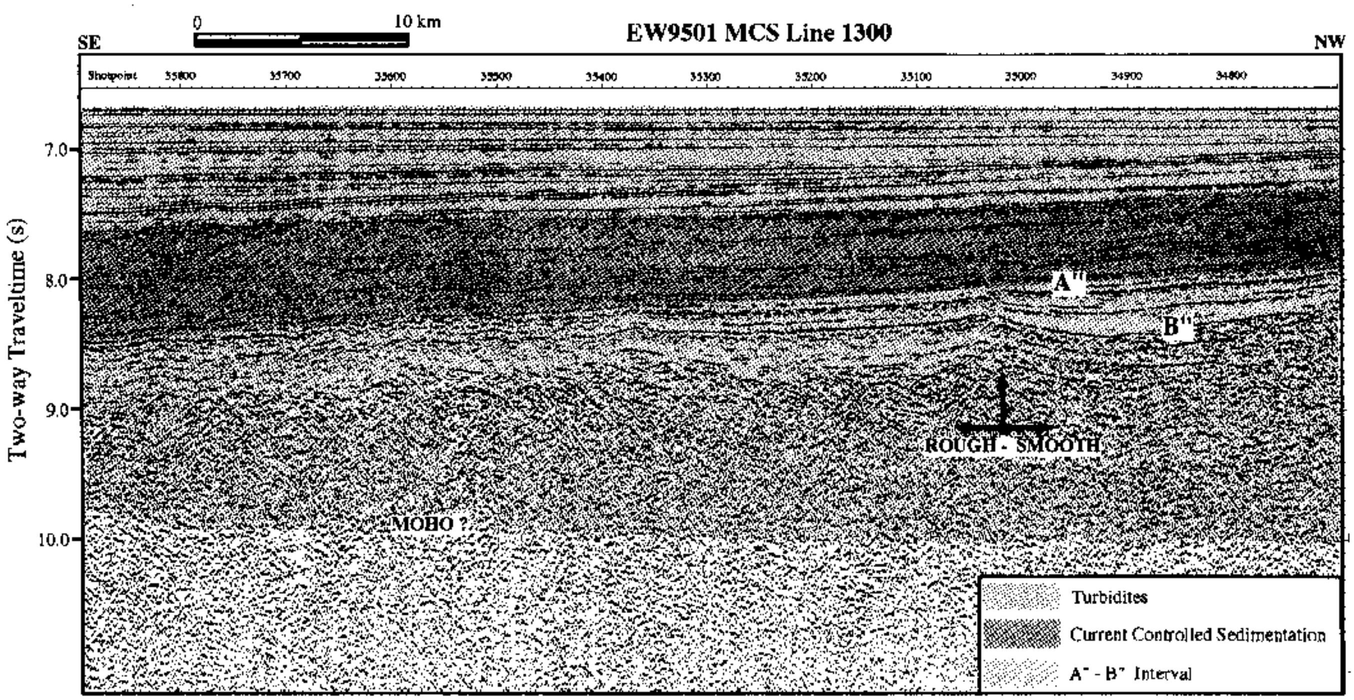
# Geophysical Investigation of the Caribbean




## CRUISE EWING 95-01

**Chief Scientists:**

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# CRUISE SUMMARY

# EW-9501

## GEOPHYSICAL INVESTIGATION OF THE CARIBBEAN

Tampa, Fla., U.S.A - Balboa, Canal Zone, Panama
02/16/95 (JD-47) -- 03/21/95. (JD-80)

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***R/V MAURICE EWING***

## TABLE OF CONTENTS

Page

Preliminary Report on the R/V EWING Cruise
9501
February 16 - March 21, 1995

# Mesozoic Crustal Development of the Caribbean Region: A Geophysical Investigation

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# Background and Scientific Objectives

## Venezuelan Basin

The origin and subsequent tectonic history of the crust beneath the Caribbean basins remains an enigma, despite forty years of investigation by geologists, geophysicists, and even by drilling. Many hundreds of miles of single channel and multichannel seismic profiles have been accumulated, but very few of these were acquired with systems powerful enough to reliably and consistently image the entire crustal sequence. Using the R/V *Ewing's* multichannel seismic capability we revisited two key areas to ascertain the origin and subsequent development of the Caribbean crust. The Venezuelan Basin contains several physical and geophysical features that can be explained a number of ways. Between its eastward edge at the west Aves Rise and the Beata Ridge to the west (Figure 1), the Venezuelan Basin has a northeasterly-trending grain, defined by apparently linear magnetic anomalies, basement faulting, and a marked boundary between two distinct crustal types (smooth and rough), with little to no gravity signature. The deep structure of this basin certainly contains the missing clues necessary to determine its origin. The main objectives of the Venezuelan Basin geophysical survey were to: (1) define the rough/ smooth basement boundary better and examine the spatial and temporal relationship between the different crustal types, (2) ascertain the crustal velocity structure, (3) determine crustal thickness variations across the rough/smooth boundary, (4) image Moho, sub B", and Cretaceous to early Tertiary sediment reflectors, and (5) examine the link between the observed magnetic lineations and structural lineations.

## Beata Ridge

An understanding of the tectonic forces responsible for the formation and evolution of the Beata Ridge is crucial to solving the mystery of how the Caribbean has accommodated the stresses that have apparently resulted in differential strain and plate movement in the Colombian and Venezuelan Basins. Recent plate kinematic models for the Caribbean region have required that the Venezuelan and Colombian basins experienced differential motion since at least the middle Miocene, with east-northeast and east-southeast azimuths, respectively. This two-plate kinematic model predicts that deformation across Beata Ridge may have accommodated the differential motion between the eastern and western Caribbean (Figure 1). Therefore, to determine the relative plate motion of the Caribbean region and to discern whether the deformation of the Beata Ridge is actually registering the development of a diffuse plate boundary, it is imperative to determine the tectonic origin and evolution of the Beata Ridge. The main objectives of the Beata Ridge survey are to: (1) determine if crustal thickness variations can explain the differential topography between Beata Ridge and the Venezuelan and Colombian Basins (2) determine if additional deformation affected the region due to differential plate motion, and (3) ascertain whether the additional deformation and the resulting topography was due to tensional or compressional forces. Finally, determining the deformational history of the Beata Ridge will provide critical information necessary to address the history of the relative motion of the Caribbean plate and to discern whether the azimuthal and deformation data can be belter explained by one or two plates for the Caribbean region.

## Pre-Cruise Preparation

Prior to the cruise, we reprocessed large portions of the *Conrad* MCS data (cruises 1904, 2102, and 2103) and also re-examined the velocity determinations based on sonobuoys and expanding spread profiles (ESP's). We brought the reprocessed seismic reflection data and velocity determination data onboard for continued interpretation and to help refine/modify the cruise tracks. At the last moment, some confusion regarding our research objectives occurred at the Venezuelan Foreign Ministry and it was perceived that our study would focus on environmental issues, particularly "TAR BALLS." As a result of this confusion, the Venezuelan Foreign Ministry denied clearance for our study. In an all out effort, John and I contacted several Venezuelan scientists (e.g., Mario Paparoni and Franco Urbani) in an attempt to clarify the confusion and foster support for our research expedition. We believed that by clarifying the confusion concerning our research objectives, the Venezuelan Foreign Ministry would look favorably on our request to conduct scientific research in Venezuelan waters. As the cruise began, numerous communications by phone, fax and Federal Express had yet to resolve the problem. We sailed from Tampa with the hope that our colleagues in Venezuela would soon resolve the clearance problems with the Foreign Ministry. Although we made all the appropriate arrangements for a Venezuelan Observer to participate in the cruise, previous commitments on their behalf and short notice on our behalf made this all but impossible. Arrangements for the participation of a Colombian Observer had been made earlier and our plan was to work out the logistics of data transfer with him (Miguel Garzon) during the cruise.

## Cruise Narrative

Thursday, February 16th (JD47) - We left the dock at Tampa, Florida at 03:00 PM heading toward the seabuoy. Pilot away at 18:19L, we increased to full speed heading for the first way point just north of the Mona Passage (68'W 19' 30'N), where the MCS gear will be deployed. Upon passing the seabuoy, we started collecting 3.5 kHz sub-bottom profile data. Prior to departing Tampa, we collected a gravity tie-in measurement from the Tampa Airport benchmark using the Lacoste-Romberg (model G) gravity meter. A pier/ship reading and GPS position were also collected for the gravity tie-in. The gravity tie-in measured at the Beechcraft General Aviation at Tampa International Airport should be treated with caution because the entire area has undergone construction after the reference point was established. Drift factor and recalculation of gravity using corrected scale factor was performed for both the KSS-30 and Bell gravimeter.

Friday, February 17th (JD48) - Today we passed by Dry Tortuga at approximately 10:00L (15:00 GMT). We discussed with Miguel Garzon, the Colombian observer, what data he would receive from the cruise as well as GMT data from previous Lamont cruises in the region. We will also provide Miguel with a shotpoint/time navigation map for the cruise. Michael Rawson phoned ca. 11:30 to inform us that he re-contacted Tom Cocke at the State Department The Venezuelan Foreign Ministry is apparently reconsidering their decision. No official word is expected before Friday, February 24th. During the transit, we interpreted the reprocessed *Conrad* MCS lines to map the stratal geometries, thicknesses of the stratigraphic successions overlying B", and the rough/smooth boundary. Many lively discussions concerning the emplacement of smooth B" basement occurred today and promise to be ongoing. We developed a preliminary model that accounts for the spatial and temporal distribution of rough/smooth basement in a Caribbean tectonic framework.

Saturday, February 18th (JD49) - Today we were passing through the Bahama Straits. Cloud shrouded Cuba lay off to starboard. We continued mapping the stratigraphic successions across the Venezuelan Basin and correlating horizons to existing DSDP sites in the region. We discussed further the origin and evolution of the Venezuelan Basin in light of the possible existence of thin crust (possible even rough basement) SW of Haiti, along the northwestern edge of the Beata Ridge. Accordingly, we opted to extend the northern transects across the Beata Ridge to determine if the crust to the northwest of the Beata Ridge was actually thinned, rough basement similar to that observed in the Venezuelan Basin. We received a fax from Michael Rawson outlining our position concerning Venezuelan clearance as interpreted from the Law of the Sea. At this point we discussed alternative areas of interest en route to the Venezuelan Basin to allow the Venezuelan Foreign Ministry sufficient time to clarify the misconceptions and look favorably on our clearance request. We decided to conduct a small survey (three lines, ~1 day) along the northwest coast of Puerto Rico to image the fault controlled Mona Canyon to examine the diffuse deformational nature of the Hispaniola and Puerto Rico blocks.

Sunday, February 19th (JD50) - We are heading east through the Windward Passage. Strong headwinds with gusts up to 25 knots have slowed our progress. Consequently, we are approximately 4 hours behind schedule because our average speed has been consistently below 11 knots. Miguel requested the corrected gravity (crossing errors removed) for all L-DEO lines in Colombian territorial waters. After numerous discussions, we opted for a triangular survey "Lew's Triangle" that would cross the predominantly east-west trending 19° fault rather than the previously decided. Mona Canyon survey. Tension concerning Venezuelan clearance is starting to rise; only five more days before we are scheduled to enter into Venezuelan territorial waters. Peter Buhl has been working on the custom-built SCSI splitter, which will allow data to be split off prior to the data logger. Near real time viewing of the seismic data will enable us to make on-line decisions concerning our survey strategy and sonobuoy deployment.

Monday, February 20th (JD51) - We have yet to receive word from Michael Rawson concerning the clearance, we eagerly await. Mike has been contacting Mario Paparoni, at Conicit, on our behalf to apply internal scientific pressure on the Venezuelan Navy. Strong headwinds persist (25 knots) and moderate swell has made for a bumpy ride. Nevertheless, the R/V *Ewing* rides the seas quite nicely. We reached the deployment site (68°W 19° 30'N) at approximately 19:30L. We were roughly 16 nautical miles north west of our first line through the Mona Passage when we began deploying the streamer. Streamer deployment went smoothly with only a few minor delays. New bird collars had to be added to the streamer as well as additional lead weights to the old portion of the streamer. Oil was added to the last few sections of the streamer after bleeding out localized pockets of water. After deploying the tailbuoy at 20:01L, Joe Stennett noticed that the strobe light wasn't operating properly. Consequently, we pulled in the tailbuoy, secured it on deck at 20:42L and mounted a new strobe light. The airgun array was deployed (See Figure 3 and Table 4 for chamber size and towing configuration) and the first shot fired at 07:24L (1524 GMT). Communication with all of the streamer sections was established and the active streamer was successfully "built" by the DMS2000 seismic acquisition system. So far so good.

Tuesday, February 21st (JD52) - Guns appeared to be firing consistently and the acquisition system was up and running. We were in the process of setting up the CSRU and CEO for the start of Line 1288 when we noticed that the airgun firing system (TAGS) was not working properly - the guns were not firing in synch. Start of Line 1288 occurred at 13:16. We rebooted the acquisition system at 08:28L (13:28 GMT) in an attempt to synchronize the guns. After a few futile attempts, Joe Stennett discovered that the gun firing system was still set up for waterguns. Alterations to the hardware via card swapping resolved the gun firing problem. At this point, we decided to turn back to the north to restart the line. We finished the turn at 15:36 GMT and began to proceed toward the Mona Passage. The system is back on line, firing 30 second shots in an attempt to image deep returns from the Mona Passage. According to advice from Joyce Alsop, L-DEO MCS processing system manager, the first EW-9501 MCS line is designated 1288. Two guns still are off line because of problems with the shuttle motion detector (SMD) circuitry. One of the compressors went down for 10 minutes at 17:02 and we were forced to shut off half the array. Tape drives starting ping-ponging and rejected tapes 44-46. Starting a new box of tapes appeared to solve the tape drive problem. We received a positive sounding message from Michael Rawson concerning our clearance request. Thus far, he has heard nothing official from the Venezuelans, either positive or negative (thank goodness).

Wednesday, February 22nd (JD53) - We completed the small three-sided survey NW of Puerto Rico (Figure 2; lines 1289,1290,1291), crossing the E-W trending 19° fault and the fault-controlled Mona Canyon. The dipping and divergent reflectors within the canyon axis suggest that the eastern fault has been active more recently than the western fault. Line 1291 ended with a tie to the southern end of Line 1288. Continuing south, Line 1292 crossed the Muertos Trough. Along this line, transpressional deformation north of Muertos appears to have been more intense and recent than within the trough itself. Cruise participant Lewis Abrams plans to integrate the results of these lines into a larger study of the tectonics of Puerto Rico and surrounding regions.

Thursday, February 23rd (JP54) - We proceeded southward along Line 1292 toward the Venezuelan Basin survey area. We changed the shot rate from 30 seconds to 20 seconds after we crossed the Muertos Trough, accordingly we also changed the line number. Line 1293 started at 18:22 GMT (Figure 2 and Table 2). We planned to cross a large seamount previously imaged by USGS Gloria side-scan data. Because it was imaged during Cathy Scanlon's Gloria survey, we referred to it as Cathy's Seamount. Cathy's seamount is located approximately 25 nautical miles north of the proposed drill site C-l. Hydrosweep swath bathymetry indicates that we crossed directly over the summit of the seamount. The seamount is asymmetric with a low ridge to the south. South of the seamount, the seafloor rises gently, and is exhibits a hummocky roughness characteristic of current ripples. Peter Buhl has been developing software for plotting MCS data in real time, and this has been working effectively for the last couple of days, greatly improving our ability to make real-time decisions concerning line adjustments and sonobuoy launch locations. Joe Stennett and Chris Leidhold replaced the bottle for the proton procession magnetometer which was leaking, causing very noisy data.

Friday, February 24th (JD55) - We received two faxes from Michael Rawson, today with verbal approval for Venezuelan clearance. The timing was optimum as we were scheduled to enter Venezuelan waters in just over five hours. At 16:00L we received a fax from Caracas with the official permission. The efforts and support of Michael Rawson, Mario Paparoni, and Franco Urbani in obtaining clearance are greatly appreciated. The survey of the Venezuelan Basin continues. About 15:00L a large Helicopter marked "NAVY" [whose Navy, not known] examined the ship & tail buoy. We were at about 15° 5' North, far from any land when the helicopter appeared. The rough smooth boundary is marked by a structural scarp on Line 1293 at shotpoint 11,250. The thickness of the B" to A" sediment interval systematically increases toward the south along Line 1293 with a marked increase occurring across the rough/smooth boundary. Laminated sequences above A" are lenticular and appear to be current-controlled deposits. Overlying the laminated sequences is an acoustically hummocky chaotic sequence that also appears to have a current controlled origin.

Saturday, February 25th (JD56) - Arrived at the end of Line 1293 at 10:55 GMT. Began turning to starboard to begin Line 1294. Line 1294 began at 12:24 GMT. Minor problems with gun

#19 (850 cubic inches). We pulled it in to check the gun at 13:33 GMT, repairs were made and gun was back in the water at 14:33. Diebold's "brute," "segd2sun" and JDseis software allows onboard processing of the seismic reflection data. For examples of the processed lines see Figures 4 and 6. We are making a brute stack of Line 1293 to produce better images of the rough/smooth boundary, the overlying sediments and Moho. Similar to Line 1293 the rough/smooth boundary is delineated by an escarpment, however, along Line 1294 the scarp appears to have two tiers. On Line 1294, the boundary occurs at shotpoint 15,900. The streamer depth has been extremely consistent over the last few days and we opted to bring it up from 10 meters to 8 meters to match the gun towing depth. Shallower towing depth shifts the notch due to the free surface “ghost" reflection to higher frequencies. The frequency where the "ghost" notch occurs is governed by water velocity divided by twice the towing depth (e.g., for a towing depth of 7.5 meters, the notch occurs at 100 Hz). Four sonobuoys were deployed along Line 1294. The sonobuoy failure rate has been very low (~10%), even though we are using mostly the open pallet of sonobuoys from the last cruise, which were reported to be faulty. Sonobuoy #9 deployed over smooth B" basement looks as if it has Moho returns, as well as sub-B" arrivals, but it's possible that only the paper record is good. Radio frequency (RF) interference is diminishing the signal to noise for the new sonobuoy receiver. We may have to scan some of the paper recordings of the sonobuoys back at Lamont. The same large helicopter labeled NAVY returned again at dusk.

