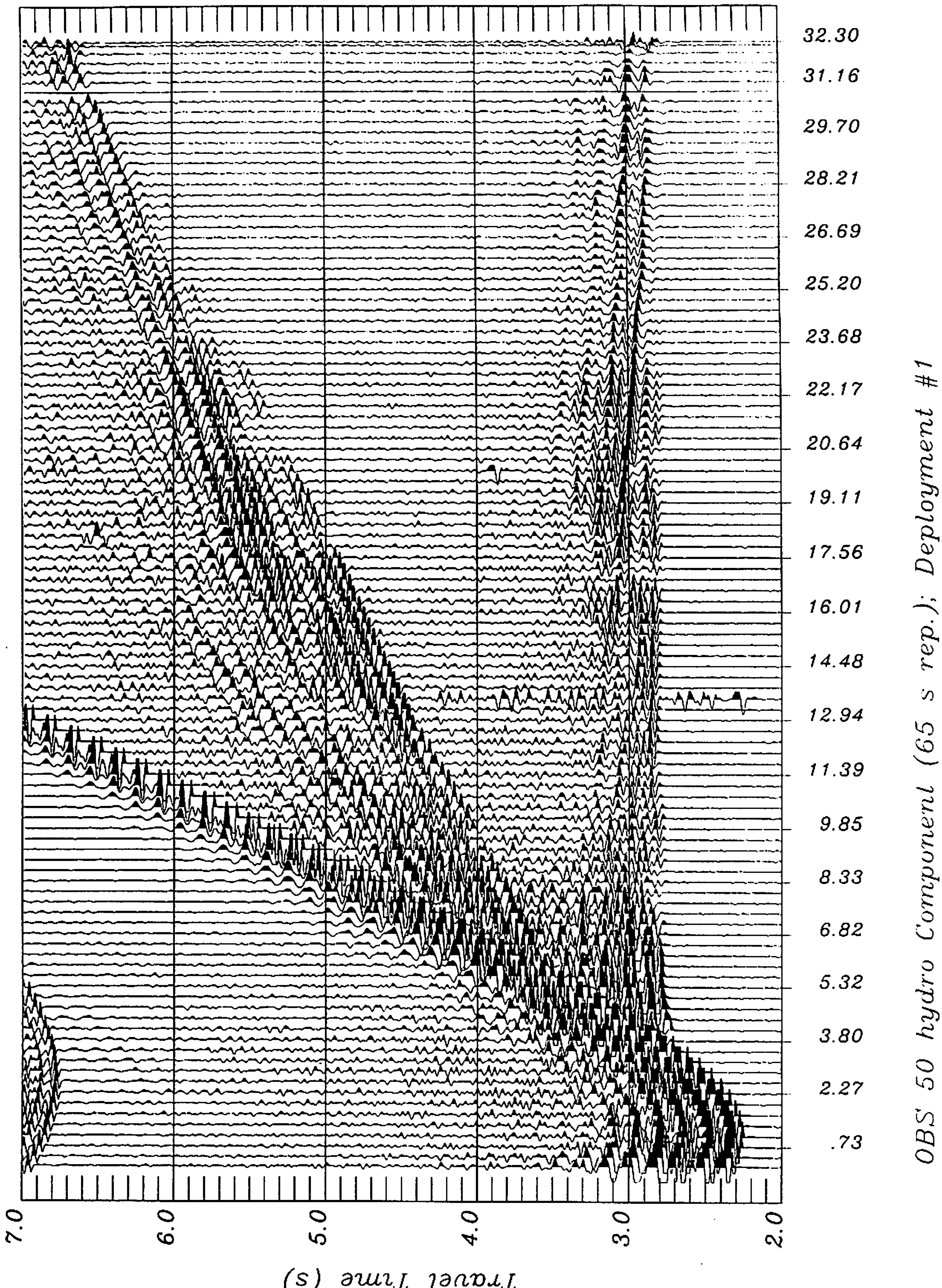

OBS 50 hydro Component (65 s rep.); Deployment #1
32.30
31.16
29.70
28.21
26.69
25.20
23.68
22.17
20.64
19.11
17.56
16.01
14.48
12.94
11.39
9.85
8.33
6.82
5.32
3.80
2.27
.73
7.0
6.0
5.0
4.0
3.0
2.0
Travel Time (s)

Figure 4d

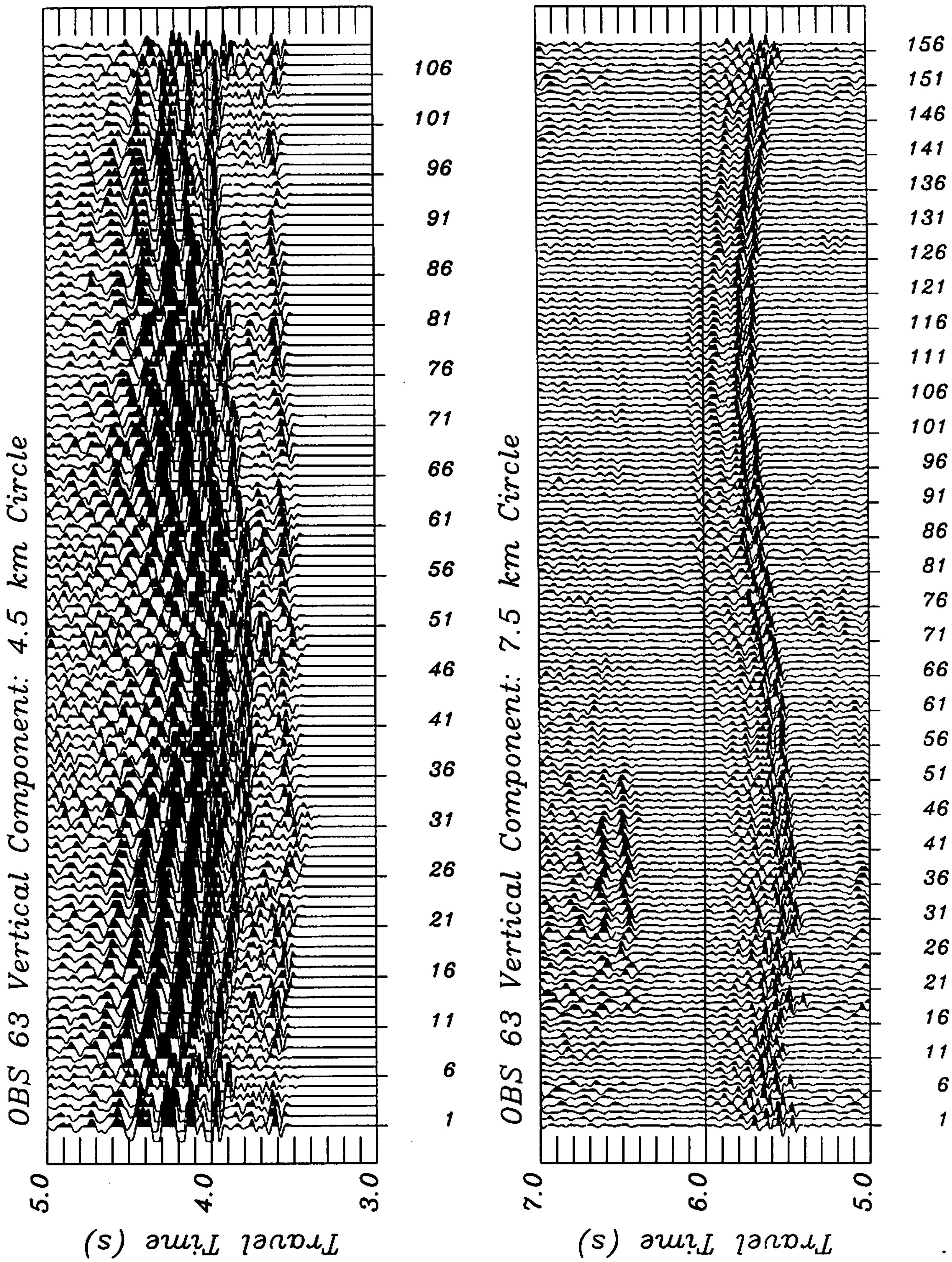

OBS 63 Vertical Component: 4.5 km Circle
Travel Time (s)
OBS 63 Vertical Component: 7.5 km Circle
Travel Time (s)