Sunday, February 26th (JD57) - The RF interference on sonobuoy channel 177 continues to be a problem. Although grounding and moving the new receiver has improved the problem, the RF interference still remains. We will change the wire connectors to see if that remedies the problem. Line 1294 ends at 07:07 GMT and we start Line 1295 at 07:21 GMT. Tape drives start ping-ponging at 10:14 GMT for a few tapes. Re-enabling the tape drives solves the problem. We finished line 1295 and Line 1296 started at 12:22. The northern portion of the line is highly structured with numerous normal faults down-dropping basement toward the southeast. Thick lenses of onlapping sediments occur between rough B" and A" horizon and appear to be predominantly gravity flows (turbidites). The laminated acoustic sequence also persists above A." Barbecue today.

Monday, February 27th (JD58) - Basement starts to shoal along the southern portion of Line 1296. This shoaling is probably related to the track crossing a protrusion of the west Aves Ridge. The A" to B" sediment interval thins dramatically across this structural high consistent with the interpretation that these deposits are gravity flows. Line 1296 ends at 10:34 GMT and we begin a starboard turn to start Line 1297. Continuing to the southwest we rapidly step off the basement high and the A" to B" sediment interval thickens precipitously away from the basement high. Line 1297 ends at 16:54 GMT and Line 1298 starts at 17:51 GMT. Sonobuoy 18(21:31 GMT) on Line 1298 looks good. Along the southern portion of Line 1298 there are thick onlapping turbidites that comprise the upper sequence.

Tuesday, February 28th (JP59) - Gun problems with #7 (250 cubic inches) and #10 (145 cubic inches) at 00:17. Both guns are back in the water at 02:14 GMT. The air guns have performed extremely well so far, hopefully this will be the norm for the remainder of the cruise. Rough/smooth boundary occurs at shotpoint 26,070 and is again marked by an abrupt basement escarpment. Further processing might resolve if the escarpment is structurally (fault) controlled or formed by volcanic construction or represents some combination of both processes. Sonobuoy # 26 was deployed on smooth B" and appears to be one of the best sonobuoy records so far. A thick lens of laminated sediment is again seen above A" horizon. The thickest portion of this lens is spatially coincident with the rough/smooth boundary and thins both toward the south and north.

Wednesday, March 1st (JD60) - Finished Line 1298 at 03:41Z and initiated a fillet turn to port to begin Line 1299. Just at the turn onto 1299, we crossed right over a volcanic protrusion. Sonobuoy 30 and 32 look fantastic, the refracted first arrivals have a large gap, suggesting the existence of a low velocity zone below B," which must diminish to the south - the low velocity zone was not detected on ESP 3 [or was the gap "filled," due to the power in the ESP explosive source?]. We discovered some one-way crosstalk on sonobuoy receiver channels [178 -> 178,177 -> 177 + 178]. This cross-talk appeared to be related to the old sonobuoy receivers, which were wired to channel 178 at this time. Subsequently we discovered that by switching on the AFC switch on the old sonobuoy receiver solved the "cross-talk" problem, which was actually the result of the radio re-tuning itself to the frequency of the new buoy's stronger signal. Additionally, when the AFC switch was on, the sonobuoy receiver failed to track the sonobuoy channel after approximately 1-1/2 to 2 hours. Without the AFC switch turned on, normal sonobuoy reception was 4+ hours. Along Line 1298 reflector A" appeared to have a negative polarity (i.e., phased reversed) reflection. In contrast, the reflector appears to have a positive polarity along Line 1299. Started Line 1300 at 13:43 GMT.

Thursday, March 2nd (JD61) - Deep apparent critical reflection observed on sonobuoy 33, which produced an excellent analog record. Graphical determination of the critical angle yields an apparent velocity of 8.9 km/sec. The sonobuoys were shot over smooth B" basement. Considering the sonobuoy was shot updip, this may be correct for Moho. Dip corrections for the sonobuoys will be performed back at Lamont. In a area of smooth B" basement on Line 1300, they are some graben structures centered around shotpoints 31,700 and 33,700. Reflector A" is offset over the graben features indicating that the deformation occurred post-A" (middle Eocene). The supra-A" sediment interval overlying smooth B" has an acoustically hummocky character (Figure 4). The rough/smooth B" boundary occurs at approximately shotpoint 35,400 and is associated with a reversal of dip near the boundary. We refer 10 this local (~10 km) change in dip as the "Ski-Jump" (Figure 4). Coincident with the rough/smooth boundary is a marked increase in the thickness of the A" to B" sediment interval. The sequence above A" is becoming systematically less well laminated toward the east (from Lines 1294 to 1300) and exhibits a more hummocky acoustic character. The acoustic character and thickness distribution suggests that these are drift deposits. The free-air gravity signature along MCS Lines 1300 and 1302 is typical of the region (Figures 5 and 7). and is of little help in delineating the crustal structure. Similar gravity anomalies were measured during *Conrad* cruises 1904, 2102, and 2103, which also showed a gradual and smooth increase towards the northwest. ESP 3 *(Conrad)* and sonobuoys indicate that the crust is thicker to the northwest, however, because the free-air gravity anomaly increases toward the northwest then the increasing depth 10 Moho must be offset by the shoaling of basement toward the northwest. Upon returning to Lamont, we will model the gravity and magnetic data. The source of the magnetic anomalies remains a question. The orientation of the lines should help us determine if they are caused by structure or magmatic emplacement. Finished Line 1300 at 17:59 GMT and turned to port to start Line 1301. Line 1301 was very short, ending at 20:39 GMT, and we started Line 1302 at 20:45 GMT.

Friday, March 3rd (JD62) - Problems with air gun #7 (250 cubic inch) at 05:12, gun repaired back in water at 07:29 GMT. At 10:42 GMT we lost both compressors, and ship speed dropped to 1.3 knots. This loss in main generator output was only temporary, and we shortly regained the speed and the streamer and guns recovered nicely. The maximum streamer depth that occurred during the power loss and slowdown was approximately 30 meters. As a result of the power loss, we missed shots 39,500 through 39,521. One of the compressors remained off line at 10:49, consequently 5 guns were still off line for a period. We replaced the coaxial cable leading from the new receiver to the OBAD digitizer can, which solved the RF interference problem. Sonobuoys look great for the last two days. During sonobuoy #41 the system hung up. However, the air guns kept shooting and thus the analog record is complete. We will scan the analog sonobuoy record back at Lamont. The rough/smooth boundary is not marked by an escarpment on Line 1302; in fact the boundary is much more subtle and occurs at approximately shotpoint 38,780 (Figure 6). The rough/smooth boundary has very little gravity signal (Figure 7). The two sequences above A" (acoustically hummocky and acoustically laminated sequences) both systematically thicken toward the southeast (Figure 6). At 20:56 GMT, the main GPS satellite receiver went down. Subsequently, we determined that the MARISAT transmissions were interfering with the GPS receivers on certain course headings. All six sonobuoys deployed on Line

1302 were successful. The smooth B" basement surface is made up of several en echelon reflectors that commonly downlap onto the underlying surface, suggesting multiple flows.

Saturday, March 4th (JD63) - Sonobuoy failure rate began to increase (sonobuoy #43a failed -03:51 GMT), specifically when we started using sonobuoys from the pallet in the CTD room instead of from the pallet on the A-deck. Line 1302 ended at 03:03 GMT. We made a "fillet" turn to port and started Line 1303 at 03:25 GMT. The character of the rough/smooth boundary has been quite variable from line to line and we discussed and planned a zigzag survey across the rough/smooth boundary to determine if there were tongues of smooth basement which infilled between fault segments as well as trying to determine the change in character of the rough/smooth boundary from the "Ski-Jump" to a more subdued gradual boundary along Line 1302 and *Conrad* Line 08. Consequently, we decided that we would break off from Line 1304 and cross some previously mapped faults just south of 14°N and "zigzag" across the rough/smooth boundary filling in between the existing lines. Finished Line 1303 at 10:37 GMT and started to the southeast along Line 1304 at 10:46 GMT. Low compressor pressure caused us to turn off 7 guns at 11:01 for a couple of minutes. Pressure back up above 2000 psi, all guns back on line at 11:03. Maintaining streamer depth at 8 meters started to become a problem at 11:13 GMT, we tried the usual techniques [burnt offerings, owl guts] to maintain the depth. Finally at 13:27 GMT, we increased the streamer towing depth from 8 to 10 meters to minimize the influence of the surface swell. This adjustment of towing depth appeared to solve the problem. Line 1304 crossed over proposed ODP site S-7A near shotpoint 43,900. The sediment interval overlying basement thins by downlap and possibly minor amounts of truncation toward the south away from the proposed site. Six sonobuoys were deployed along Line 1304, of which four were successful.

Sunday, March 5th (JD64) - Line 1304 ended at 07:01 GMT and Line 1305 began at 07:17. The zigzag lines will each be approximately 4 to 5 hours and thus we planned to deploy a sonobuoy at the beginning of every line. During the turn the streamer shoaled to the surface and repeatedly during the beginning of the line. We increased streamer depth selection to 12 meters, which solved the problem for a while. However, the middle portion of the streamer developed a hump and was near the surface as is evident by the noise in the stack output to Profiler B. The noise is not observed on Profiler A because this is the single channel trace (trace 150) that is from the front of the streamer. Line 1305 crossed a small fault that is dipping toward the southwest, which is opposite to that shown on previous maps of this region. We need to go back and examine the seismic data used in generating the DNAG Caribbean Map. Line 1305 ended at 10:34 GMT. Line 1306 crossed the rough/smooth boundary at shotpoint 48,300. The boundary in this location is marked by a small scarp. Line 1306 ended at 15:21 GMT and we turned and headed back toward the north-northwest to cross the boundary again on Line 1307. The rough/smooth boundary is more subtle along this line and occurs at shotpoint 49,300. Along some lines there are zones where it is difficult to discern whether the basement is rough or smooth, in these zones the basement has attributes of both. Two possible explanations could account for this observation, first the rough basement has a preferred fabric that is better imaged on certain azimuths and second that these areas are characterized by thin flows over pre-existing rough basement. Line 1307 ends at 19:50 GMT and we turned and headed east-northeast along Line 1308. We selected a number of different azimuths with which to cross the rough smooth boundary to determine if the morphology of the boundary was dependent on the insonification direction. The rough/smooth basement boundary occurred at shotpoint 50,000 on Line 1308. The acquisition system is hung at 22:10 GMT several shots were lost, guns were turned off.

Monday, March 6th (JD65) - Line 1308 ends at 01:08 GMT. The streamer is very sensitive to minor velocity fluctuations; when the ship speeds up the front of the streamer starts shoaling, if we slow down the streamer tends to hump in middle. The quality of the sonobuoys varies by the pallet - our overall success rate has now dropped from 85% to about 75 - 80%. We have completed 12 crossings of the rough-smooth B" boundary to analyze its character which should hold clues regarding its emplacement. Real time displays of the MCS data using the custom-built SCSI splitter have been extremely helpful in determining the best azimuths to cross the rough-smooth B"

boundary. Examination of the MCS and 3.5 kHz data indicates that current-controlled deposits are pervasive throughout the Venezuelan basin. Line 1309 shows some ponded areas of smooth basement (shotpoints 51,100 to 51,300) surrounded by regions that appear to be rough basement on either side. We interpret these isolated regions of smooth basement as tongues of basalt that flowed sub-parallel to the north-northeast trending faults. At 06:18 GMT we turned back toward the east-northeast along Line 1310. Line 1310 is oriented sub-parallel to the faults in the region and appears to be imaging the down-dropped block of a graben structure. The western portion of the line crosses structure and it is not clear whether the area is faulted smooth or rough basement. Further processing will hopefully discern between these two possibilities. We turned to the north-northeast at 12:48 GMT and began Line 1311. The rough/smooth boundary on Line 1311 is characterized by the "Ski-Jump" variety and occurs at shotpoint 53,150. The escarpment is made up of two faults in this region. Turning to port, we began Line 1312 at 18:06 GMT. Line 1312 crossed three normal faults (CVBF) in north and
imaged the eastward extent of the smooth basement tongue observed in Line 1309. The basement within the down-dropped blocks appears to be smooth. This late stage structuring could be caused by cooling, contraction, and subsidence subsequent to emplacement. After discovering the potential tongue of smooth basement we decided to continue on this line past the original waypoint.

Tuesday, March 7th (JD66) - At the waypoint, we turned north on a parallel trajectory to Line 1312. Small areas of smooth basement may be present between the highs. Stacking and migration of the MCS data will help to determine if this is actually smooth basement ponded in the structural lows. The faults and tilted blocks imaged in the region have a only a local expression. It is difficult to trace these faults over large distances, they have an en echelon geometry in map view. Given the local nature of these fault systems, the questions arise as to the extension direction and whether these fault systems are recording transtension across the region (i.e., they are wrench faults). At 02:45 GMT, we turn toward the west onto Line 1314. There is no rough/smooth boundary observed on Line 1314. It appears that Line 1314 passed over the tongue of smooth basement that was imaged in the north-south oriented Lines 1309, 1312, and 1313. At the end of Line 1314, we turned to port and headed southeast along Line 1315. The rough/ smooth boundary occurs at Shotpoint 56,320 and is marked by a small escarpment. Line 1316 began at 11:44 GMT and was designed to connect with the end of Line 1304 in order to continue Line 1304 farther south along the same trajectory. Line 1316 crossed the rough/smooth boundary at shotpoint 57,480. It also crossed a fault dipping toward the east. After crossing Line 1304 we made a large turn to starboard before initiating Line 1317. This maneuver returned us to a point approximately 2 km before the end of Line 1304, which allowed us to straighten out the streamer before continuing the line to the south-east. At 17:56, the water velocity correction for the hydrosweep was changed from 1500 to 1520 m/sec. This change violates standard EWING practice, but was required to remove artifacts in the real-time bathymetry displays. Airgun #10 (145 cu. in.) was pulled in for repair. Tape drives started ping-ponging at 20:12 GMT. The MCS acquisition system has operated smoothly, with only a few short episodes of the premature tape ejection (ping-ponging), a problem which plagued the '94 season. This is partly due to the intervention of the custom-built SCSI splitter, whose subtle effect on signal timing seems to be beneficial. We began Line 1317 at 21:31 GMT.

Wednesday, March 8th (JD67) - Air gun #9 (385 cu. in.) was pulled in for repairs at 00:50 and redeployed at 02:50 GMT. The A" to B" sediment interval is thin here in the western region of the Venezuelan Basin. The thickness of this interval has systematically decreased from east to west. The sequences overlying A" (lower sequence - acoustically hummocky and the upper sequence - acoustically laminated) thicken dramatically toward the southeast with a pronounced increase in thickness across the rough/ smooth boundary. The rough/smooth boundary occurs at shotpoint 58,900 and is delineated by a large basement high. Line 1317 ended at 04:51 GMT and Line 1318 began at 04:59 GMT. We began to output stacked data from the SCSI splitter on the analog profiler (Profiler B) at the beginning of Line 1318. The velocity function required for stacking was derived from JDseis interpretation of sonobuoys. Line 1318 crosses the deformational front and indicates that the A" to B" interval is subducted beneath the front rather than offscrapped. These horizons can be traced laterally at least 30 km inboard of the accretionary prism. It is difficult to identify the rough/smooth boundary on this line because of the thick sediment in the prism, however a possible candidate for the boundary occurs at shotpoint 60,200. Caution should be exercised before labeling this the rough/smooth boundary because the change from smooth to rough basement is spatially coincident with the deformation front and thus could be an artifact due to the overlying deformed sediments. Clearly, further processing will help determine if this is the rough/smooth boundary. Line 1318 finished at 09:23 GMT and we began Line 1319 at 09:31 GMT. Though our ability to maintain the streamer at a constant depth is improving, we are still towing it at 10 meters. Numerous faults (at least 4) that down drop the A" to B" to the south are observed on Line 1319. The structure imaged on Line 1319 is greater than that observed on the nearby *Conrad* cruise 2103 Line 119. One of the fault systems imaged in the seismic data is clearly a candidate for a reverse fault. The hemipelagic-pelagic deposits overlying A" on the downgoing plate thin dramatically at the point where they are onlapped by the well laminated sequence (upper sequence - inferred turbidites). One possible explanation for the observed thinning is erosion of the underling hemipelagic-pelagic sediments by turbidity currents sourced from the Magdalena Fan toward the west. The acoustically hummocky sequence (lower sequence above A") is not observed on Line 1319. The *Conrad* MCS lines indicate that the lower sequence thins towards the west. As in the case of Line 1318, it is difficult to assess whether Line 1319 crossed the rough/smooth boundary. A possible candidate for the rough/smooth boundary occurs at shotpoint 61,900. However, this boundary is again roughly coincident with the deformational front and the change in the basement's acoustic character could be solely due to the overlying deformed sediment. We hope that further processing of the MCS data will resolve this issue. Weak magnetic lineations have previously been reported for the Venezuelan Basin, and even identified as seafloor spreading anomalies but these identifications are ambiguous. Preliminary interpretation of the magnetic anomalies plotted along track (Figure 8) suggest that there is only one correlatable magnetic lineation in the region. We plan to replot all the existing magnetic data in the region and model the magnetic data to resolve the origin of the magnetic anomalies in the Venezuelan Basin more definitively. Tape drives started ping-ponging at 20:40 GMT, however, only 3 shots were missed due to excellent and attentive watchstanders.