Figure 5

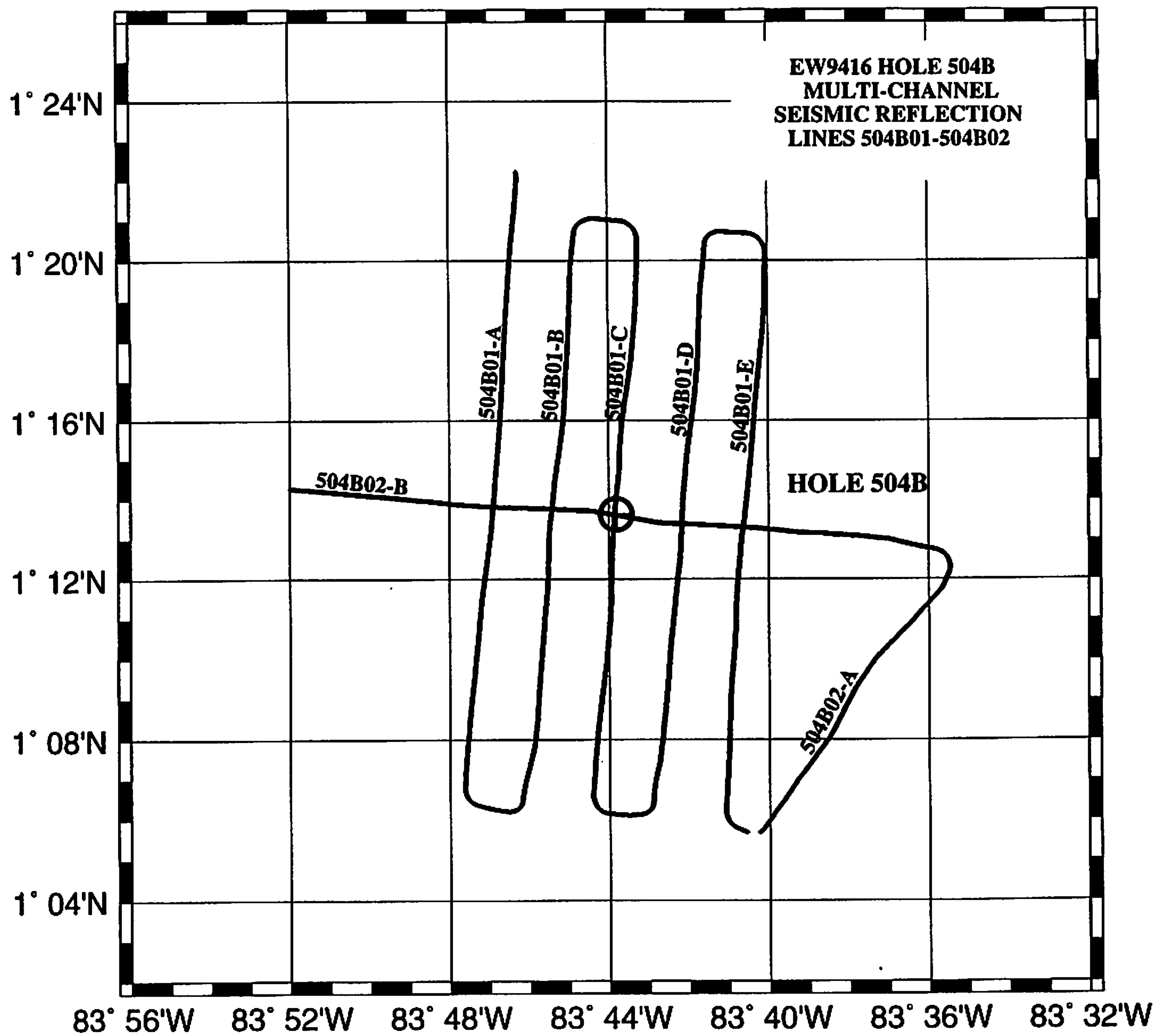
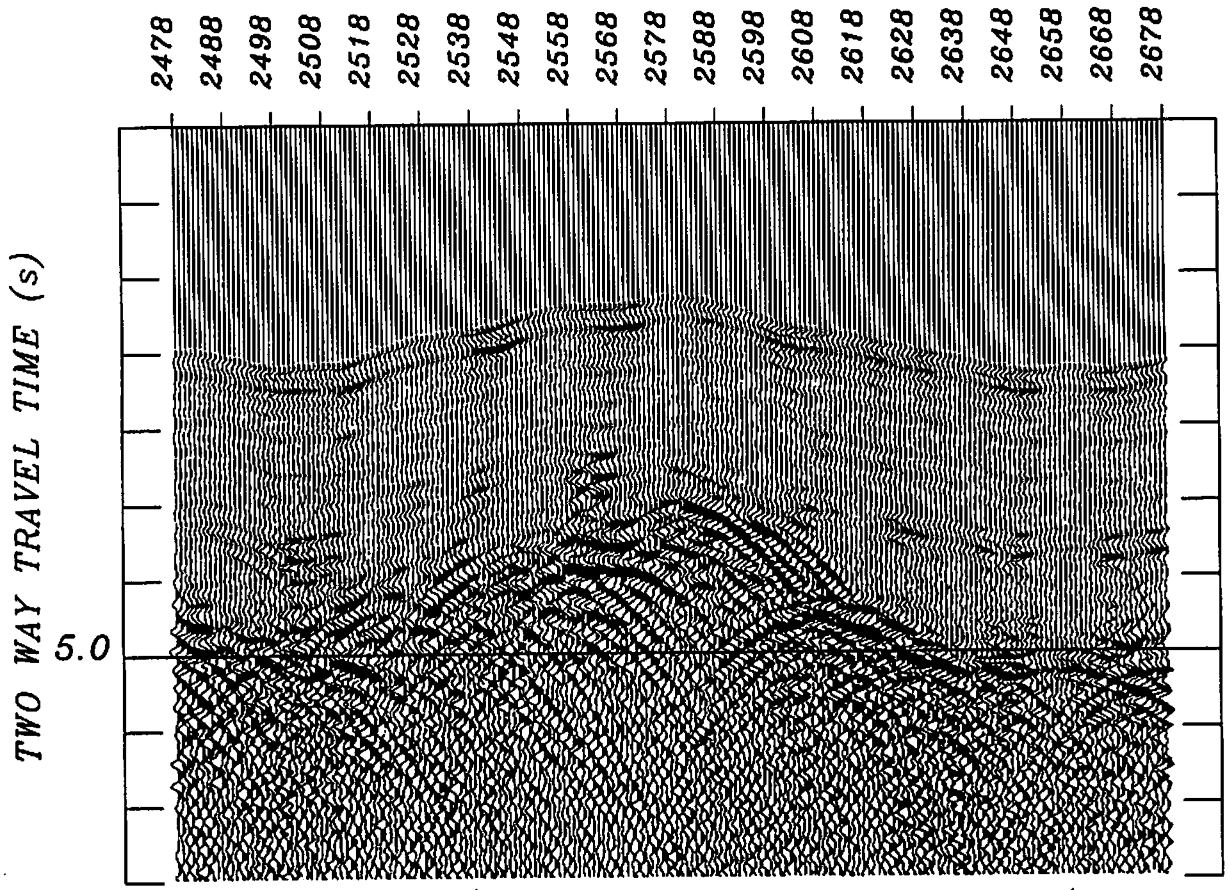
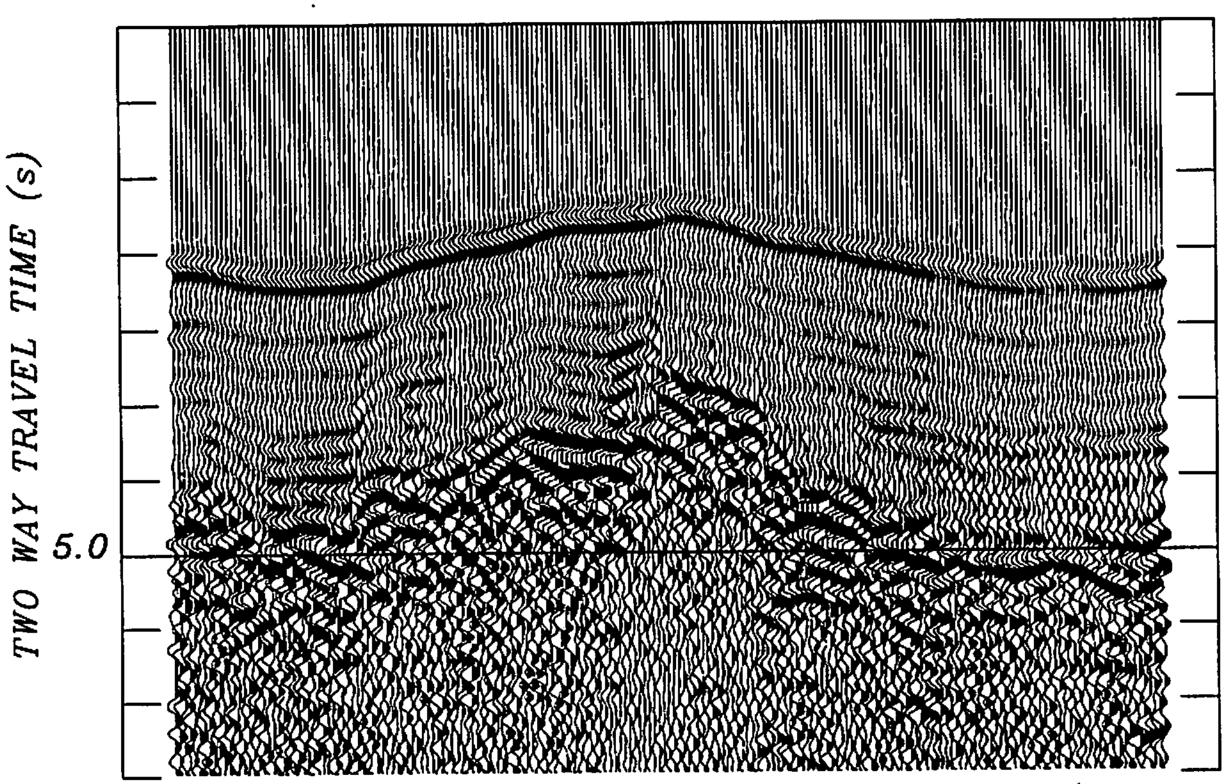

EW9416 HOLE 504B
MULTI-CHANNEL
SEISMIC REFLECTION
LINES 504B01-504B02
HOLE 504B
504B02-A
504B02-B
504B01-A
504B01-B
504B01-C
504B01-D
504B01-E
1° 24'N
1° 20'N
1° 16'N
1° 12'N
1° 08'N
1° 04'N
83° 56'W
83° 52'W
83° 48'W
83° 44'W
83° 40'W
83° 36'W
83° 32'W