Thursday, March 9th (JD68) - Air gun #11 (145 cu. in.) out of the water at 03:50, fixed and redeployed at 04:30. Finished Line 3319 at 04:13 and began Line 1320 heading north toward the DSDP Sites 150 and 146/149. Airgun #11 pulled in because of autofiring, repaired and back on line at 07:33 GMT. Airguns #1 (145 cu. in.) and #2 (875 cu. in.) down at 07:33 and back on line at 07:47. The sediment interval overlying basement thins by downlap and truncation toward the south away from DSDP Site 146/149. This is one of the few areas in the study region where the hemipelagic-pelagic deposits show signs of truncation. Together with the interpreted drift deposits, we interpret this truncation and nondeposition to record the counterclockwise flow of bottom currents around the Venezuelan Basin. A core of bottom water flow appears to be concentrated near the 4000 meter isobath (Figure 1). This ribbon of flow appears to explain the erosion and nondeposition observed along Line 1320 (Figure 2). DSDP site 150 is located at shotpoint 65,300 in an area where the maximum hiatus occurs due to erosion and nondeposition. Farther to the north DSDP site 146 (Shotpoint 66,520) sampled the sedimentary section farther away from the ribbon of swift current and thus sampled a more complete sedimentary section. At 19:35 we pulled in Airgun #8 (850 cu. in.) and it was back in the water at 20:01 GMT. One compressor down at 23:05 GMT, 5 guns were temporarily shut off. Compressor back on line at 23:12. Additional problems occurred with Airgun #8 (850 cu. in.): we needed to pull it in again at 23:36. We have finished Line 1320 at 22:30 GMT and are leaving the Venezuelan Basin and heading northwest to survey the Beata Ridge. We started Line 1321 at 22:39 GMT.

Friday, March 10th (JD69) - We shut down a number of airguns because one compressor went down at 01:36 GMT. Compressor back on line at 02:25 GMT, all airguns back on. The winds are calming down, hardly any swell. It is a very hot day; the heat is quite noticeable because of the lack of a breeze. Tape drives started ping-ponging at 13:12 GMT, consequently we are missing tapes 1481-1486 (missing 8 shots). At 22:01 the navlog tape terminated near shot 71,965. A number of basement highs, small seamounts, are observed along Line 1321. Across one of these basement highs, near shotpoint 70,500. The basement has a DC offset being almost 200 to 300 milliseconds shallow toward the northwest. The A" to B" sediment interval thins across these structural highs suggesting that the features existed prior to the onset of deposition. Many of these features appear to be constructional, but it is difficult to explain the DC offset of basement across some of the structural highs. Another possible explanation proposed for the origin of these features is that they are "pop-up" (inversion) structures. Nevertheless, this explanation doesn't account for the basement offset across these features either. Furthermore, if the reverse faults inferred to cause these "pop-up" structures exist, then they are poorly imaged in the seismic data (i.e., not observed).

Saturday, March 11th (JD70) - Passed Beata Island during the morning. It appears to be the onshore continuation, along with Beata Peninsula, of the offshore Beata Ridge. The seas are even calmer than yesterday without a breath of wind. Perfect weather conditions for MCS. The streamer is towing well. We crossed over a series of normal faults beginning at shotpoint 71,700, which down dropped basement toward the east. Starting to climb up the eastern flank of the Beata Ridge. The A" to B" sediment interval is thin in this region. The sediment interval overlying A" is acoustically hummocky and is indicative of current-controlled deposit. Along the eastern flank of the Beata Ridge is a graben structure centered around shotpoint 72,700. The basal reflectors in the graben dip toward the west suggesting that the western fault delineating the graben has been most active. The lower reflectors are barely discernible in the single trace analog profile, however, they are clearly imaged in the stack analog Profiler B record. Many times the slack record proved extremely worthwhile for imaging deeper sediment horizons, sub B" reflectors, and Moho. The western flank of the Beata Ridge also appears to be fault controlled. The basement offset across the normal fault is approximately 5 seconds two-way travel time (TWT; ~3750 m). Beata Ridge is markedly asymmetric with the western scarp having more offset and a steeper slope. The marked asymmetry across the northern Beata Ridge suggests that some of the observed topography is flexurally supported, which implies that the major normal fault occurs along the western escarpment and Beata Ridge is the uplifted and rotated footwall. Toward the west of the ridge are thick ponded turbidites. Minor growth faults occur in the lower sections and their occurrence diminishes upsection. That is, the overlying turbidites are predominantly undeformed. A large southeastward dipping normal fault delineated the boundary between the ponded turbidites and the Hispaniola margin. The margin is highly faulted with a number of small grabens. We turned southwest at sunset. Line 1321 finished at 23:06 GMT and we began Line 1322 at 23:17 GMT. Today is Lew Abrams' birthday. As usual with such events, Frank baked a cake.

Sunday, March 12th (JD71) - High winds (25-30 knots) and accompanying swell are back; typical streamer depth control problems return. If we speed up, the streamer head surfaces. On the other hand, if we slow down too much the middle of the streamer shoals. It is a constant juggling act. The bridge is doing an incredible job at trying to maintain control of the streamer. Add to the streamer problem, airgun towing depth variations and the juggling act becomes more difficult. We crossed a large basement structure near shotpoint 76,550 that shoals to 1.5 seconds TWT prior to plummeting down to the abyssal plain (5-5 seconds TWT). The deeper seismic reflectors (turbidites) are dipping toward the large normal fault. The overlying sequences are predominantly flat lying with minor faulting, which may be the result of differential compaction. Line 1322 ends at 05:20 GMT and we turned to port and began Line 1323 at 05:25 GMT. We are now taking the seas on the port bow, and speed fluctuations are common due to the moderately large swell. Speed made good over the ground averages only 4.5 knots. Airgun #5 offline at 09:20 GMT, repaired and back in the water at 12:22 GMT. Airguns #1 and #2 were tangled at 12:22 GMT, we untangled guns and they were back on line at 12:33 GMT. The basement beneath the abyssal plain west of the Beata Ridge is quite rough, resembling normal oceanic crust (Figures 9 and 10). We deployed five sonobuoys across the region of rough basement to determine if the crustal thickness in this region is similar to that determined for the rough B" in the Venezuelan Basin. Furthermore, large faults offset the rough basement in this region (e.g., near Shotpoint 78, 700). Continuing east, we crossed the western escarpment of the Beata Ridge near shotpoint 80,700. A small rider block is observed along the western Beata escarpment. Similar to the northern transect, the ridge is markedly asymmetric with a steeply dipping western escarpment and a more gently dipping eastern slope. The wavelength and shape of the eastern Beata Ridge are consistent with a flexural origin for some of the observed topographic relief. The free-air gravity anomaly across the Beata Ridge is greater than 100 mgals (Figure 10). Crustal thickness estimates determined from sonobuoys as well as thermal mechanical modeling of Beata Ridge will allow us to determine how the topography is compensated. As a result of the large swell that we were taking on the starboard quarter, airguns #1 and #2 repeated were entangled (e.g., 18:31 and 20:00 GMT).

Monday, March 13th (JD72) - Rough seas and high winds continue. Today we had some minor difficulties with the airguns. A number of guns required some work. Airgun #20 (145 cu. in.) went down at 02:50 GMT. At 03:14 we had to take a few turns off the speed because of the tension on the streamer - strong quartering seas. Airgun #8 (850 cubic inches) was shut down at 03:32 GMT and airgun #20 went back on line at this time. Airgun #8 back on at 05:03 GMT, however a half-hour later airgun #17 (235 cu. in.) went down, we pulled it in, repaired it, and redeployed it at 14:21 GMT. Airgun #13 (850 cu. in.) was pulled in at 18:05 and back in the water at 18:48 GMT. The single ridge to the north has bifurcated into two smaller basement peaks that are observed on Line 1323, the larger of the two peaks occurring approximately 500 shotpoints toward the east of the western escarpment. A small graben structure is bounded on the west by the large basement structural high. The graben is centered around shotpoint 81,500. This graben structure is much smaller than that observed on the northern crossing on Line 1321, if in fact this is the southern extension of the northern graben system. Furthermore, the seismic reflectors dip toward the east in this graben similar to the overall dip of Beata Ridge in contrast to the deeper reflectors in the northern graben, which dip toward the west. Small offsets of the basement as well as basement highs are observed along the eastern flank of the Beata Ridge on Line 1323. Toward the southeast portion of the line, sub B" fanning reflectors are imaged from shotpoint 83,500 to the end of the line. These sub B" reflectors do not appear to be peg-leg multiples from B" or other shallower reflectors because the sub B" reflectors dip toward the west opposite to the overlying reflectors (e.g., A" and B"). Line 1323 ended at 20:19 GMT, we turned to starboard and started Line 1324 at 20:40 GMT. Sub B" reflectors are also observed on Line 1324 and they seem to dip toward the southwest, away the basement high and in the opposite direction to the reflectors overlying B." We deployed a sonobuoy at the beginning of Line 1324 to determine the velocity structure of the sub B" reflectors.

Tuesday, March 14th (JD73) - Line 1324 ended at 03:20 and we turned to starboard to start Line 1325, which was started at 03:28 GMT. Today we will complete the third of five transects across the Beata Ridge. As of now, we have filled 1600+ seismic tapes, and have shot 86 sonobuoys. Even though we encountered large sea surface swells during the end of the Venezuelan basin survey and during the second transect of the Beata Ridge, the MCS system continued to perform well. We modified the streamer depth from 8 to 12 meters during these periods of increased swell to minimize surface-related noise and surfacing of the streamer itself. The overall success rate of the sonobuoys has leveled off at about 75-80%. Analog and processed (brute/segy2sun/JDseis) MCS profiles indicate that only minor deformation has occurred across the northern Beata Ridge since its initial formation. Airgun #13 (850 cu. in.) pulled in at 04:55 GMT and back in the water at 05:41 GMT.

Smooth B" basement is observed along the eastern flank of Beata Ridge. A lens of downlapping sediment overlies reflector A" between shotpoint 86,400 and 87,400. The stratal geometry suggests that it is current-controlled drift deposit. Similar to the Venezuelan basin, current-controlled deposits are common along the flanks of the Beata Ridge. Along the eastern Beata Ridge, there are two grabens. The displacement across Beata Ridge is distributed across more faults in the south than in the north as evidenced by Lines 1321, 1322, 1323. Consequently, the width of the ridge increases and the
relief decreases toward the south. Three sonobuoys were deployed along the eastern flank of Line 1325.

Wednesday, March 15th (JD74) - We crossed over the Beata Ridge. Basement is down dropped approximately 2 seconds TWT across a large normal fault that delineates the western flank of the ridge. The basement character changes markedly across the Beata Ridge with rough basement occurring toward the west and smooth basement toward the east. Furthermore, the rough basement appears to offset by normal faults. These normal faults predominantly dip toward the northwest, similar to the faults observed on Line 1323. The basement depth west of the ridge progressively shoals to the south. Consequently, the thickness of the onlapping sequences systematically diminishes toward the south. Furthermore, toward the south, pan of the sequence overlying basement is composed of hemipelagic-pelagic deposits, whereas along the northern transects these sequences were not observed (e.g., 1321 and 1323). We deployed two sonobuoys over this region of rough basement to determine the crustal thickness. Line 1325 finished at 10:07 GMT and we turned to port to begin Line 1326. Line 1326 began at 10:25 GMT. The basement shoals to the south and the overlying sediments thin to the south. The character of the basement appears rough. We deployed a sonobuoy at the beginning of the Line 1326. Line 1326 finished at 17:19 GMT. We turned to port and began Line 1327. We encountered problems starting Line 1327, the CSRU crashed at 17:25 GMT. Consequently we had to bring the system down and rebooted it. Back on line at 18:21 and restarted Line 1327, which by now it was labeled 1327D because of the previous failures. At 19:12 the MCS data acquisition system crashed again. The streamer switch was left on the CSRU and when the watchstander tried to reboot the streamer depth display program, they actually cratered the data acquisition system. The system was back on line at 20:04 GMT. We opted not to turn around and restart the line because we were still on the abyssal plain. In addition, while the MCS data acquisition system was down, we continued to collect gravity and bathymetry data; as a result, the gravity modeling will not be compromised. The thickness of the turbidites is thinner on Line 1327 than seen on the transects to the north. The turbidites appear to have a northern source rather than being sourced from the Magdalena fan.
Further interpretation and correlation with existing profiles across the region will help confirm this preliminary hypothesis. The thickness of the hemipelagic-pelagic sequences continues to thicken toward the south. The western escarpment is less prominent toward the south along Line 1327. A large rotated rider block occurs near shotpoint 94,000. A graben structure is centered around Shotpoint 94,600.

Thursday, March 16th (JD75) - The prevailing winds (15-20 knots) and swell are finally starting to abate. Large basement highs are common along the eastern flank of the Beata Ridge. These structures are more prevalent along Line 1327 than on the previous transects. A lens of downlapping sediment overlies reflector A" between shotpoint 96,300 and 96,850. The stratal geometry of the deposit suggests that it is a current-controlled drift deposit and might correlate with the lens observed on Line 1325 to the north. A large structural high occurs at Shotpoint 98,650, ODP proposed site B-l is situated on top of this structural high. Line 1327 crossed proposed site B-l near shotpoint 96,900. After stepping up on the high we deployed a sonobuoy to determine velocity structure. The sediment horizons above basement (A" to B" interval) thin across the structural high suggesting that this feature has been highstanding since the onset of sedimentation. The highstanding block would enhance the influence of geostrophic currents and thus explain the observed sediment thinning. The origin of these features remains an enigma. Two possible options were discussed; first that they are constructional features related to the emplacement of the smooth basement and second that they are "pop-up" structures bounded by reverse faults due to in-plane compression. Toward the northern end of the line, the smooth basement surface displays an en echelon character similar to that observed northwest of the rough/smooth boundary on Line 1302. A preliminary interpretation is that overlapping basalt flows might generate this pattern, now frequently observed in the seismic reflection data.

<u>Friday, March 17th (JD 76)</u> - Today is St. Patrick's Day, celebrated patron saint of Ireland. We finished Line 1327 at 03:45 GMT and turned to starboard to begin Line 1328. We encountered an incredible head-on current and were making only about 3.8 knots over ground. The streamer tension was extremely high and front of streamer kept shoaling both conditions prevented us from increasing the speed. Airguns #13 (850 cu. in.) and #14 (250 cu. in.) became entangled at 07:13 probably due to swell; we shut them off, pulled them in, untangled the guns, and redeployed. At 11:29 GMT airgun #8 (850 cu. in.) was pulled in, repaired, and redeployed at 13:26 GMT. Line 1328 crossed a large structural high. The sediment intervals overlying basement thinned dramatically across the basement step suggesting that current-controlled erosion and nondeposition occurred in the regions of the steeper topography. Line 1328 finished at 17:47 GMT and we turned to starboard to complete the final transect of Beata Ridge. *Conrad* 2103 (Line 122) crossed the southern edge of the Beata Ridge and will complement our five transects located to the north. We began Line 1329 at 17:55 GMT.

<u>Saturday, March 18th (JP77)</u> - We are heading northwest along the last transect across Beata Ridge. We experienced problems with airgun #12 (540 cu. in.). We repaired the air gun three times, to no avail; it still leaked. Finally, Carlos Alvarez had to wake up the airgun guru, Johnny Dibernardo. After a preliminary examination, John ascertained the problem and repaired the gun. The current that was setting us on Line 1328 is now more favorable and we are making good speed over the ground. Along the eastern flank the basement is highly faulted (e.g., down dropped grabens). The acoustic character of the basement fluctuates between what appears to be smooth basement to regions of rough crust over extremely short length scales. A large graben is centered at Shotpoint 103,700. This graben can be observed in the older single channel seismic data as well as in the MCS Conrad Line 122. Line 1329 crossed DSDP Site 151 near shotpoint 104,370. The site is located on the structural high that delineates the western edge of the graben structure. While the site location for DSDP 151 made it possible to reach deeper (crustal) targets, this increased penetration came at the expense of being able to correlate the reflectors laterally away from the site. That is, the information gleaned from the site has only local significance. The western escarpment of the Beata Ridge is rather subdued in this region. Similar to the northern transects, the basement underlying the abyssal plain has a rough character. The hemipelagic-pelagic sequence continues to thicken toward the south as evidenced by this last transect. The acoustic character and lateral thinning of these deposits are indicative of current-controlled deposition. A prominent onlap surface is observed between the turbidites and the underlying hemipelagic-pelagic deposits.

<u>Sunday, March 19th (JD78)</u> - Toward the end of Line 1329 we leave the abyssal plain and step up onto the Hess escarpment. The slope is characterized by extensive slump scars that may have been reshaped and sculpted by geostrophic currents. Line 1329 crossed proposed site S-3C near Shotpoint 107,750 on the Hess escarpment. At 03:00 GMT the gyro in the Bell gravimeter (BGM3) became flaky. The BGM-3 stopped collecting reliable gravity information. The KSS-30 gravimeter has been down the entire cruise and is basically used as ship ballast. We will collect a gravity tie-in at Cristobal, but this won't be very useful, since the BGM-3 is not operating. Crossover corrections with *Conrad* 2103 cruise and other cruises in the region that collected gravity data will hopefully allow us to calculate the drift in the gravity meter. Line 1329 finished at 09:11 GMT and we turned to port to begin Line 1330, the last MCS line of cruise EW-9501. Line 1330

began at 09:20 GMT. We headed southwest and crossed the Hess escarpment again. Line 1330 crossed ODP proposed site S-3B near Shotpoint 108,900. Line 1330 finished at 18:00 GMT. The seas were flat and the winds calm to moderate. The MCS gods were smiling on us -- perfect weather to recover the MCS equipment. We started to secure all the MCS equipment at 13:00. We added oil to all the old sections (1.5 km) of the streamer. While pulling in the streamer we noticed that Bird #3 was only held on by the rear lock-down and was flying backwards. We recovered the bird with extra care. This explains why we had lack of communication with Bird #3 for most of the cruise. In addition, the tailbuoy was lost somewhere during the expedition, and only a Norwegian float remained. Upon retrieving the Norwegian float it became possessed and blatantly attacked mild-mannered Joe Stennett. Naturally Joe won, but the match was anything but a push-over. Watch was stopped and we raced to Panama at breakneck speed - the scientific portion of the cruise is over. In all aspects, this cruise has been a smashing success, and the chief scientists risked carpal tunnel syndrome in patting themselves on the back.