Figure 6

Single Trace Example of MCS Data: Ewing 94-16



Single channel display of LINE 504B01C



Stolt Migration near fault: LINE 504B01C

Figure 7

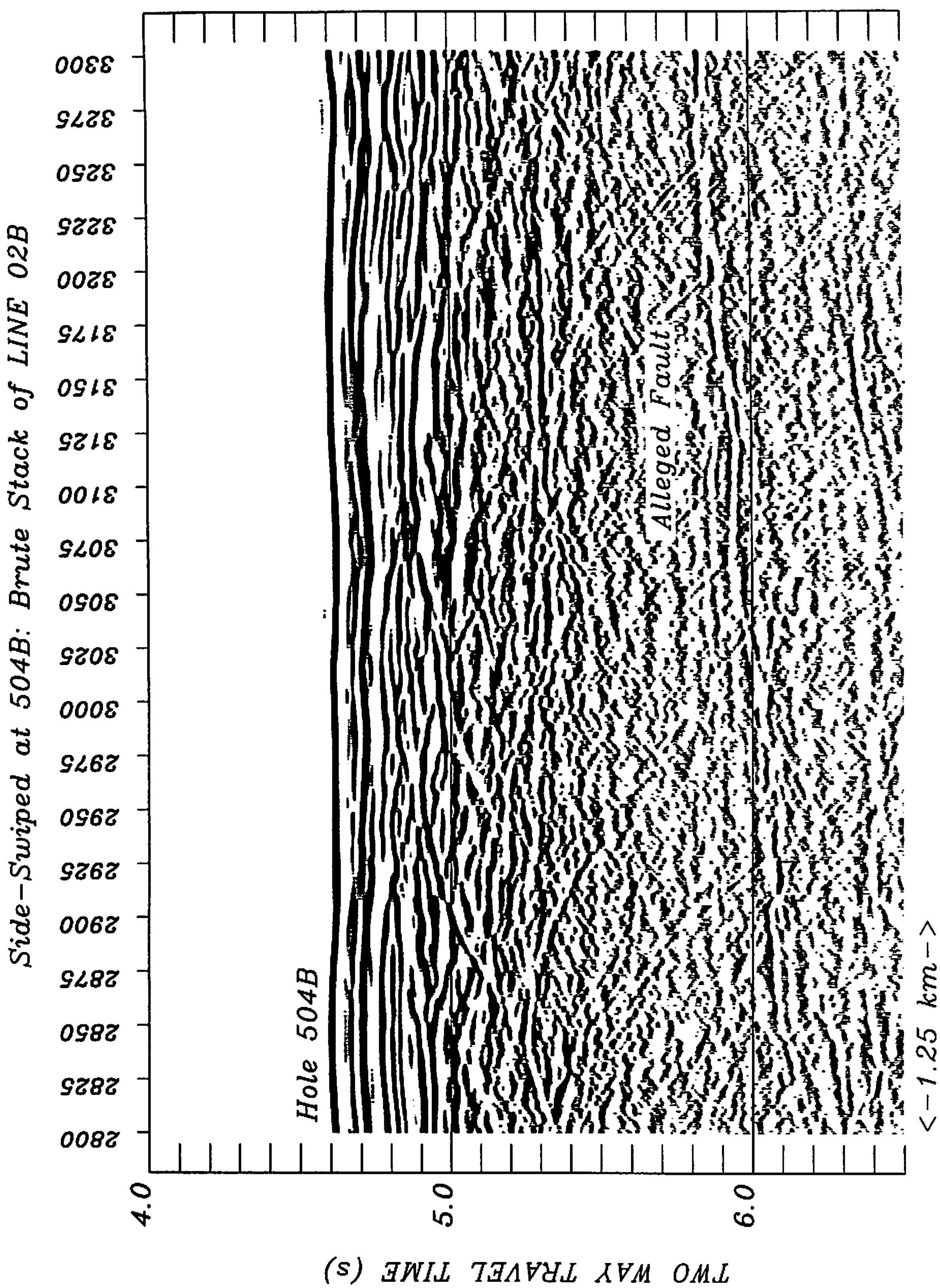

Side-Swiped at 504B: Brute Stack of LINE 02B
3300
3275
3250
3225
3200
3175
3150
3125
3100
3075
3050
3025
3000
2975
2950
2925
2900
2875
2850
2825
2800
Hole 504B
Alleged Fault
<-1.25 km->
4.0
5.0
6.0
TWO WAY TRAVEL TIME (s)