## Cruise Summary

During EWING Cruise 9501, we collected over 5700 km of MCS data and we deployed 104 successful sonobuoys in the Caribbean. Preliminary interpretation of the high-quality single-trace and 8 fold stacked data in conjunction with the previously collected seismic data allowed us to address many of the scientific objectives of the cruise.

Our new MCS survey better defined the complexity of the rough/smooth basement boundary around the western limit of the Venezuelan Basin (Figure 11). The character of the rough/smooth boundary has been quite variable from line to line and our zigzag survey across the rough/smooth boundary helped to discern if there were tongues of smooth basement which infilled between fault segments as well as trying to determine the change in character of the rough/smooth boundary from a well defined escarpment to a more subdued gradual boundary. The rough/smooth B" boundary along some lines is associated with a reversal of dip near the boundary and is delineated by a scarp. We refer to this local (~10 km) change in dip as the "Ski-Jump" (Figure 4). It is not certain whether these escarpments are structurally (fault) controlled or formed by volcanic construction or represents some combination of both processes. Some of the escarpments are clearly faults (CVB fault Zone) because the hanging wall block is deformed and rotated. These faults and tilted blocks imaged in the region have a only a local expression. It is difficult to trace these faults over large distances, they have an en echelon geometry in map view. The local nature of these fault systems suggests that they arc recording transtension across the region (i.e., possibly wrench faults). Conversely, along other crossings the rough/smooth B" boundary is more subtle and there are zones where it is difficult to discern whether the basement is rough or smooth, in these zones the basement has attributes of both. Two possible explanations could account for this observation, first the rough basement has a preferred fabric that is better imaged on certain azimuths and second that these areas are characterized by thin flows (e.g., basalt tongues) over pre-existing rough basement. We selected a number of different azimuths with which to cross the rough smooth boundary to determine if the morphology of the boundary was dependent on the insonification direction. In summary, the rough/smooth basement boundary along the western Venezuelan Basin has many different structural styles, in some regions its termination is coincident with NNE trending escarpments, whereas in other regions the transition is quite gradual and appears to be the result of thin flows masking the underlying rough basement. Furthermore, because of segmented nature of the observed faults systems, tongues of basalt flows have penetrated farther to the southeast subparallel to the downdropped hanging walls between the NNE fault systems and have generated a complex pattern between the rough and smooth B" basement.

Our survey west of the Beata Ridge confirmed the existence of rough basement adjacent to the western edge of the Beata escarpment. In addition, the rough basement appears to be offset by normal faults. We deployed several sonobuoys in the region of rough basement to ascertain if the crust to the northwest of the Beata Ridge was actually thinned, rough basement similar to that observed in the Venezuelan Basin (Figure 11). We have developed a preliminary model for the origin and evolution of the Venezuelan Basin in light of the existence of rough faulted basement (possible even thin crust) SW of Haiti, along the northwestern edge of the Beata Ridge. In our preliminary interpretation, we propose that extensional deformation of the Caribbean oceanic crust occurred prior to the Senonian. This NW-SE extension could be related to back-arc tensional forces. The extensional deformation accounts for the thinned rough basement observed in the Venezuelan Basin and west of the Beata Ridge (Figure 11). Toward the end of, and concomitant with, the extensional deformation, late Cretaceous flood basalts were sourced in a broad region located between the two regions of rough basement. The smooth B" basement surface is made up of several en echelon reflectors that commonly downlap onto the underlying surface, suggesting multiple flows. Further processing the MCS data will allow us to define belter the source location of these basalts by imaging the deeper reflector packages and by determining the associated crustal thickness variations. The crust in the region between these two regions of rough basement is thicker than normal oceanic crust (-12 km) and appears to be associated with the flood basalts. Continued extension after the emplacement of the basalt flows is consistent with the faulted smooth basement observed in both the Venezuelan Basin and the Beata Ridge regions.

Coincident with the rough/smooth boundary is a marked increase in the thickness of the A" to B" sediment interval. Correlation from existing DSDP sites in the Caribbean constrains the age of this interval to be older than middle Eocene (~50 Ma) and younger than Senonian (~88 Ma). The A" to B" sediment interval is thickest in the southeast portion of the Venezuelan Basin and systematically decreases toward the east, north, and west. The thinning of the sequence occurs by onlap onto pre-existing structural highs. The well laminated acoustic character, together with the onlap pattern suggests that these deposits are the result of gravity flows infilling topographic lows. The maximum thickness of this sequence is approximately 300 to 400 m and its distribution is roughly coincident with the area of rough basement in the Venezuelan Basin. The thickness and distribution of this sedimentary succession suggests that it represents the distal portion of a large fan complex. The proximal portions of the fan may underlie the Curacao ridge and might explain the large negative gravity anomaly observed in that region. If our interpretations are correct and these flat lying, acoustically laminated sediments are the distal portion of a large terrigenous fan system, then these sediments might provide valuable insight with regard to Caribbean plate motion in the Late Cretaceous and early Tertiary. Discerning the source of these sediments by applying sediment provenance techniques will allow us to constrain between the two end member models proposed for the origin and relative motion of the Caribbean plate with respect to South America. One possible source for these terrigenous sediments is the antecedent Orinoco River, which may have had an axial parallel drainage pattern east of the uplifting and deforming Andean Cordillera. Future drilling of these sediments may provide a pseudo "piercing point" to constrain the magnitude of the right lateral motion between the Caribbean Plate and the South American Plate. Plate reconstruction estimates for the relative motion between the Caribbean and South American Plates vary by at least an order of magnitude. The undeformed late Cretaceous to early Tertiary sedimentary succession preserved in the Venezuelan basin is the "tape recorder" of the tectonic and stratigraphic history of the Caribbean Plate and will provide the unifying framework within which to interpret the other disparate data from around the region.

The sequence above A" becomes systematically less well laminated toward the east (from Lines 1294 to 1300) and exhibits a more hummocky acoustic character. The acoustic character and thickness distribution suggests that these are drift deposits. The sequences overlying A" (lower sequence - acoustically hummocky and the upper sequence - acoustically laminated) also thicken dramatically toward the southeast with a pronounced increase in thickness across the rough/smooth boundary. Along Line 1320, is one of the few areas in the study region where the hemipelagic-pelagic deposits show signs of truncation. Together with the postulated drift deposits, we interpret this truncation and nondeposition to record the counterclockwise flow of bottom currents around the Venezuelan Basin. A core of bottom water flow appears to be concentrated near the 4000 meter isobath (Figure 12). This ribbon of flow would explain the erosion and nondeposition observed along Line 1320 (Figure 2). DSDP site 150 is located (shotpoint 65,300) in an area where the maximum hiatus occurs due to erosion and nondeposition. Farther to the north, DSDP site 146 (Shotpoint 66,520) sampled the sedimentary section farther away from the ribbon of swift current and thus sampled a more complete sedimentary section. The onset of current-controlled deposition began in the middle Eocene above reflector A" and continues to the present. Sediment waves are commonly observed in the 3.5 kHz sub-bottom profiles. Lateral variation in acoustic character is observed in many of the seismic lines and records the interplay between turbidity currents and geostrophic currents. In close proximity to the source, the turbidites overwhelm the contour currents and the reflectors are fiat-lying and onlap pre-existing highs. Conversely in distal regions, the currents shape and sculpture the sediment into sediment waves with amplitudes of 100's of m and wavelengths of kms.

The Beata ridge is markedly asymmetric with a steeply dipping western escarpment and a more gently dipping eastern slope. The wavelength and shape of the eastern Beata Ridge are consistent with a flexural origin for some of the observed topographic relief. The free-air gravity anomaly across the Beata Ridge is greater than 100 mgals (Figure 10). Crustal thickness estimates determined from sonobuoys as well as thermal mechanical modeling of Beata Ridge will allow us to determine how the topography is compensated. The extensional deformation across Beata Ridge is distributed across more faults in the south than in the north. Consequently, the width of the ridge increases and the relief decreases from north to south. Sedimentary horizons above basement thin across structural highs along the eastern flank of the Beata Ridge suggesting that the morphology structure of the ridge was imparted early on in its evolution. Even though minor faulting and deformation are observed across the Beata Ridge, we propose that the majority of the deformation and structure were generated early in the evolution of the ridge.

## Acknowledgments

The crew of the R/V *Ewing* and the Marine Department at Lamont-Doherty Earth Observatory/ Columbia University were responsible in large part for the success of this cruise. The expertise and friendly attitude of the crew made for an enjoyable and productive cruise. We look forward to our next cruise on the R/V EWING. This research was funded by the National Science Foundation.

**Figure Captions**

Figure 1. Location map of Caribbean region showing the location of the Venezuelan Basin and the Beata Ridge. DSDP sites are also shown. Note that the 5000 m contour roughly defines the area of rough basement in the Venezuelan Basin.

Figure 2. Track chart for EWING cruise 9501. Line numbers are annotated along track and sonobuoy locations are denoted by circles along track.

Figure 3a. A schematic showing the EWING airgun array. 20 airguns were used during the Caribbean MCS project. The airgun volumes are shown. See Table 1 for specifics regarding airgun chamber volumes.

Figure 3b. Ewing MCS acquisition geometry.

Figure 4. Seismic reflection profile 1300 across the rough/smooth B" boundary illustrating the "ski-jump" escarpment that delineates the boundary in some regions. Preliminary interpretation of the stratigraphic succession is shown. Note that the A" - B" interval dramatically thickens across the rough/smooth B" boundary.

Figure 5. Free-air gravity, magnetics and interpreted seismic section for Line 1300. There is no marked gravity signal associated with the rough/smooth B" boundary. Further analyses of the magnetic data is required to determine the origin of the anomalies in this region.

Figure 6. Seismic reflection profile 1302 across the rough/smooth B" boundary showing a more subtle rough/smooth boundary. The smooth B" basement surface is made up of several en echelon reflectors that commonly downlap onto the underlying surface, suggesting multiple flows. Note the hummocky acoustic character of the sedimentary sequence overlying A."

Figure 7. Free-air gravity, magnetics and interpreted seismic section for Line 1302. Note that similar to Line 1300, the rough/smooth B" boundary is not associated with a large gravity signature.

Figure 8. Magnetic anomalies plotted along track for the Venezuelan Basin. Most of the previously proposed SW-NE trending anomalies are not observed. Preliminary interpretation of the magnetic anomalies suggest that there is only one identifiable magnetic lineation in the region and it may correlate with the escarpment delineating the rough/smooth B" boundary.

Figure 9. Seismic reflection profile 1323 across the Beata Ridge illustrating the steep western escarpment. The hemipelagic-pelagic intervals along the eastern flank thin over structural highs. Thick turbidite sections onlap the western flank of the ridge and show minimal signs of deformation.

Figure 10. Free-air gravity, magnetics and interpreted seismic section for Line 1323. Note the marked asymmetry across the ridge, steeply dipping toward the west and more gently dipping toward the east. Further processing of the gravity data is required to remove the artifacts observed in this profile.

Figure 11. A simple schematic illustrating regions of rough, thin basement in the Caribbean. Note the symmetry of these regions of inferred extended and thinned crust with respect to the regions of thicker smooth crust (i.e., the intervening region). Our preliminary

interpretation is that the flood basalts were sourced from a broad region centered along the eastern edge of the Beata Ridge.

Figure 12. A simple schematic illustrating the inferred current axis in the Caribbean. The contour current appears to flow along and parallel to the 4000 meter isobath. The onset of current activity occurred in the Middle Eocene, above reflector A," and the current intensity started to wane toward the middle/late Miocene. Our preliminary interpretation is that the currents entered the Caribbean from the west. The timing and flow patterns suggest that the currents are a branch of Antarctic bottom waters flowing north along the south American continent.

Figure 13. A cartoon illustrating the trials and tribulations of working in the Caribbean in February.

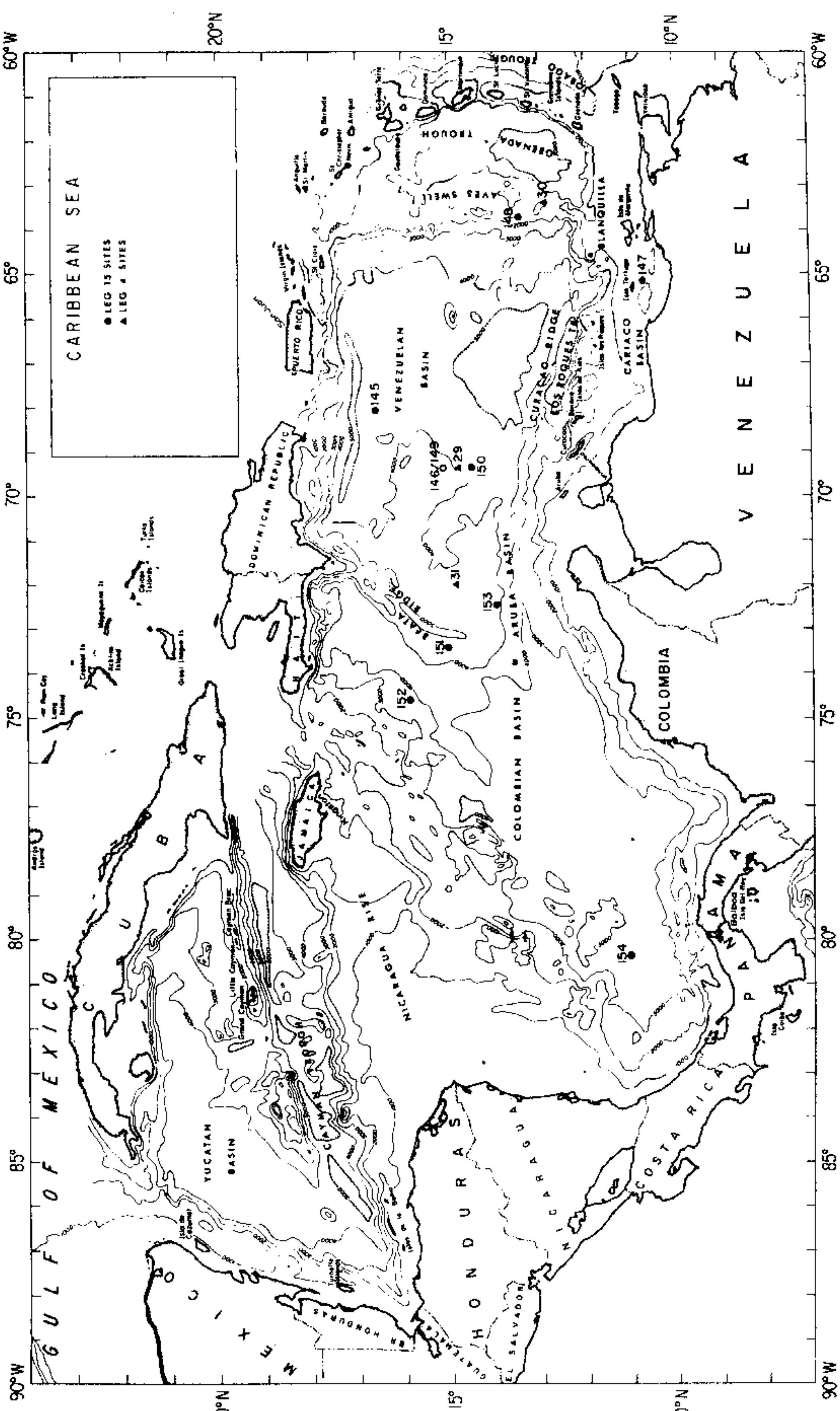

CARIBBEAN SEA
● LEG 15 SITES
▲ LEG 4 SITES
GULF OF MEXICO
MEXICO
CUBA
JAMAICA
HAITI
DOMINICAN REPUBLIC
PUERTO RICO
HONDURAS
EL SALVADOR
NICARAGUA
COSTA RICA
PANAMA
COLOMBIA
VENEZUELA
YUCATAN BASIN
CAYMAN TR.
NICARAGUA RISE
COLOMBIAN BASIN
VENEZUELAN BASIN
BEATA RIDGE
ARUBA BASIN
CURACAO RIDGE
LOS ROQUES TR.
CARIACO BASIN
BLANQUILLA
AVES SWELL
GRENADA TROUGH
145
146/149
29
150
31
153
151
152
154
147
148
30
60°W
65°
70°
75°
80°
85°
90°W
20°N
15°
10°N