Figure 8

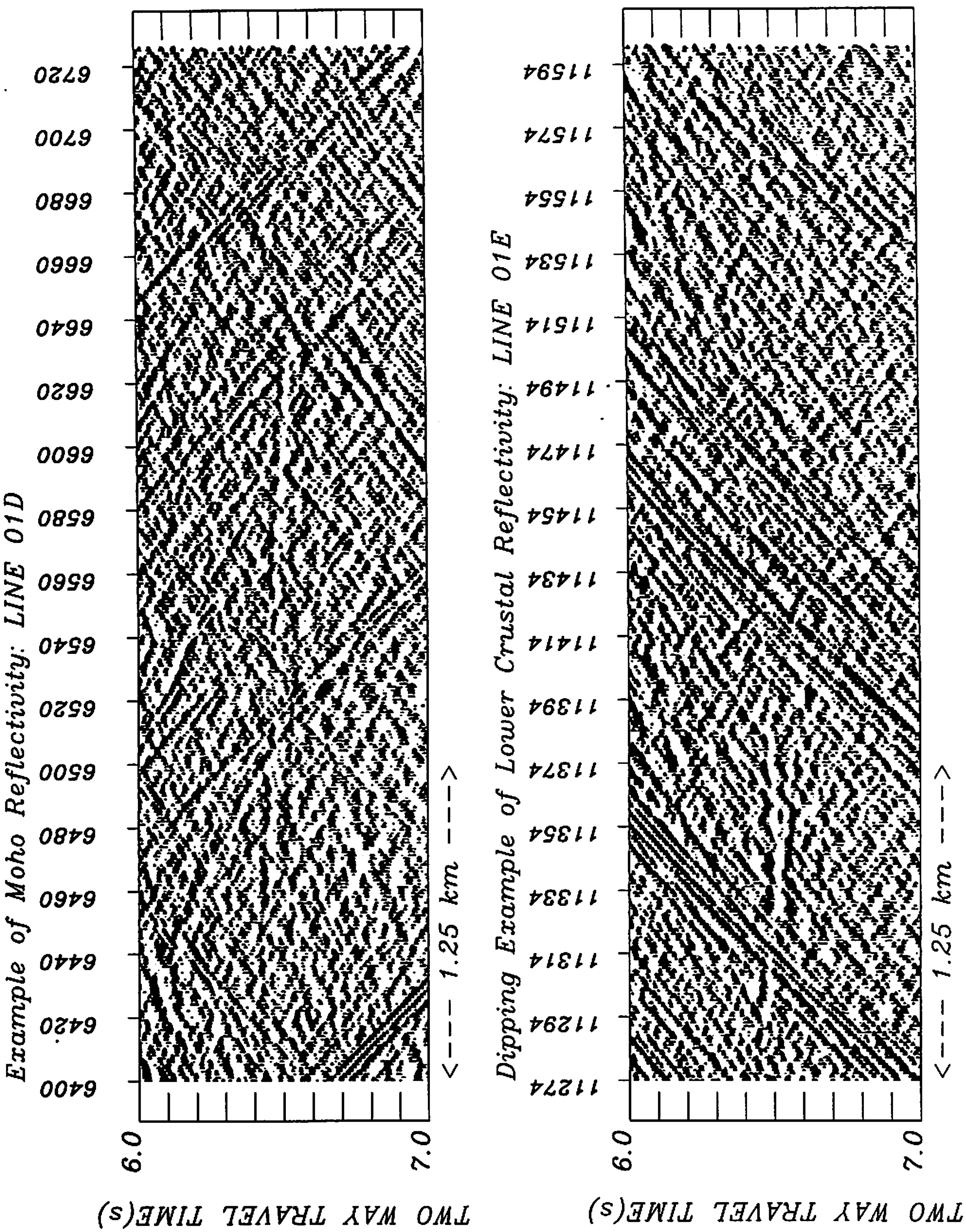

Example of Moho Reflectivity: LINE 01D
6400
6420
6440
6460
6480
6500
6520
6540
6560
6580
6600
6620
6640
6660
6680
6700
6720
<--- 1.25 km --->
6.0
7.0
TWO WAY TRAVEL TIME(s)
Dipping Example of Lower Crustal Reflectivity: LINE 01E
11274
11294
11314
11334
11354
11374
11394
11414
11434
11454
11474
11494
11514
11534
11554
11574
11594
<--- 1.25 km --->
6.0
7.0
TWO WAY TRAVEL TIME(s)

Figure 9

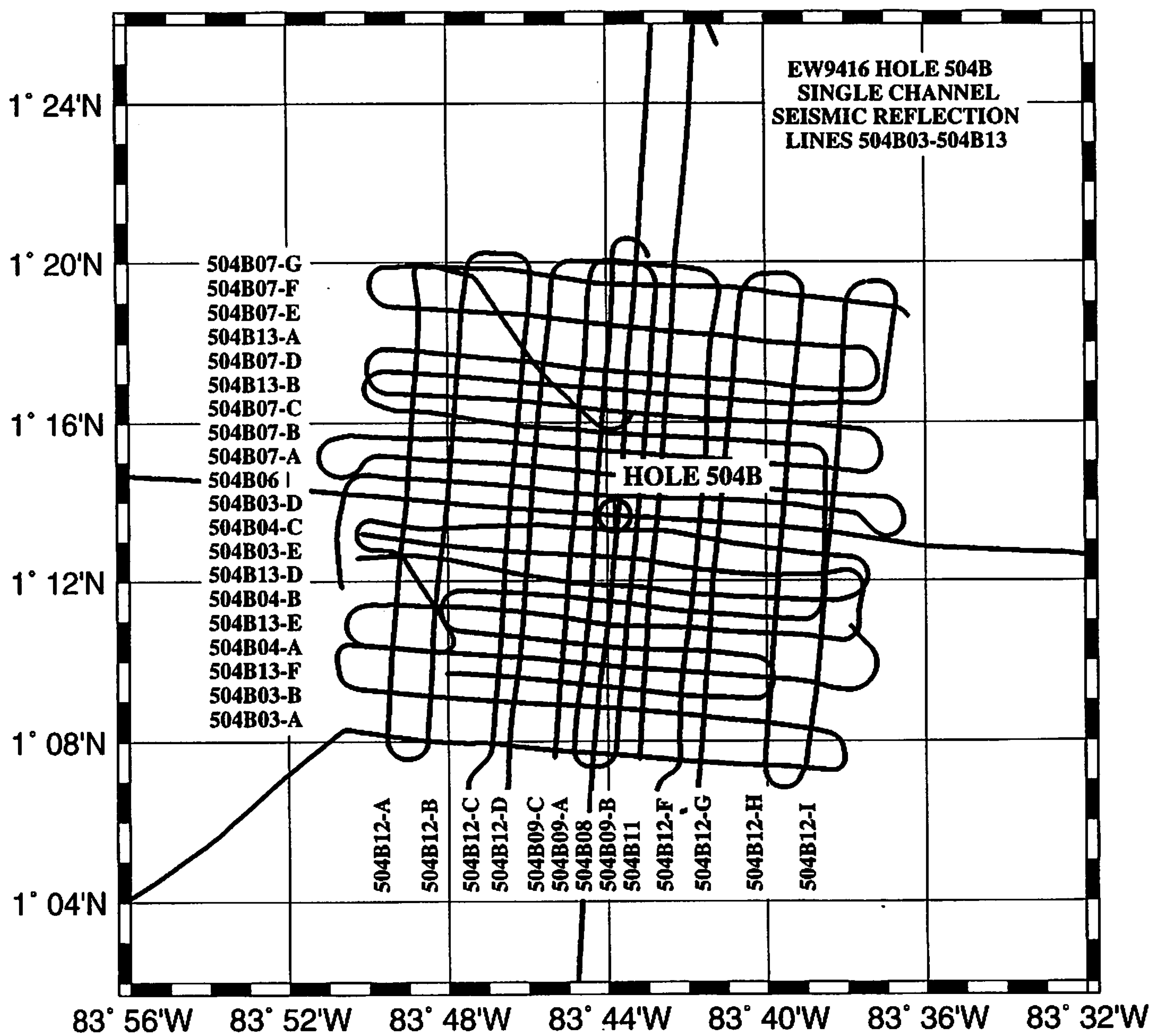

EW9416 HOLE 504B
SINGLE CHANNEL
SEISMIC REFLECTION
LINES 504B03-504B13
HOLE 504B
504B07-G
504B07-F
504B07-E
504B13-A
504B07-D
504B13-B
504B07-C
504B07-B
504B07-A
504B06
504B03-D
504B04-C
504B03-E
504B13-D
504B04-B
504B13-E
504B04-A
504B13-F
504B03-B
504B03-A
504B12-A
504B12-B
504B12-C
504B12-D
504B09-C
504B09-A
504B08
504B09-B
504B11
504B12-F
504B12-G
504B12-H
504B12-I
1° 24'N
1° 20'N
1° 16'N
1° 12'N
1° 08'N
1° 04'N
83° 56'W
83° 52'W
83° 48'W
83° 44'W
83° 40'W
83° 36'W
83° 32'W