Figure 1

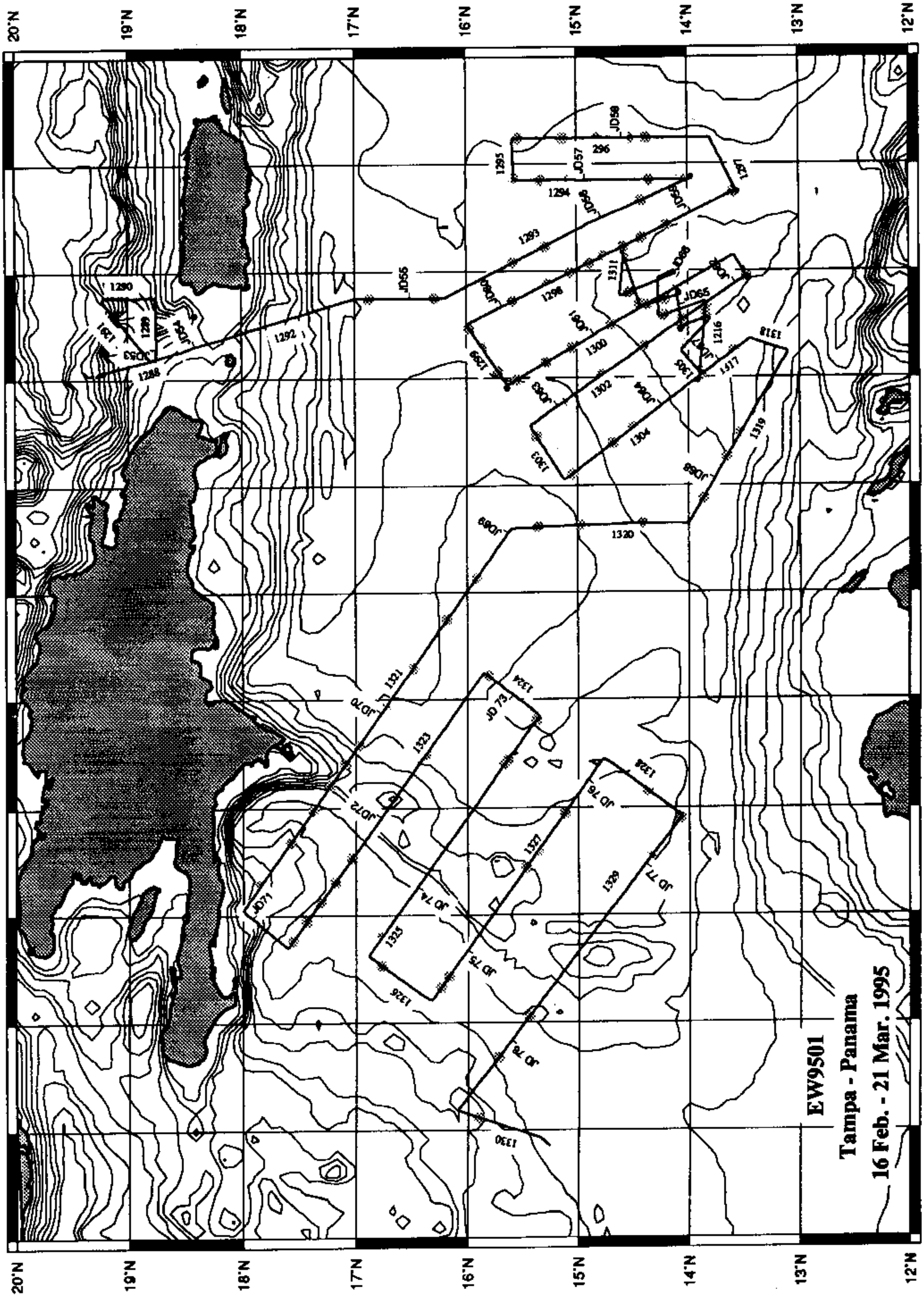

EW9501
Tampa - Panama
16 Feb. - 21 Mar. 1995
65°W
66°W
67°W
68°W
69°W
70°W
71°W
72°W
73°W
74°W
75°W
76°W
20°N
19°N
18°N
17°N
16°N
15°N
14°N
13°N
12°N

Figure 2

# EWING AIRGUN ARRAY- 20 GUN FOR CARIBBEAN MCS PROJECT

VOLUME= 8470 cu in

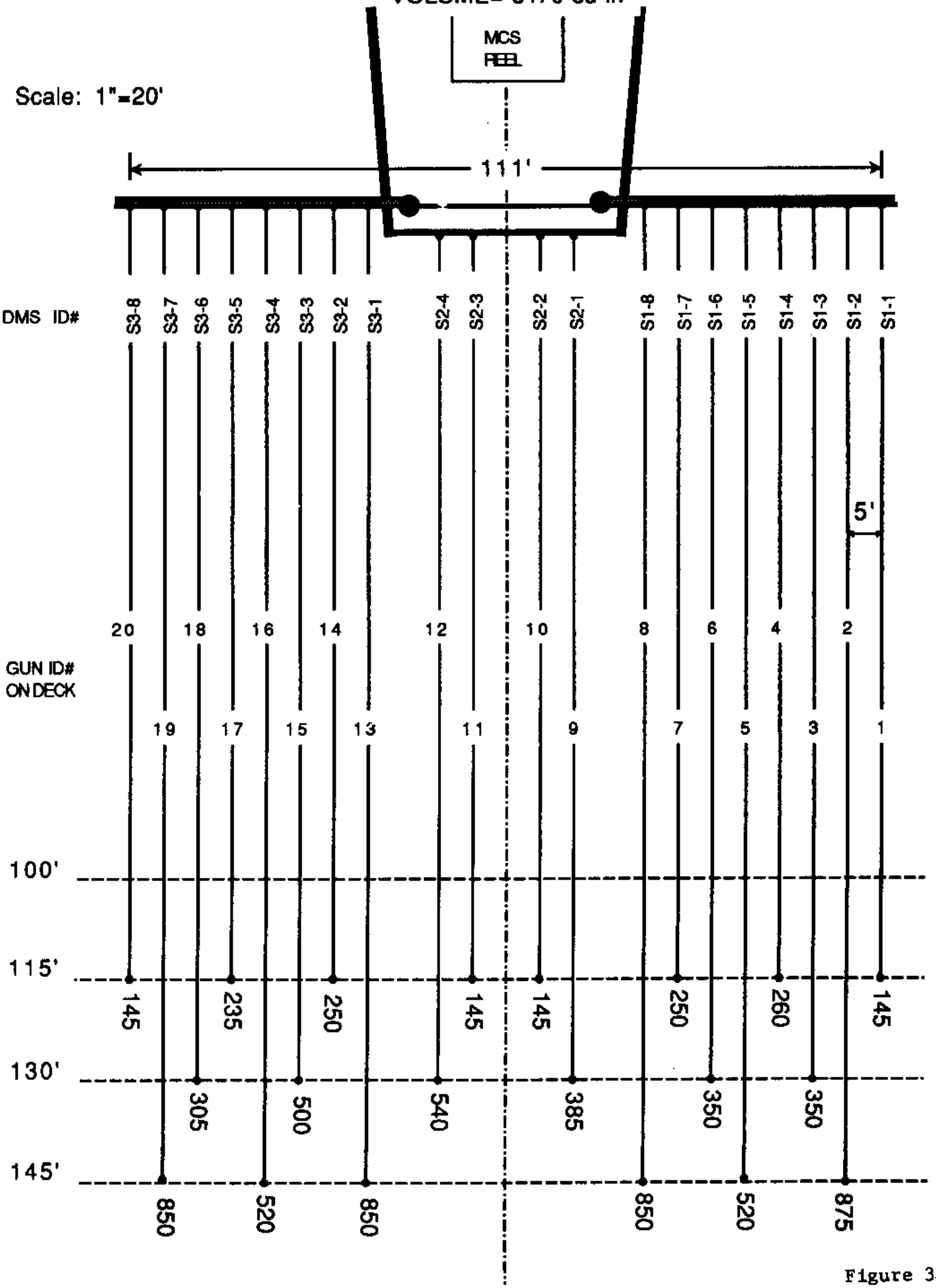



Figure 3a

# MAURICE EWING SETBACK AND OFFSET DIAGRAM

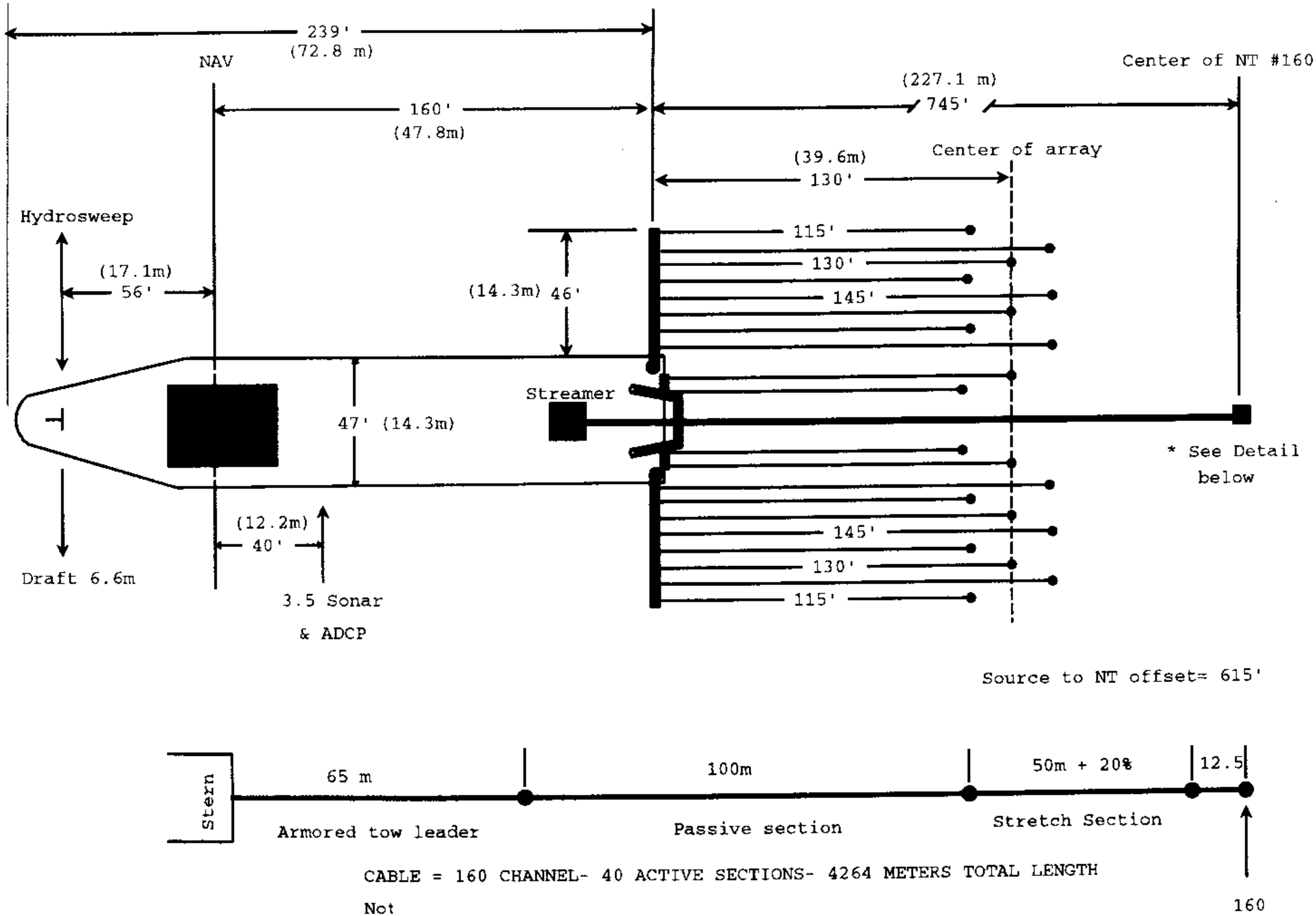



Figure 3b

## EWING AIRGUN ARRAY - 20 AIRGUNS FOR CARIBBEAN MCS PROJECT

| VOL | N | Z | "X" | "Y" | GUN# |
|---|---|---|---|---|---|
| 145 | 1 | 7.5 | -16.8 | -4.6 | 1 |
| 875 | 1 | 7.5 | -15.2 | 4.6 | 2 |
| 350 | 1 | 7.5 | -13.7 | 0.0 | 3 |
| 260 | 1 | 7.5 | -12.2 | -4.6 | 4 |
| 520 | 1 | 7.5 | -10.7 | 4.6 | 5 |
| 350 | 1 | 7.5 | -9.1 | 0.0 | 6 |
| 250 | 1 | 7.5 | -7.6 | -4.6 | 7 |
| 850 | 1 | 7.5 | -6.1 | 4.6 | 8 |
| 385 | 1 | 7.5 | -3.9 | 0.0 | 9 |
| 145 | 1 | 7.5 | -2.4 | -4.6 | 10 |
| 145 | 1 | 7.5 | 2.4 | 4.6 | 11 |
| 540 | 1 | 7.5 | 3.9 | 0.0 | 12 |
| 850 | 1 | 7.5 | 6.1 | 4.6 | 13 |
| 250 | 1 | 7.5 | 7.6 | -4.6 | 14 |
| 500 | 1 | 7.5 | 9.1 | 0.0 | 15 |
| 520 | 1 | 7.5 | 10.7 | 4.6 | 16 |
| 235 | 1 | 7.5 | 12.2 | -4.6 | 17 |
| 305 | 1 | 7.5 | 13.7 | 0.0 | 18 |
| 850 | 1 | 7.5 | 15.2 | 4.6 | 19 |
| 145 | 1 | 7.5 | 16.8 | -4.6 | 20 |

8470 total cubic inches

* minus sign refers to starboard array for "X" and forward of the array center line for "Y"

TABLE 1

Airgun Array

| LINE | Start Line | Longitude | Latitude | Datatape | Logtape | End Line | Longitude | Latitude | Datatape | Logtape |
|---|---|---|---|---|---|---|---|---|---|---|
| 1288 | JD52 13:16 | 67° 57.8' | 19° 20.8' | 5 | 1 | JD52 23:04 | 67° 49.1' | 18° 46.5' | 66 | 1 |
| 1289 | JD52 23:18 | 67° 49.4' | 18° 45.5' | 67 | 2 | JD53 06:00 | 67° 14.3' | 18° 45.3' | 89 | 2 |
| 1290 | JD53 06:10 | 67° 14.9' | 18° 45.6' | 90 | 3 | JD53 11:04 | 67° 15.0' | 19° 13.5' | 106 | 3 |
| 1291 | JD53 11:28 | 67° 15.0' | 19° 13.5' | 107 | 4 | JD53 19:48 | 67° 48.8' | 18° 46.2' | 136 | 4 |
| 1292 | JD53 20:12 | 67° 48.7' | 18° 46.2' | 137 | 5 | JD54 18:12 | 67° 15.0' | 17° 00.0' | 211 | 6 |
| 1293 | JD54 18:22 | 67° 15.0' | 17° 00.0' | 212 | 7 | JD56 10:55 | 66° 07.7 | 13° 59.3' | 351 | 8 |
| 1294 | JD56 12:24 | 66° 08.8' | 13° 58.9' | 352 | 9 | JD57 07:07 | 66° 08.9' | 15° 33.3' | 417 | 9 |
| 1295 | JD57 07:21 | 66° 07.9' | 15° 34.1' | 418 | 10 | JD57 12:06 | 65° 46.3' | 15° 34.8' | 441 | 10 |
| 1296 | JD57 12:22 | 65° 45.7' | 15° 33.8' | 442 | 11 | JD58 10:34 | 65° 45.7' | 13° 48.0' | 422 | 11 |
| 1297 | JD58 10:39 | 65° 46.1' | 13° 47.6' | 523 | 12 | JD58 16:54 | 66° 16.5' | 13° 33.4' | 544 | 12 |
| 1298 | JD58 17:51 | 66° 14.9' | 13° 34.0' | 545 | 13 | JD60 03:41 | 67° 30.0' | 15° 59.0' | 662 | 13 |
| 1299 | JD60 04:01 | 66° 31.1' | 15° 59.4' | 663 | 14 | JD60 12:36 | 68° 06.0' | 15° 36.9' | 692 | 14 |
| 1300 | JD60 13:43 | 68° 04.0' | 15° 37.4' | 693 | 15 | JD61 17:59 | 66° 51.5' | 13° 36.1' | 793 | 15 |
| 1301 | JD61 18:09 | 66° 51.4' | 13° 35.3' | 794 | 16 | JD61 20:39 | 67° 02.9' | 13° 28.9' | 802 | 16 |
| 1302 | JD61 20:45 | 67° 03.3' | 13° 28.6' | 803 | 17 | JD63 03:03 | 68° 26.7' | 15° 25.2' | 913 | 17 |
| 1303 | JD63 03:25 | 68° 27.0' | 15° 25.0' | 914 | 18 | JD63 10:37 | 68° 56.6' | 15° 07.0' | 938 | 18 |
| 1304 | JD63 10:46 | 68° 56.6' | 15° 06.9' | 939 | 19 | JD64 07:01 | 67° 58.7' | 13° 53.2' | 1009 | 19 |
| 1305 | JD64 07:17 | 67° 57.6' | 13° 53.9' | 1010 | 20 | JD64 10:34 | 67° 45.0' | 14° 03.9' | 1029 | 20 |
| 1306 | JD64 10:40 | 67° 45.0' | 14° 03.9' | 1030 | 21 | JD64 15:21 | 67° 27.0' | 13° 47.2' | 1052 | 21 |
| 1307 | JD64 15:32 | 67° 26.0' | 15° 32.6' | 1053 | 22 | JD64 19:50 | 67° 34.3' | 14° 03.5' | 1068 | 22 |
| 1308 | JD64 20:10 | 67° 32.9' | 14° 03.9' | 1071 | 23 | JD65 01:08 | 67° 11.2' | 14° 05.0' | 1087 | 23 |
| 1309 | JD65 01:21 | 67° 11.0' | 14° 04.0' | 1088 | 24 | JD65 06:18 | 67° 20.0' | 14° 25.5' | 1105 | 24 |
| 1310 | JD65 06:19 | 67° 19.9' | 14° 25.6' | 1106 | 25 | JD65 12:48 | 66° 50.0' | 14° 35.1' | 1128 | 25 |
| 1311 | JD65 12:58 | 66° 49.5' | 14° 35.6' | 1129 | 26 | JD65 17:39 | 67° 13.9' | 14° 35.4' | 1145 | 26 |
| 1312 | JD65 18:06 | 67° 13.6' | 14° 34.6' | 1146 | 27 | JD66 00:29 | 67° 00.0' | 14° 07.1' | 1173 | 27 |
| 1313 | JD66 00:37 | 67° 00.6' | 14° 07.1' | 1174 | 28 | JD66 02:40 | 67° 04.8' | 14° 16.3' | 1180 | 28 |
| 1314 | JD66 02:45 | 67° 05.0' | 14° 16.3' | 1181 | 29 | JD66 06:33 | 67° 24.5' | 14° 16.3' | 1194 | 29 |
| 1315 | JD66 06:43 | 67° 25.3' | 14° 16.0' | 1196 | 30 | JD66 11:39 | 67° 17.3' | 13° 51.5' | 1213 | 30 |
| 1316 | JD66 11:44 | 67° 17.2' | 13° 51.4' | 1214 | 31 | JD66 21:30 | 68° 00.4' | 13° 55.1' | 1254 | 31 |
| 1317 | JD66 21:31 | 68° 00.3' | 13° 55.0' | 1254 | 31 | JD67 04:51 | 67° 38.8' | 13° 27.4' | 1280 | 32 |

TABLE 2

MCS Lines

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1318 | JD67 04:59 | 67° 38.6' | 13° 26.6' | 1281 | 32 | JD67 09:23 | 67° 45.5' | 09° 26.0' | 1296 | 32 |
| 1319 | JD67 09:31 | 67° 46.0' | 13° 06.4' | 1297 | 34 | JD68 04:13 | 69° 20.9' | 13° 59.0' | 1365 | 34 |
| 1320 | JD68 04:21 | 69° 21.3' | 14° 00.4' | 1366 | 35 | JD68 22:30 | 69° 24.0' | 15° 36.0' | 1429 | 35 |
| 1321 | JD68 22:39 | 69° 24.6' | 15° 36.2' | 1431 | 36 | JD70 23:06 | 72° 57.8' | 17° 58.9' | 1603 | 36 |
| 1322 | JD70 23:17 | 72° 57.9' | 17° 58.9' | 1604 | 37 | JD71 05:20 | 73° 17.5' | 17° 35.4' | 1623 | 37 |
| 1323 | JD71 05:25 | 73° 17.5' | 17° 35.2' | 1624 | 38 | JD72 20:19 | 70° 45.8' | 15° 51.6' | 1758 | 38 |
| 1324 | JD72 20:40 | 70° 45.8' | 15° 49.8' | 1760 | 39 | JD73 03:20 | 71° 09.0' | 15° 21.0' | 1783 | 39 |
| 1325 | JD73 03:28 | 71° 09.6' | 15° 21.1' | 1784 | 40 | JD74 10:07 | 73° 21.9' | 16° 52.8' | 1889 | 40 |
| 1326 | JD74 10:25 | 73° 23.4' | 16° 52.4' | 1890 | 41 | JD74 17:19 | 73° 47.4' | 16° 20.0' | 1913 | 41 |
| 1327 | JD74 18:21 | 73° 44.8' | 16° 17.4' | 1914 | 42 | JD76 03:45 | 71° 33.6' | 16° 17.4' | 2026 | 42 |
| 1328 | JD76 03:47 | 71° 45.9' | 14° 45.9' | 2027 | 43 | JD76 17:47 | 72° 04.7' | 14° 04.0' | 2075 | 43 |
| 1329 | JD76 17:55 | 72° 05.1' | 14° 04.0' | 2076 | 44 | JD78 09:11 | 74° 48.0' | 16° 04.6' | 2212 | 44 |
| 1330 | JD78 09:20 | 74° 49.0' | 16° 04.5' | 2213 | 45 | JD78 18:00 | 75° 03.8 | 15° 21.5' | 2242 | 45 |

| Sonobuoy# | Latitude | Longitude | Time JD:hr:m:s | Shot |
|---|---|---|---|---|
| 01EW95 | 16.876354 | -67.250633 | 54:19:49:42.9 | 6642 |
| 02EW95 | 16.286310 | -67.249374 | 55: 3:25:18.1 | 8008 |
| 03EW95 | 15.576946 | -66.918205 | 55:13:26:28.0 | 9810 |
| 04EW95 | 15.288653 | -66.766365 | 55:19:13:18.7 | 10580 |
| 05EW95 | 14.767015 | -66.497925 | 56: 0:51:40.0 | 11864 |
| 06EW95 | 14.423865 | -66.343742 | 56: 5:15:48.0 | 12656 |
| 07EW95 | 14.065402 | -66.151665 | 56:13:27:29.1 | 14111 |
| 08EW95 | 14.345915 | -66.150520 | 56:16:45: 1.2 | 14703 |
| 09EW95 | 15.067725 | -66.149956 | 57: 1: 4:49.1 | 16202 |
| 10EW95 | 15.324538 | -66.150978 | 57: 4:12:47.4 | 16765 |
| 11EW95 | 15.569888 | -66.128601 | 57: 7:29:56.8 | 17355 |
| 12EW95 | 15.527050 | -65.760719 | 57:12:50:45.8 | 18316 |
| 13EW95 | 15.127365 | -65.761581 | 57:17:46:19.6 | 19202 |
| 14EW95 | 14.818294 | -65.759567 | 57:21:44:22.8 | 19916 |
| 15EW95 | 14.534409 | -65.761017 | 58: 1:28:28.9 | 20588 |
| 16EW95 | 14.377490 | -65.759880 | 58: 3:25:15.1 | 20938 |
| 17EW95 | 13.589731 | -66.261147 | 58:18:11:17.8 | 23580 |
| 18EW95 | 13.976565 | -66.456108 | 58:23:29:12.1 | 24533 |
| 19EW95 | 14.198747 | -66.572784 | 59: 2:25:34.4 | 25062 |
| 20EW95 | 14.420109 | -66.685623 | 59: 5:35:20.6 | 25631 |
| 21EW95 | 14.582916 | -66.769257 | 59: 7:54:22.7 | 26048 |
| 22EW95 | 14.761323 | -66.861839 | 59:10:24:41.9 | 26498 |
| 23EW95 | 14.887362 | -66.927261 | 59:12:18:46.6 | 26840 |
| 24EW95 | 15.062226 | -67.015129 | 59:15: 1:36.8 | 27328 |
| 25EW95 | 15.267152 | -67.122177 | 59:17:58:55.9 | 27860 |
| 26EW95 | 15.585392 | -67.284775 | 59:22: 6:47.7 | 28603 |
| 27EW95 | 15.974167 | -67.540070 | 60: 4:22:34.6 | 29730 |
| 28EW95 | 15.858873 | -67.718193 | 60: 6:59:18.9 | 30200 |
| 29EW95 | 15.716538 | -67.936707 | 60:10:12:46.9 | 30780 |
| 30EW95 | 15.552125 | -68.023697 | 60:14:49:41.8 | 31610 |
| 31EW95 | 15.277792 | -67.858376 | 60:18:45:48.2 | 32318 |
| 32EW95 | 15.046703 | -67.720306 | 60:21:58:31.8 | 32896 |
| 33EW95 | 14.691278 | -67.507736 | 61: 2:47:20.8 | 33762 |
| 34EW95 | 14.376375 | -67.319618 | 61: 7:15:24.9 | 34565 |
| 35EW95 | 14.096684 | -67.152077 | 61:11: 6:14.2 | 35257 |
| 36EW95 | 13.779740 | -66.963257 | 61:15:32:55.7 | 36057 |
| 37EW95 | 13.479214 | -67.050316 | 61:21:58:26.3 | 37212 |
| 38EW95 | 13.813102 | -67.291046 | 62: 3: 8:40.1 | 38142 |
| 39EW95 | 14.055240 | -67.460915 | 62: 6:51:50.6 | 38808 |
| 40EW95 | 14.400320 | -67.709274 | 62:12: 7:19.4 | 39754 |
| 41EW95 | 14.771914 | -67.975731 | 62:17:41:42.5 | 40756 |
| 42EW95 | 15.139218 | -68.241600 | 62:22:52:33.1 | 41688 |
| 43EW95 | 15.368093 | -68.545006 | 63: 4:32: 5.6 | 42706 |
| 44EW95 | 15.044147 | -68.895126 | 63:11:51:59.4 | 44024 |
| 45EW95 | 14.684671 | -68.613312 | 63:17:25:53.2 | 45025 |

TABLE 3

Sonobuoys

| | | | | |
|---|---|---|---|---|
| 46EW95 | 14.496115 | -68.462822 | 63:20:24:21.9 | 45560 |
| 47EW95 | 14.234045 | -68.255386 | 64: 0:54:27.2 | 46370 |
| 48EW95 | 13.906155 | -67.950485 | 64: 7:26:56.2 | 47545 |
| 49EW95 | 14.007169 | -67.680603 | 64:11:50:14.6 | 48335 |
| 50EW95 | 13.834538 | -67.443840 | 64:15:57:16.3 | 49075 |
| 51EW95 | 14.060615 | -67.519730 | 64:20:40:40.1 | 49924 |
| 52EW95 | 14.211721 | -67.266266 | 65: 3:22:46.9 | 51080 |
| 53EW95 | 14.440155 | -67.306396 | 65: 6:43:56.3 | 51682 |
| 54EW95 | 14.582603 | -66.866364 | 65:13:42:26.9 | 52936 |
| 55EW95 | 14.534747 | -67.202278 | 65:18:43:22.2 | 53838 |
| 56EW95 | 14.150648 | -67.039825 | 66: 3:50:28.2 | 55478 |
| 57EW95 | 14.220848 | -67.421387 | 66: 7:16:17.0 | 56094 |
| 58EW95 | 13.847854 | -67.366661 | 66:12:43: 2.2 | 57073 |
| 59EW95 | 13.889413 | -67.983604 | 66:21:57:49.1 | 58736 |
| 60EW95 | 13.596169 | -67.756935 | 67: 2:36:45.3 | 59572 |
| 61EW95 | 13.527496 | -68.519417 | 67:18: 6:37.2 | 62360 |
| 62EW95 | 13.655813 | -68.743240 | 67:20:56: 3.7 | 62868 |
| 63EW95 | 13.864826 | -69.117165 | 68: 1:34:58.7 | 63704 |
| 64EW95 | 14.422254 | -69.354523 | 68: 9:21:30.7 | 65102 |
| 65EW95 | 14.980550 | -69.371941 | 68:15:46:58.4 | 66258 |
| 66EW95 | 15.355195 | -69.387527 | 68:19:56:11.7 | 67005 |
| 67EW95 | 15.680405 | -69.519981 | 69: 0:30:25.6 | 67827 |
| 68EW95 | 15.912005 | -69.861511 | 69: 5:26:50.4 | 68716 |
| 69EW95 | 16.179281 | -70.251740 | 69:10:42:58.5 | 69664 |
| 70EW95 | 16.487354 | -70.707222 | 69:17:10:24.7 | 70825 |
| 71EW95 | 16.742096 | -71.084709 | 69:22:48:11.1 | 71838 |
| 72EW95 | 16.971140 | -71.423073 | 70: 3:58: 3.1 | 72739 |
| 73EW95 | 17.089653 | -71.601433 | 70: 6:47:14.0 | 73246 |
| 74EW95 | 17.224062 | -71.797119 | 70: 9:25:16.8 | 73720 |
| 75EW95 | 17.370975 | -72.014343 | 70:12:10:42.0 | 74216 |
| 76EW95 | 17.572506 | -72.315651 | 70:15:41:46.7 | 74849 |
| 77EW95 | 17.841764 | -72.710991 | 70:20:11:48.0 | 75658 |
| 78EW95 | 17.910995 | -73.026283 | 71: 0:41:58.8 | 76467 |
| 79EW95 | 17.555962 | -73.237747 | 71: 6: 9:56.1 | 77450 |
| 80EW95 | 17.431162 | -73.052826 | 71: 9: 5:44.1 | 77977 |
| 81EW95 | 17.308096 | -72.874344 | 71:12: 5: 8.5 | 78515 |
| 82EW95 | 17.183792 | -72.692223 | 71:15: 4:35.6 | 79053 |
| 83EW95 | 17.033060 | -72.470169 | 71:18:42:18.0 | 79706 |
| 84EW95 | 16.370951 | -71.507950 | 72: 9: 4:46.7 | 82291 |
| 85EW95 | 15.813472 | -70.778976 | 72:20:54:20.4 | 84418 |
| 86EW95 | 15.372138 | -71.188683 | 73: 3:54:38.1 | 85678 |
| 87EW95 | 15.635547 | -71.563034 | 73: 8:44:13.5 | 86546 |
| 88EW95 | 15.663366 | -71.599228 | 73: 9:12:32.3 | 86631 |
| 89EW95 | 16.505835 | -72.820091 | 74: 1:16:18.0 | 89520 |
| 90EW95 | 16.767878 | -73.199364 | 74: 7:17:44.8 | 90604 |
| 91EW95 | 16.769951 | -73.467728 | 74:11:51:51.5 | 91424 |

| | | | | |
|---|---|---|---|---|
| 92EW95 | 16.239895 | -73.673271 | 74:19:14:59.4 | 92706 |
| 93EW95 | 16.167677 | -73.564697 | 74:20:39: 5.8 | 92949 |
| 94EW95 | 15.473655 | -72.563744 | 75:11: 9:17.6 | 95558 |
| 95EW95 | 15.368260 | -72.409431 | 75:13:30:33.6 | 95981 |
| 96EW95 | 15.116812 | -72.049210 | 75:19:17:46.0 | 97022 |
| 97EW95 | 14.954837 | -71.815453 | 75:23: 8:50.1 | 97715 |
| 98EW95 | 14.377153 | -71.845993 | 76:11:19:10.7 | 99904 |
| 99EW95 | 14.074630 | -72.101463 | 76:18: 7:23.5 | 101127 |
| 100EW95 | 14.355375 | -72.478645 | 76:23: 5: 0.3 | 102019 |
| 101EW95 | 15.443011 | -73.945175 | 77:20:31:29.8 | 105876 |
| 102EW95 | 15.718715 | -74.315544 | 78: 2: 4:59.6 | 106876 |
| 103EW95 | 15.905492 | -74.881966 | 78:11:36:40.8 | 108588 |
| 104EW95 | 15.718237 | -74.943474 | 78:13:49:46.3 | 108987 |