Figure 10

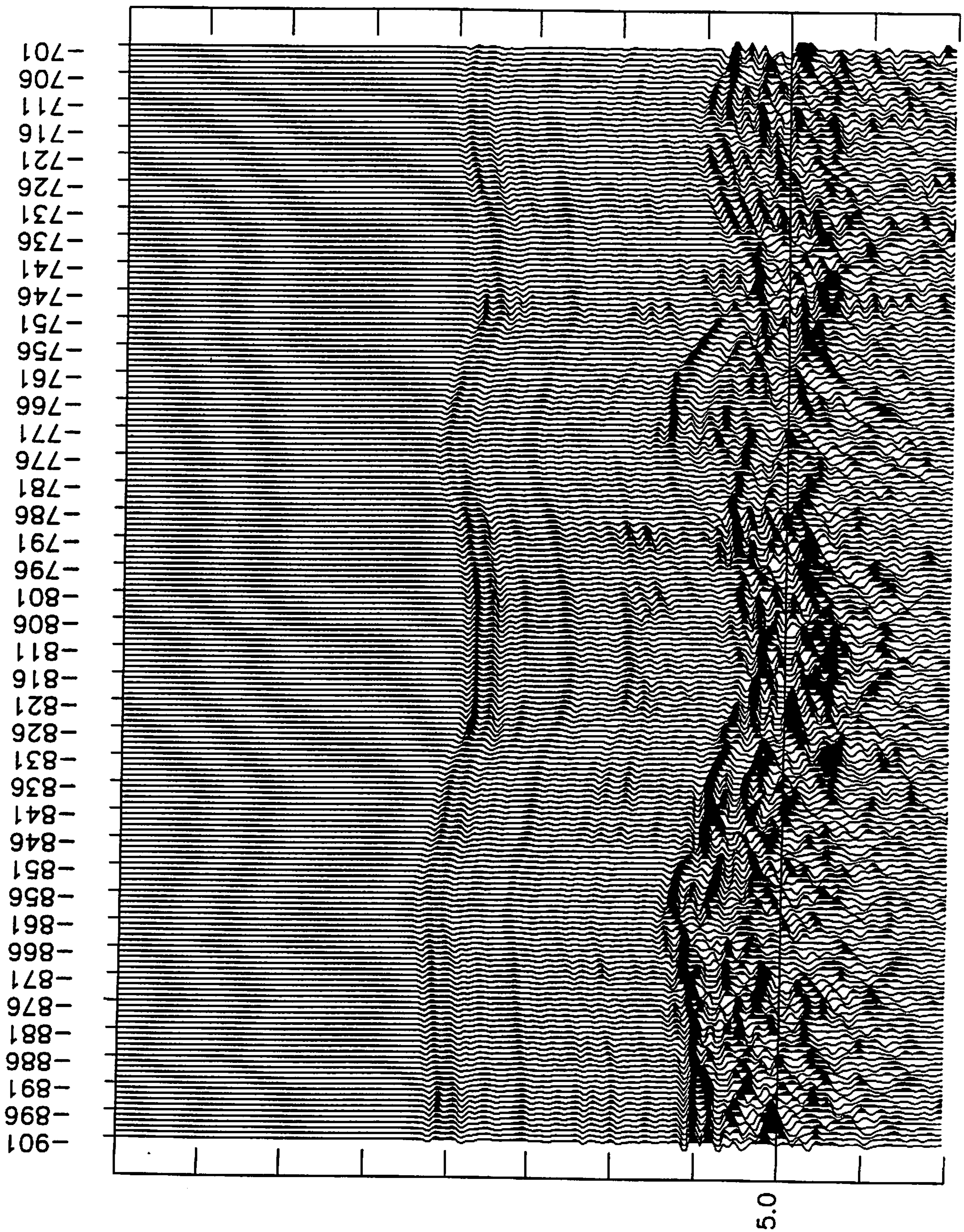


Figure 11

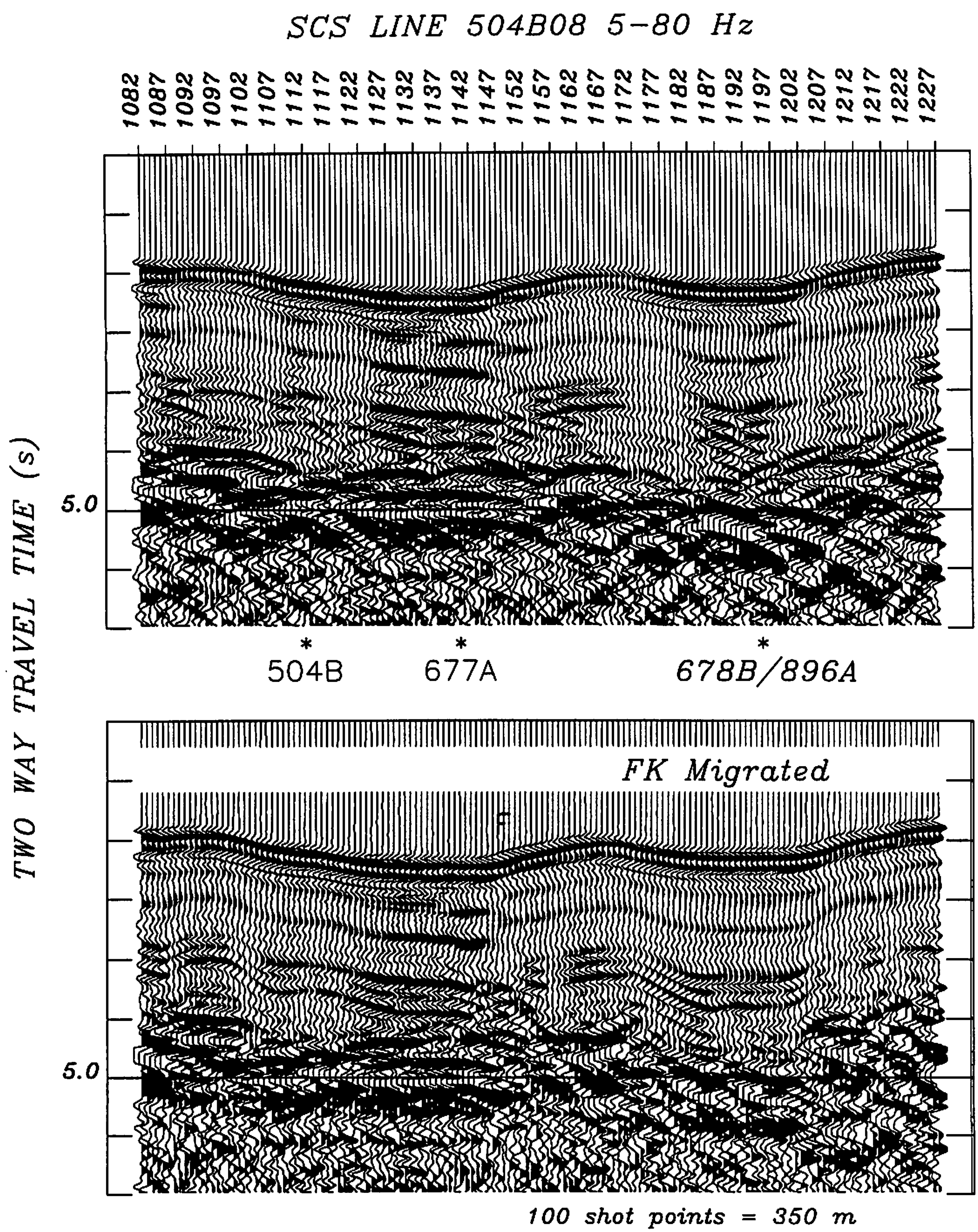

SCS LINE 504B08 5-80 Hz
1082 1087 1092 1097 1102 1107 1112 1117 1122 1127 1132 1137 1142 1147 1152 1157 1162 1167 1172 1177 1182 1187 1192 1197 1202 1207 1212 1217 1222 1227
TWO WAY TRAVEL TIME (s)
5.0
504B
677A
678B/896A
FK Migrated
5.0
100 shot points = 350 m