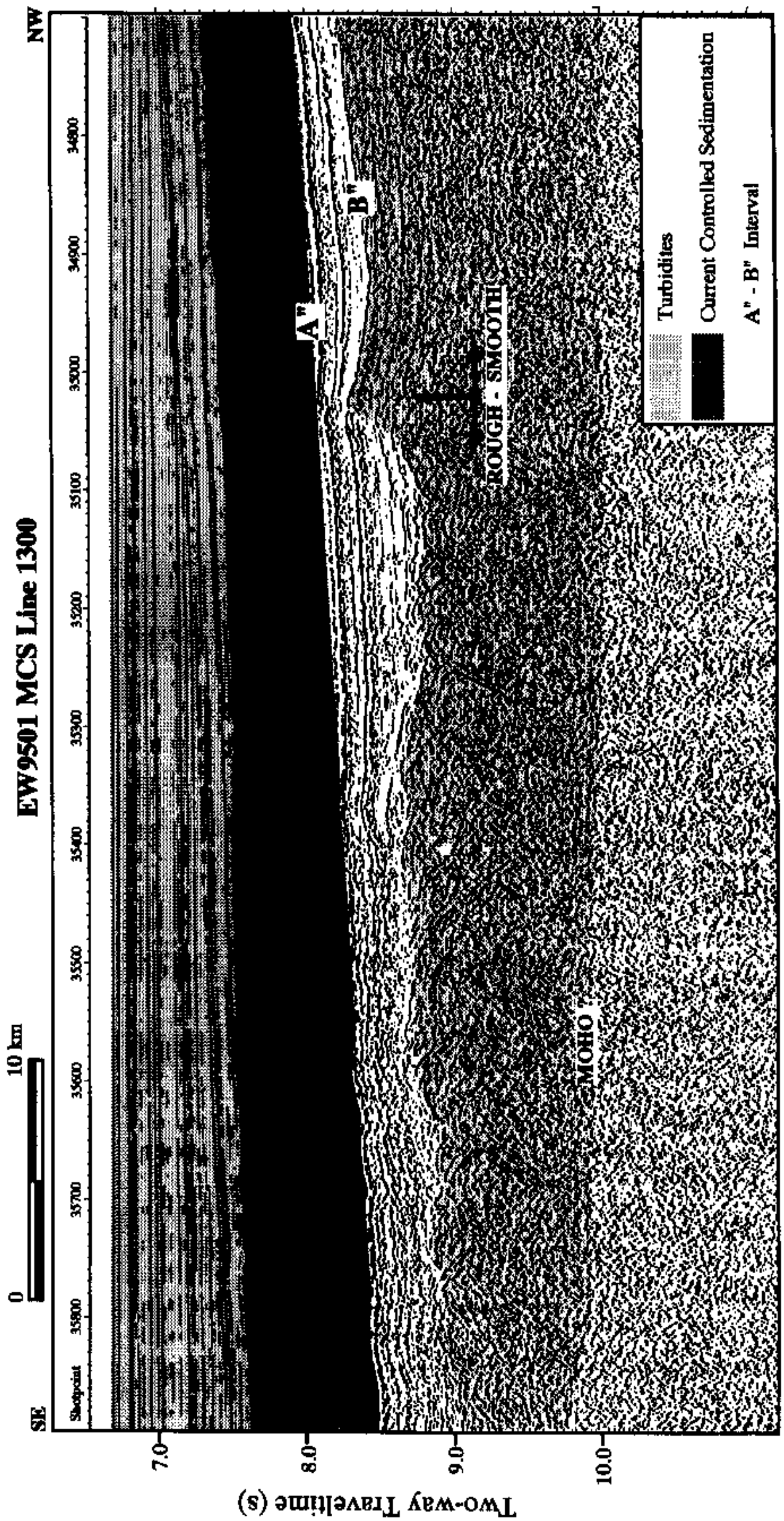
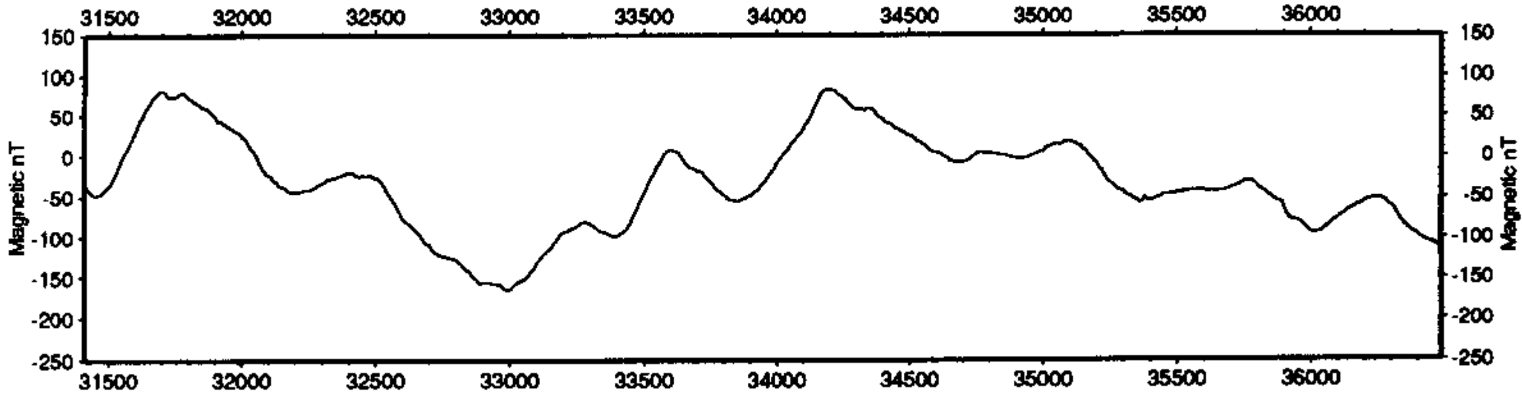
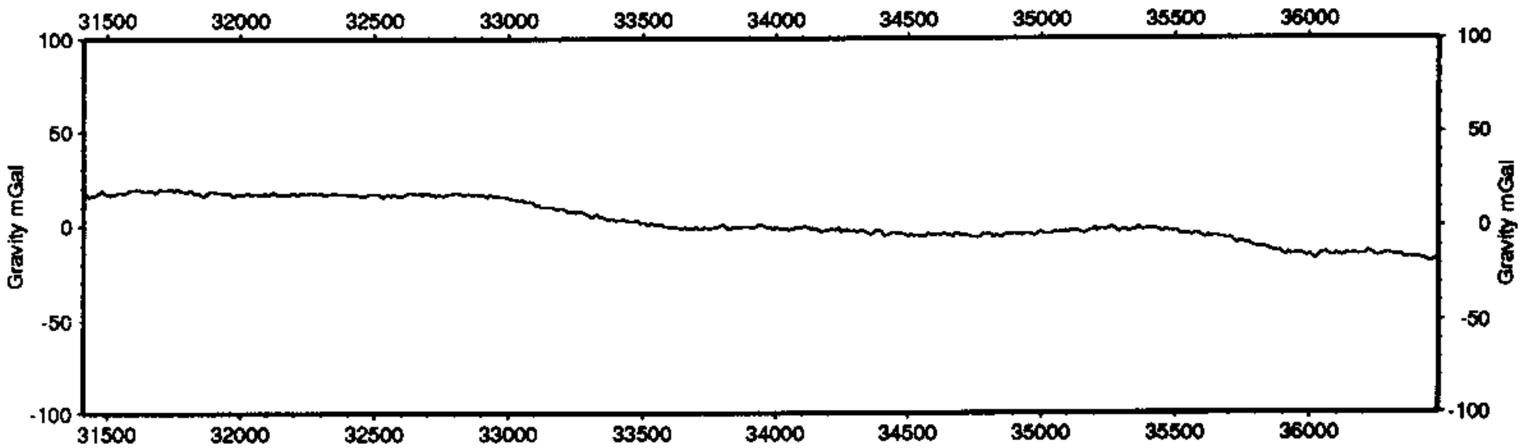

EW9501 MCS Line 1300
0
10 km
SE
NW
Shotpoint
35800
35700
35600
35500
35400
35300
35200
35100
35000
34900
34800
A"
B"
ROUGH - SMOOTH
MOHO
Turbidites
Current Controlled Sedimentation
A" - B" Interval
Two-way Traveltime (s)
7.0
8.0
9.0
10.0

Figure 4

## Line 1300 Magnetic Anomalies




## Free Air Anomalies




## Crustal structure

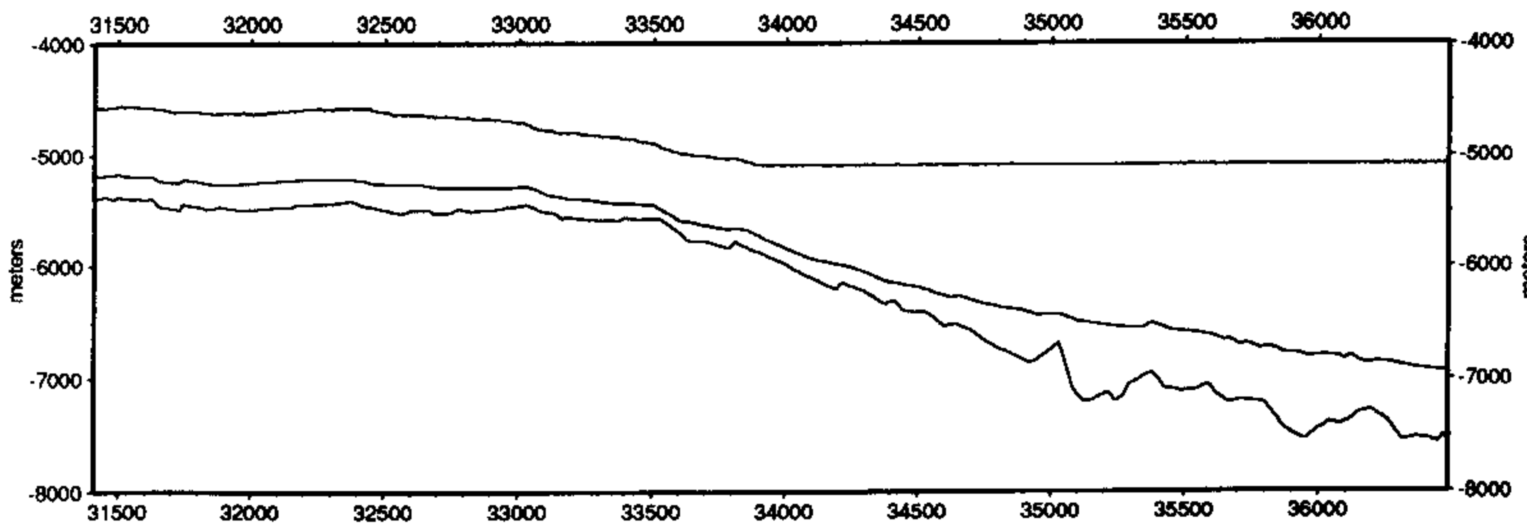



Figure 5

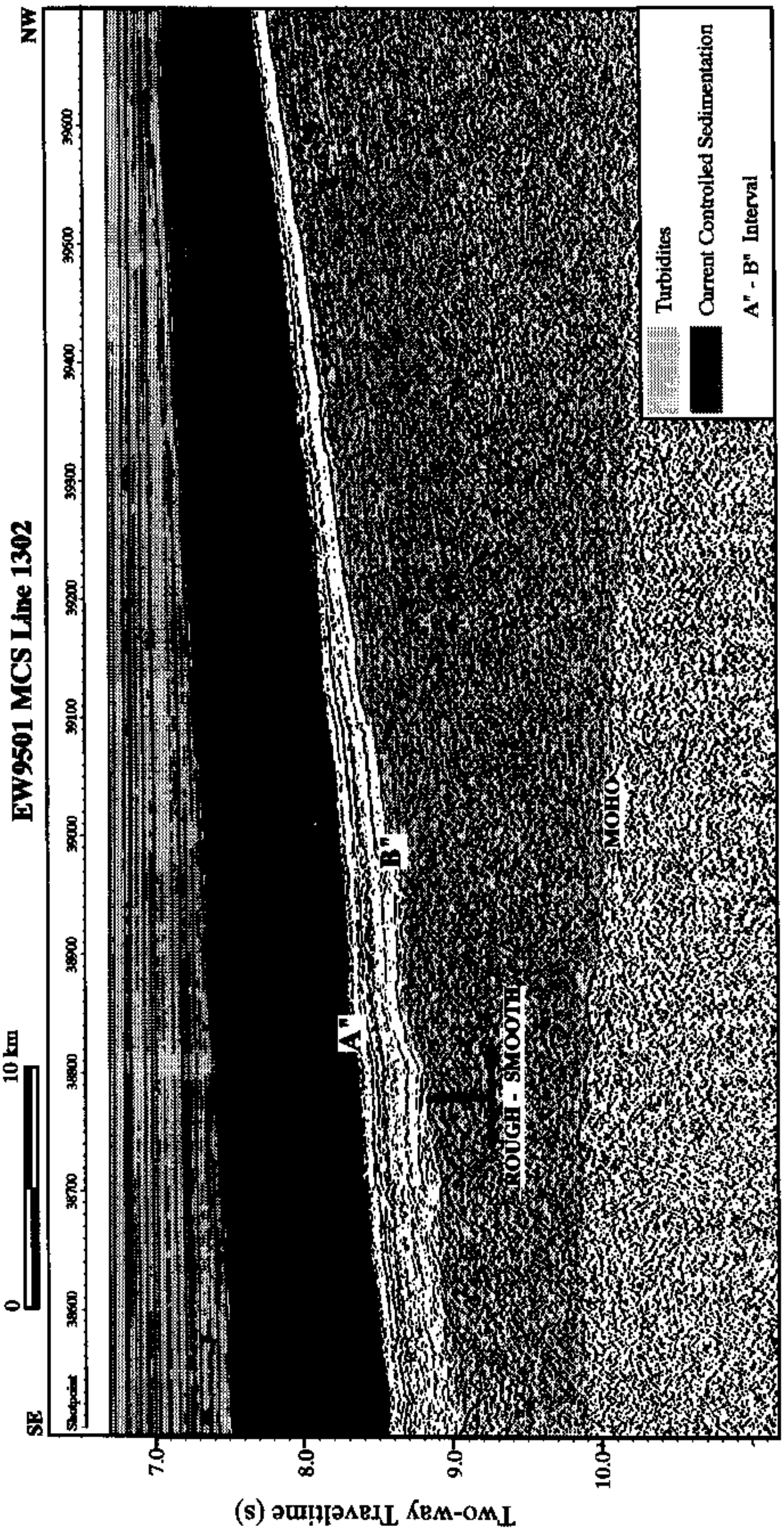

EW9501 MCS Line 1302
0
10 km
SE
NW
Shotpoint
38600
38700
38800
38900
39000
39100
39200
39300
39400
39500
39600
A"
B"
ROUGH - SMOOTH
MOHO
Turbidites
Current Controlled Sedimentation
A" - B" Interval
7.0
8.0
9.0
10.0
Two-way Traveltime (s)

Figure 6

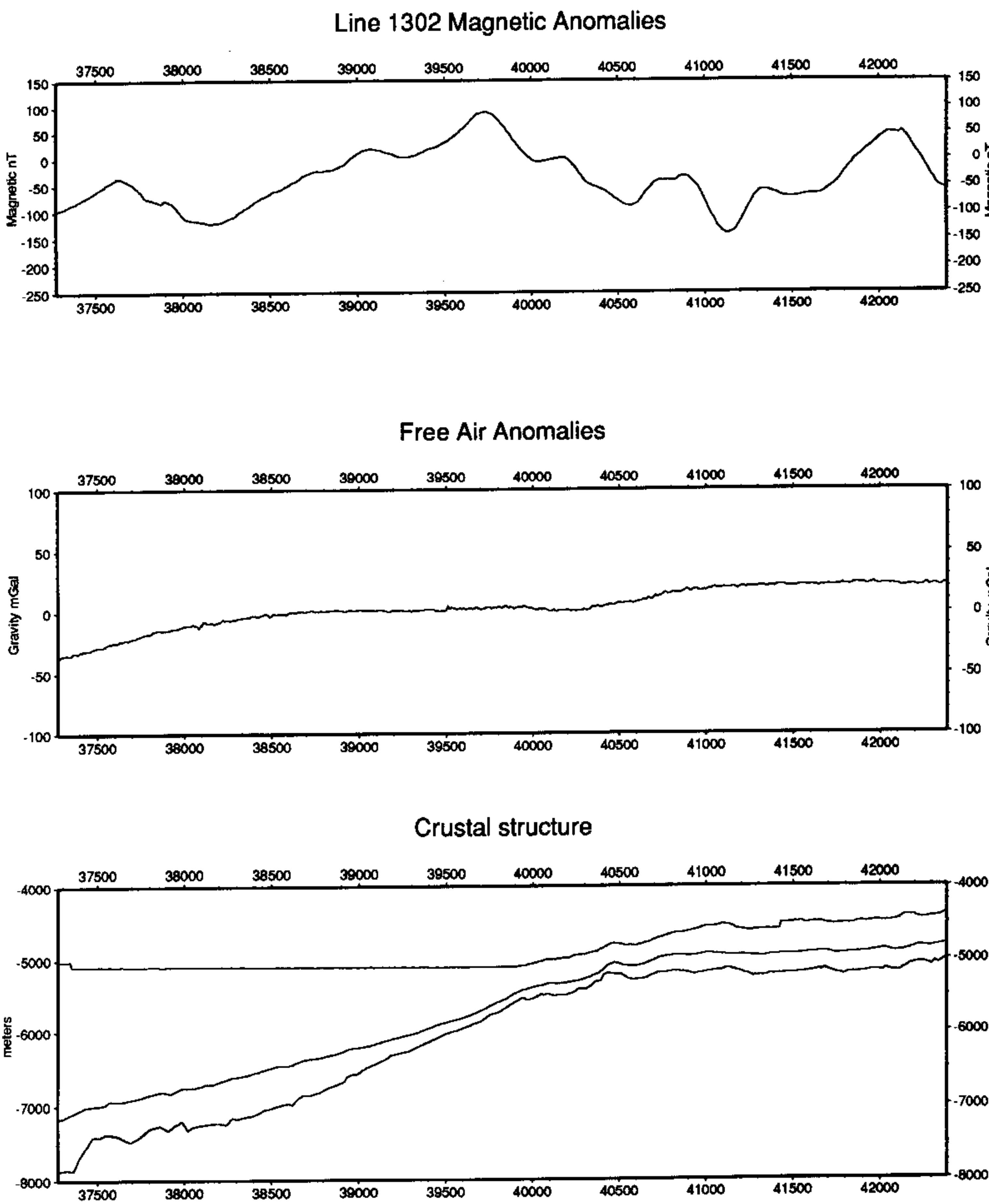

Line 1302 Magnetic Anomalies
Magnetic nT
Free Air Anomalies
Gravity mGal
Crustal structure
meters
37500
38000
38500
39000
39500
40000
40500
41000
41500
42000

Figure 7

# Magnetic Anomalies

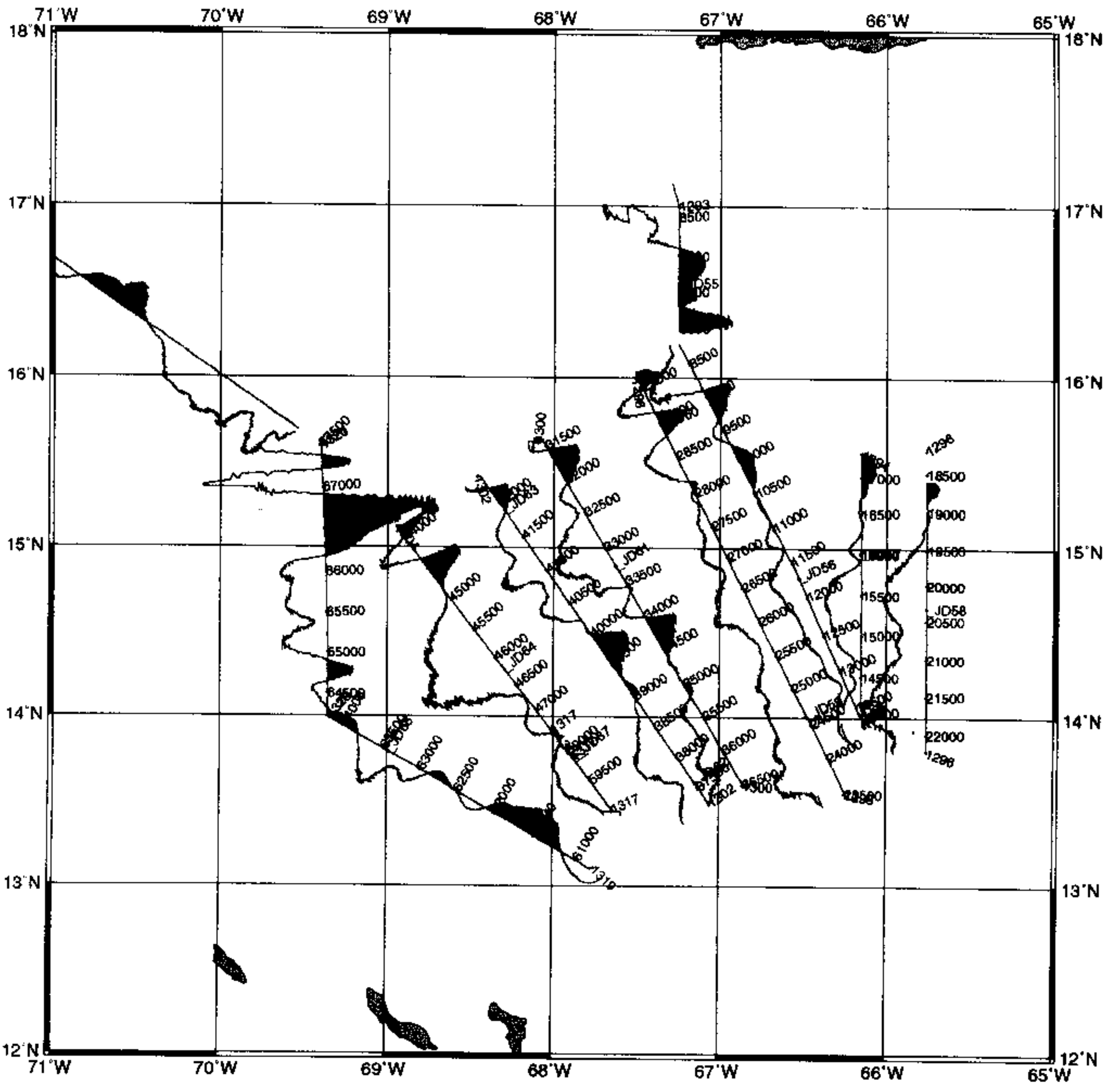
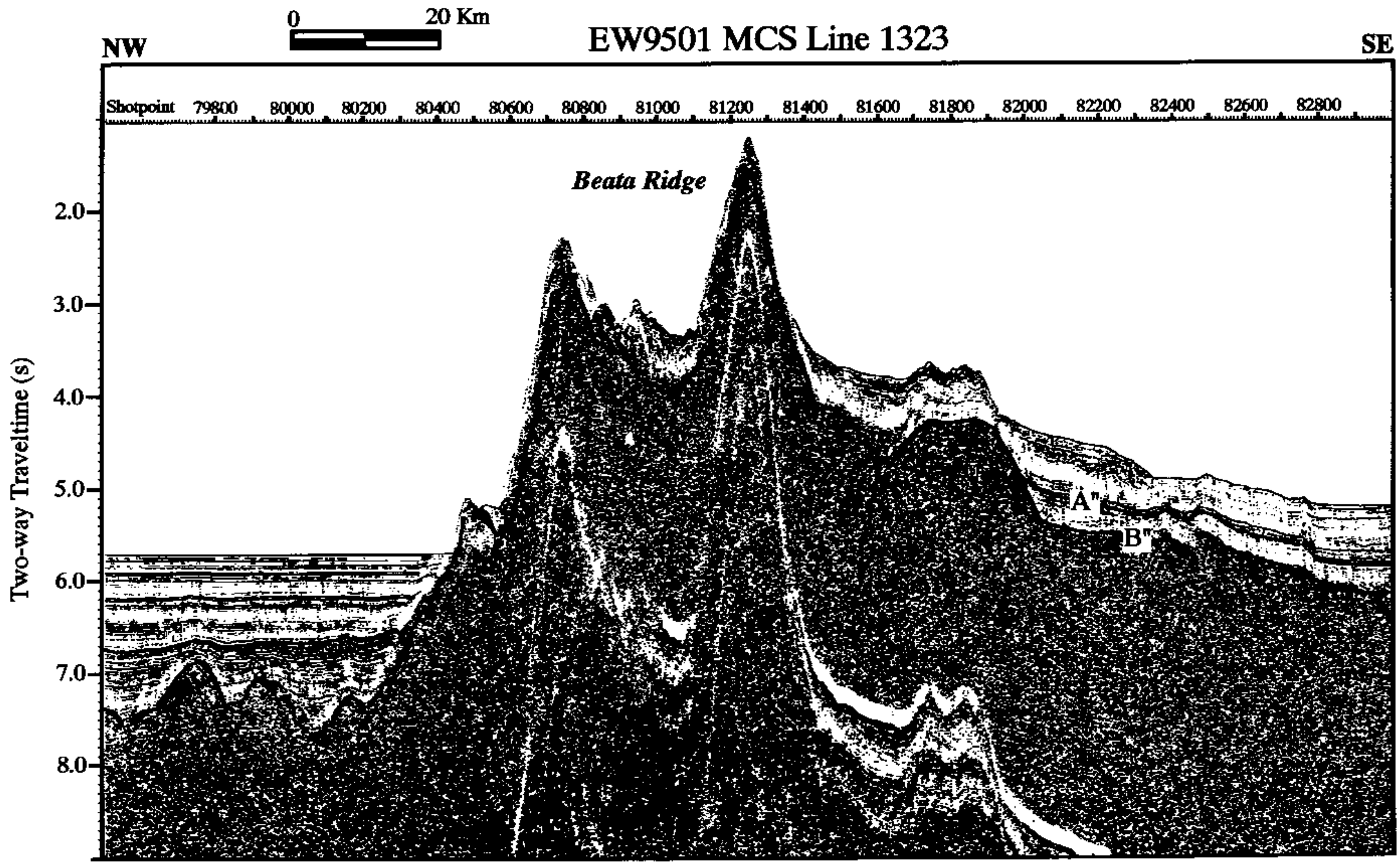



Figure 8



EW9501 MCS Line 1323
0
20 Km
NW
SE
Shotpoint
79800
80000
80200
80400
80600
80800
81000
81200
81400
81600
81800
82000
82200
82400
82600
82800
Beata Ridge
A"
B"
Two-way Traveltime (s)
2.0
3.0
4.0
5.0
6.0
7.0
8.0

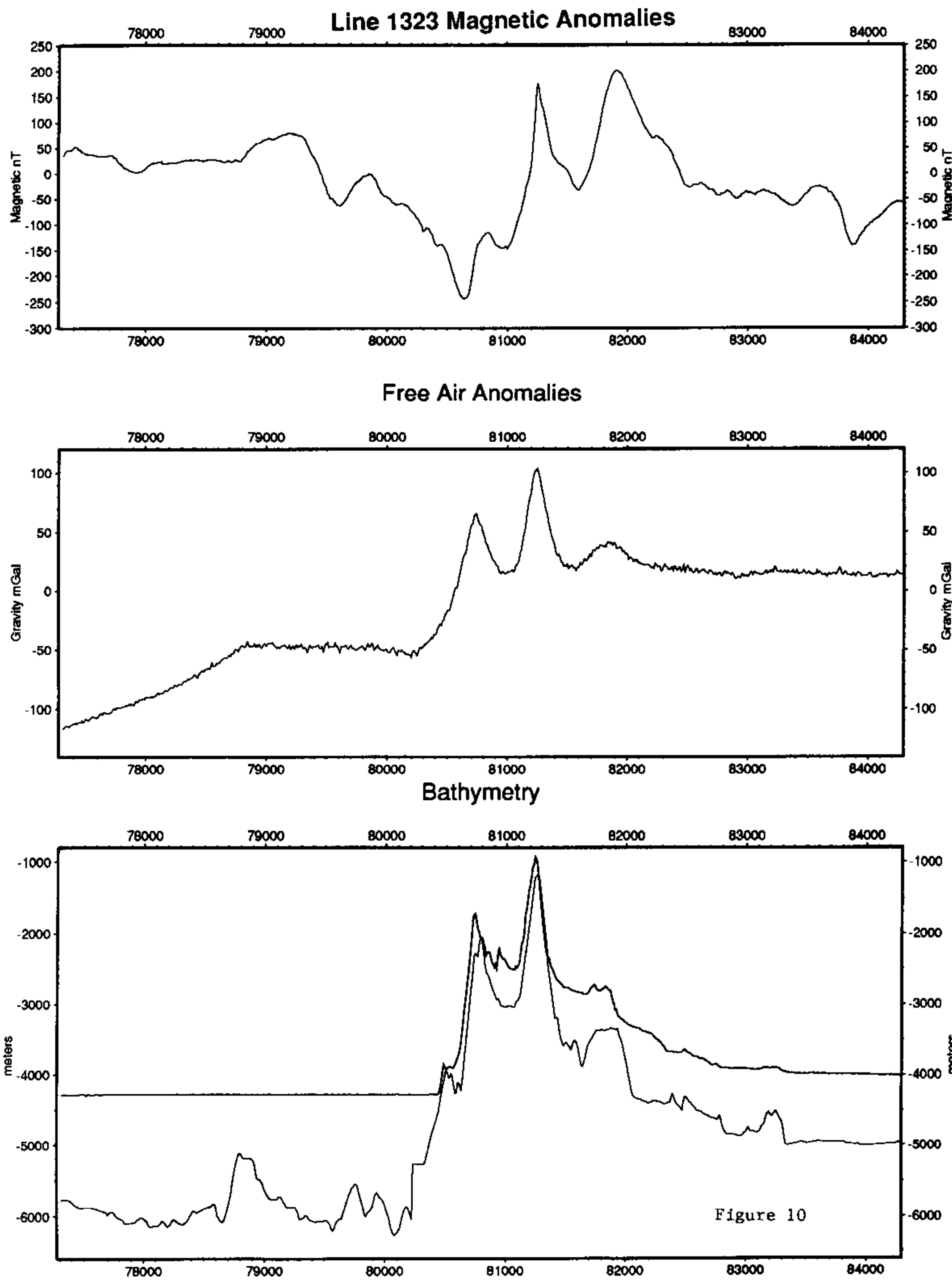

Line 1323 Magnetic Anomalies
Magnetic nT
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
78000
79000
80000
81000
82000
83000
84000
Free Air Anomalies
Gravity mGal
100
50
0
-50
-100
Bathymetry
meters
-1000
-2000
-3000
-4000
-5000
-6000

Figure 10

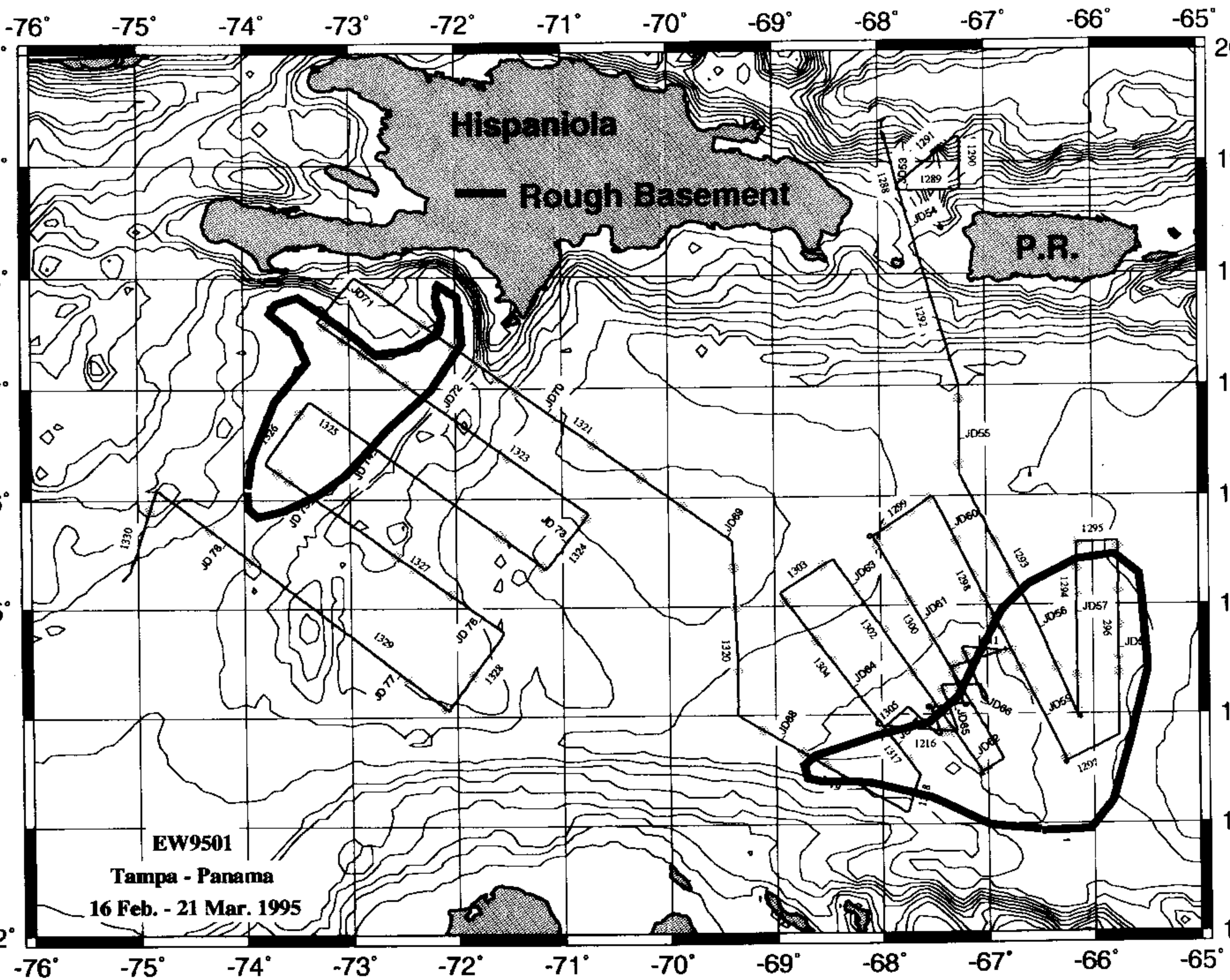

Hispaniola
Rough Basement
P.R.
EW9501
Tampa - Panama
16 Feb. - 21 Mar. 1995
-76° -75° -74° -73° -72° -71° -70° -69° -68° -67° -66° -65°
20° 19° 18° 17° 16° 15° 14° 13° 12°
JD53 JD54 JD55 JD56 JD57 JD59 JD60 JD61 JD63 JD64 JD65 JD66 JD68 JD69 JD70 JD71 JD72 JD 73 JD 77 JD 78
1288 1289 1290 1291 1292 1293 1294 1295 1298 1299 1300 1302 1303 1304 1305 1317 1320 1321 1323 1324 1325 1326 1327 1328 1329 1330

Figure 11

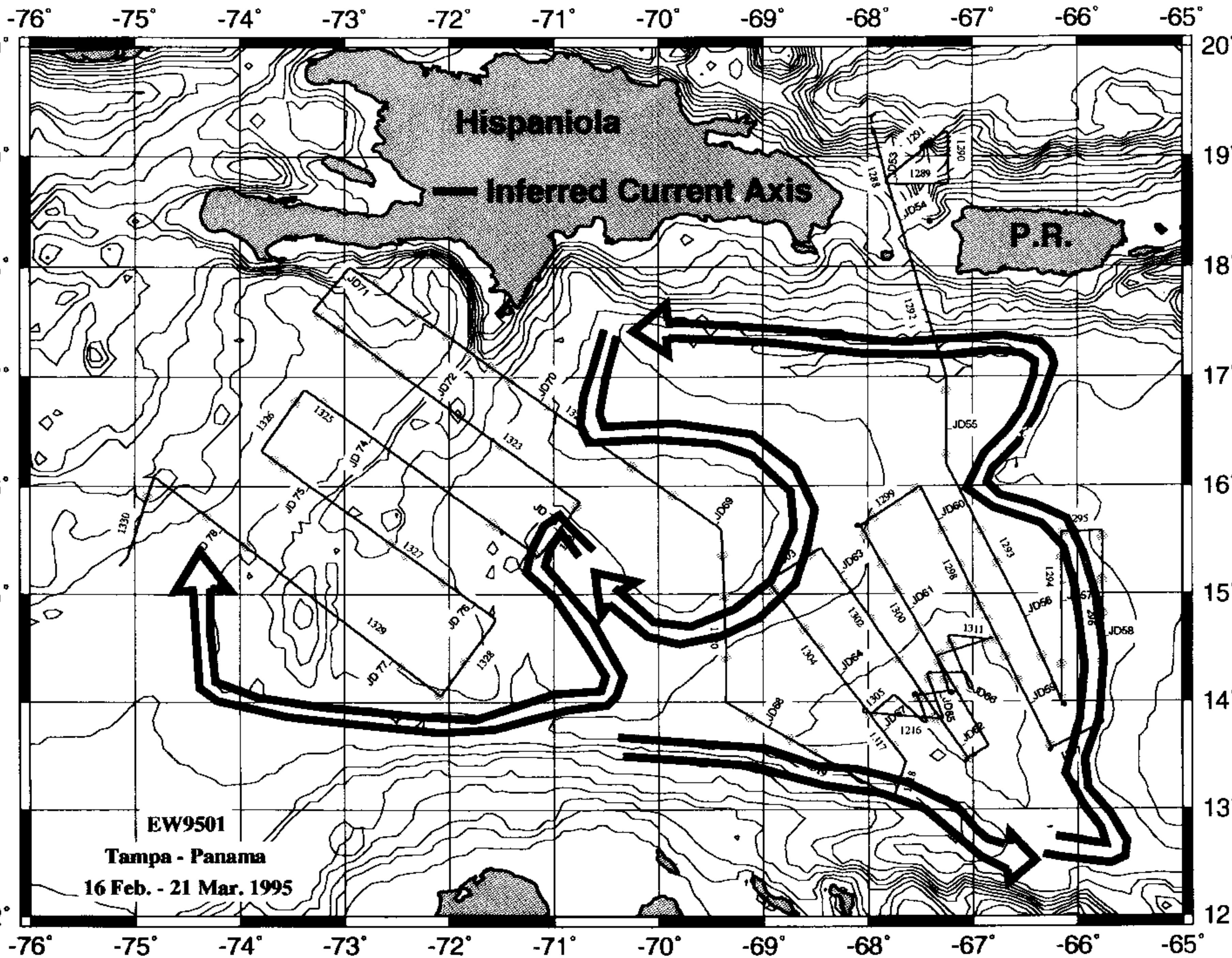

Hispaniola
— Inferred Current Axis
P.R.
EW9501
Tampa - Panama
16 Feb. - 21 Mar. 1995

Figure 12

*"I love the Caribbean in February!"*

Figure 13