Figure 12

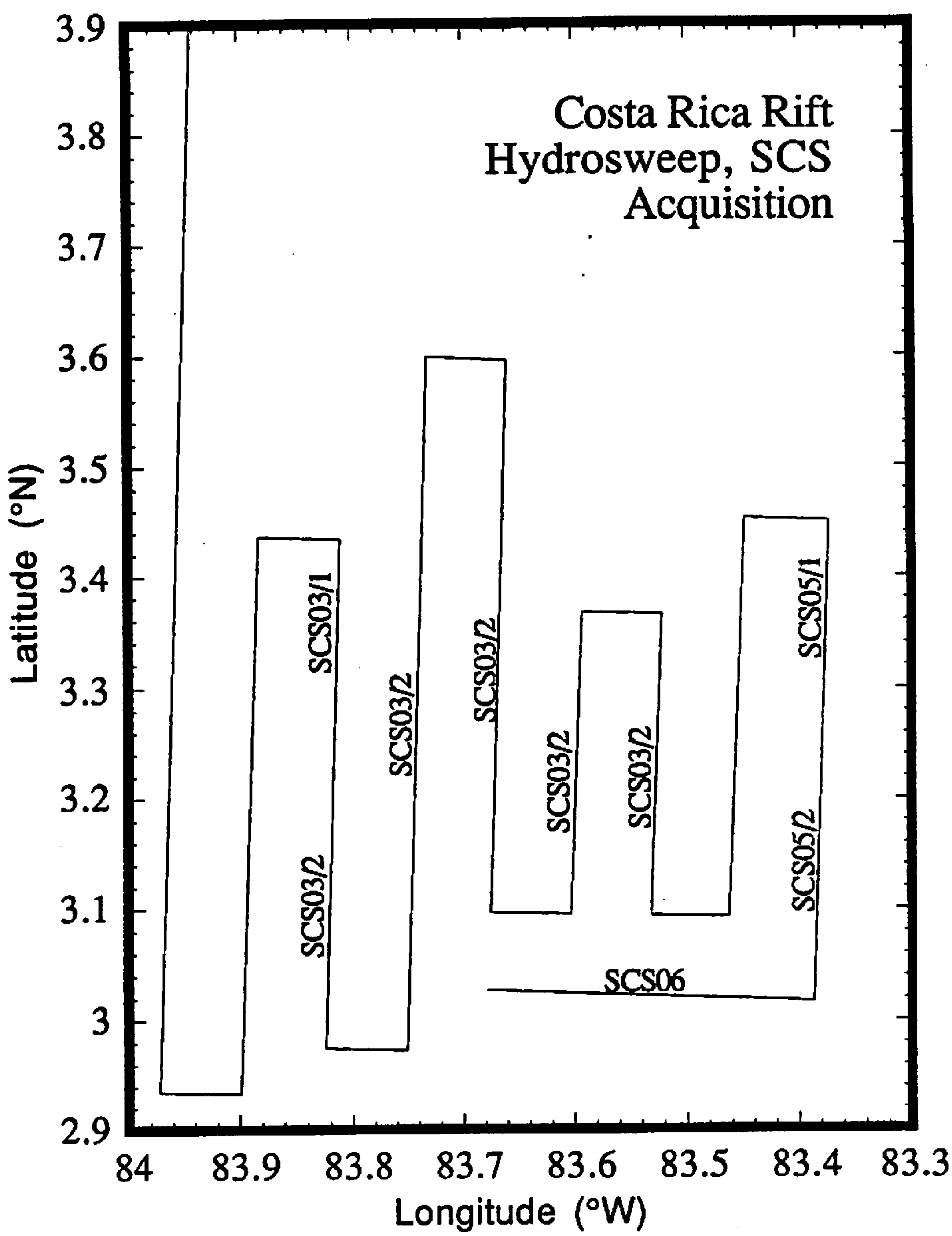
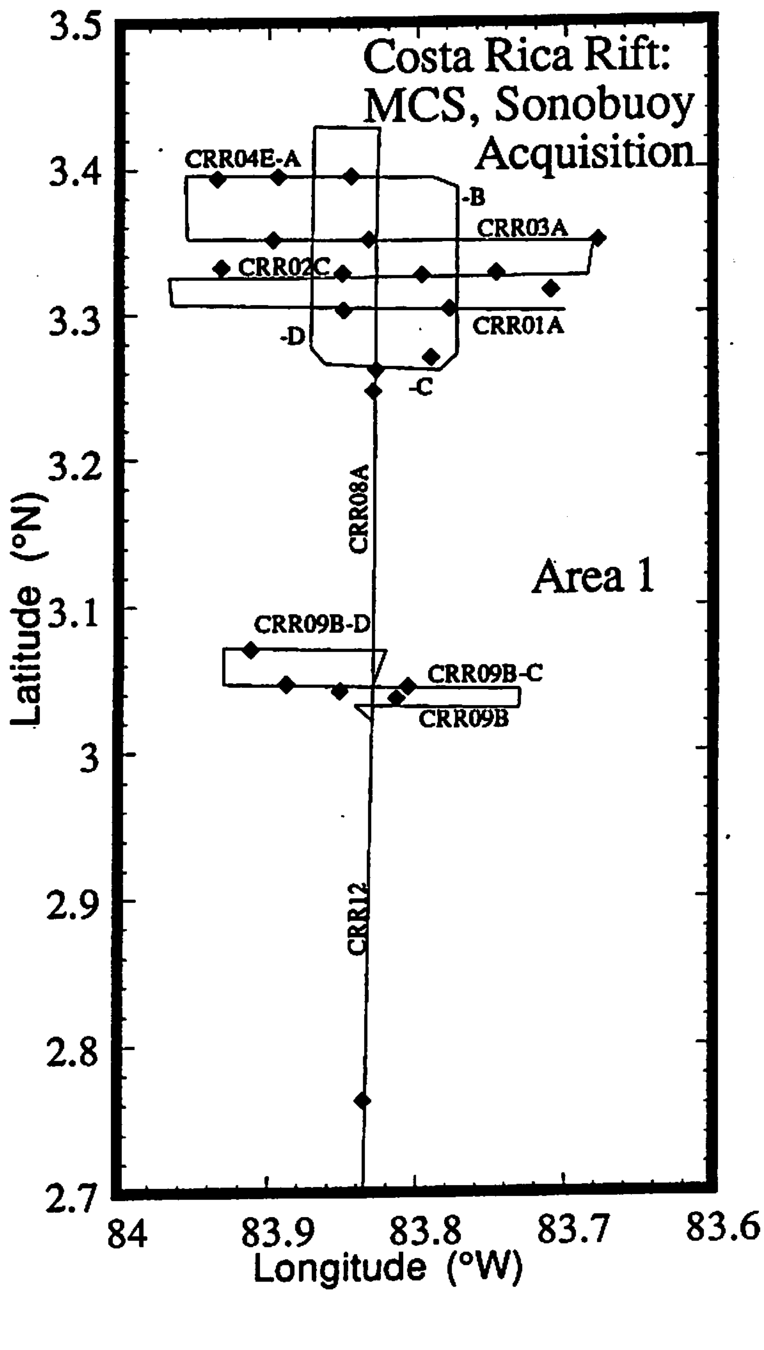
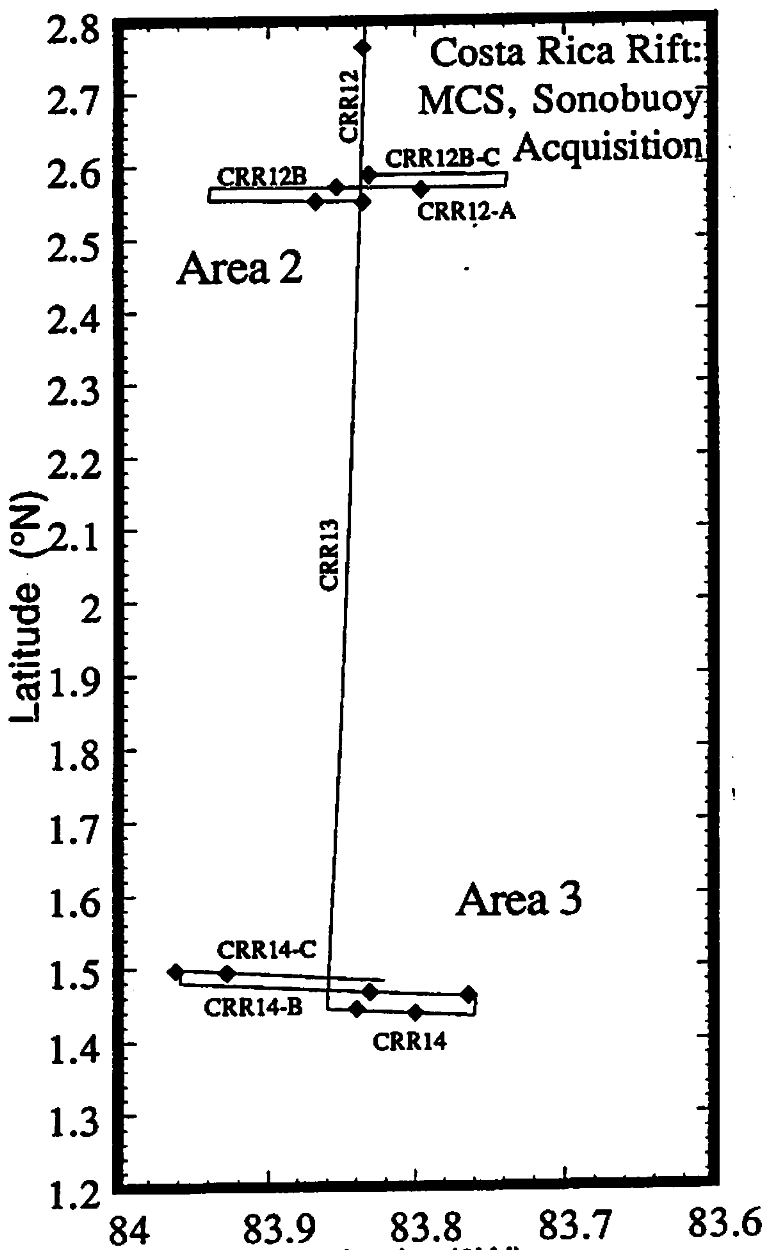

Costa Rica Rift
Hydrosweep, SCS
Acquisition
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
Latitude (°N)
84
83.9
83.8
83.7
83.6
83.5
83.4
83.3
Longitude (°W)
SCS03/1
SCS03/2
SCS03/2
SCS03/2
SCS03/2
SCS03/2
SCS05/1
SCS05/2
SCS06

Figure 13



Costa Rica Rift:
MCS, Sonobuoy
Acquisition
CRR04E-A
-B
CRR03A
CRR02C
CRR01A
-D
-C
CRR08A
Area 1
CRR09B-D
CRR09B-C
CRR09B
CRR12
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
Latitude (°N)
84
83.9
83.8
83.7
83.6
Longitude (°W)

Figure 14a



Costa Rica Rift:
MCS, Sonobuoy
Acquisition
CRR12
CRR12B
CRR12B-C
CRR12-A
Area 2
CRR13
Area 3
CRR14-C
CRR14-B
CRR14
Latitude (°N)
Longitude (°W)
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
84
83.9
83.8
83.7
83.6

Figure 14b