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**To:** Paul Stoffa, Director

**From:** Paul Mann

**Concerning:** Student training support for student participation in marine survey of the Puerto Rico trench on RV *Maurice Ewing*

**Date:** January 10, 1996

**Request, dates and field area**

I request student training salary for two University of Texas M. A. students to participate in an NSF-funded cruise entitled, "Time-transgressive deformation effects of oblique underthrusting of aseismic ridges on the Puerto Rico trench and island margin: Sidescan, seismic reflection, gravity and magnetic studies" (OCE 95-04118). The dates of the cruise scheduled on the RV *Maurice Ewing* are June 13 (St. John, Virgin Islands) to July 4 (St. John). Work will focus on the Main Ridge area of the Puerto Rico trench.

**Request for student support and travel through NSF grant**

We are currently finalizing a revised budget for Bil Haq at NSF. This has been delayed because of the government shutdown. In my revised budget I have requested the following student support:

- 6 mos. halftime support in Year One, 4 mos. in Year Two, and 1 mo. in Year Three.
- RT airfares for two students to travel to and from the ship in St. John, Virgin Islands.

**Student training activities and educational opportunities on the cruise**

The cruise will provide a unique learning experience for students interested in the application of marine geophysical technology to active tectonic problems. Data to be collected will include MR1 sidescan, SCS, magnetics and gravity. These data will be integrated with existing SeaMARC II sidescan, MCS, SCS, magnetics and gravity data as well as earthquake information.

**Student research and deliverable products based on the cruise experience**

**To: Paul Stoffa**

**From: Paul Mann**

**Date: August 14, 1996**

**Re: Cruise report for EW96-05 and summary of student activities supported by UTIG student cruise money**

The attached report summarizes the activities of two students (van Gestel and Muszala) supported with student cruise funds.

In addition to writing the sections of the report indicated, they are aware that they will need to get you an individual report.

Thanks for supporting them - as you can see they were a big asset on the cruise.

***Maurice Ewing* cruise EW96-05**

**Marine Geophysical Investigation  
of the Puerto Rico Trench**

**15 June - 8 July**

**Jean-Paul van Gestel**

## **Introduction**

The purpose of the *R/V Maurice Ewing* 96-05 cruise was to gain a better understanding of the tectonic processes that are occurring at the Puerto Rico trench. The trench lies between the subduction-tectonics of the Lesser Antilles island arc and the Septentrional-Cayman trough left-lateral strike-slip fault system and thus exhibits oblique convergence. In order to study this process, as well as the time-transgressive deformational effects of fracture zone and aseismic ridge collisional effects, single channel seismic (SCS) data and HMR1 side-scan data were collected over a large portion of the Puerto Rico trench. Magnetic and gravity data were also collected throughout the cruise. The cruise occurred between the 15th of June and the 8th of July.

## **Responsibilities**

The responsibilities that were given to me during the EW96-05 cruise can be divided in four parts, which are the following:

1. The watch stander duties
2. Processing and plotting of several seismic lines
3. Two small presentations I had to give
4. Writing a piece of the cruise report.

The first part of my duties, acting as a watch-stander, took me eight hours every day. My shift was from four till eight, both in the morning and in the evening. Watch standing duties included making sure the SCS data were being collected, checking that the magnetics, gravity and navigation data were being collected and overseeing the HMR1 data. Although I occasionally watched the SCS data collection, which included three line scan recorders and the magnetic tape drives, I acted mainly as a watch-stander for the HMR1 system. Duties here included recording the latitude and longitude, recording the swath-width, fish depth as well as other data that would indicate that the HMR1 was collecting data and was still at the proper distance behind the ship.

The second big part of my job was to process the collected seismic lines as much as was possible on the ship, to plot several lines for the cruise report and to do some data quality control. With the use of the program SIOSEIS, which I had brought with me from Austin and of which I had been given a very brief introduction, I managed to read out all the collected data, do some basic processing steps like filtering, muting, AGC and deconvolution and plot the final result. So of all the lines there were plots, which have been used for the cruise report. Several special features like the sediment layers in the trench and the carbonate layers on the south side of the field area have been migrated and plotted and are used in the cruise report. Another important thing I could do on board of the ship is read in all the collected data, which was stored on 145 3480-tapes and restore them in a different format on only 24 of these tapes. In this way we not only had a back-up of all the data, but also could take them with us in the plane. Finally I used the SIOSEIS program to check some of the tapes, of which we were

not sure the data had been stored properly and observe more closely the collected records if we thought we had a noise problem. Fortunately I could always conclude that the data was stored and that the problems of the noise were only from minor importance because they were very low frequent.

Every day, around 4:00 in the afternoon, the science staff would hold meetings in order to discuss the geology and geophysics of the Puerto Rico trench and the progress and further plans of the cruise. Although some of us may have grumbled from time to time about going to the meetings, they were instrumental in giving us a good feel for the study area, allowed us (the students) to take an active part in the research and allowed all of us to discuss various aspects of the research. As we were also part of the science crew, we were also expected to give two presentations about the regional geology or about a part of the data collecting, for example in my case about the seismic collection and processing.

The last responsibility of the cruise was in writing portions of the cruise report. I either wrote or co-wrote the following sections: Single-Channel Seismic Reflection Operations, On board processing and preliminary interpretation of seismic data, Processing plan at UTIG for the SCS data, and also put a lot of effort in making a clear and understandable table of the collected seismic lines.

For a more explicit explanation of the goals of the cruise, of the processing steps I applied on the seismic data and of the parts of the cruise report I worked on, I would like to refer to the cruise report.

### **Cruise Complications**

There were several problems that were encountered on the cruise. The main problem dealt with the HMR1, that would not give good starboard bathymetry and sidescan. After many frustrating days of pulling the HMR1 out of the water, fixing it, and re deploying it, the HMR1 group had their chief engineer fly out and meet us in San Juan. He replaced a tuning inductor, fixed the time varying gain and shielded some of the electronics from noise. After dropping him off, however, there were problems with the noise levels picked up by the HMR1. The noise seen in the sidescan output varied with the RPM level of the Ewing. Eventually this was attributed to a blown digitizer board. This as well as the starboard electronics was replaced and operation of the HMR1 was normal and the output was acceptable.

Near the end of the cruise, the Hydrosweep system malfunctioned and was effectively out of order for the remainder of the cruise. Three and a half days of Hydrosweep data were lost.

There were some other problems, but they were all relatively minor. Most dealt with the airguns misfiring or tape drive malfunctions. Although the science party received a two day extension for the cruise due to the HMR1 problems, the Ewing was called into port 12 hours early due to the advance of hurricane Bertha, which was heading directly for San Juan, Puerto Rico.

The main problem I run into myself was the inability to look more closely at the collected data on my screen. I didn't have access to a program which allowed me to look at seismic traces on the screen, so the only possibility to compare various processing steps with each other was to plot them out on the Versatec.

Another "problem" was that I didn't succeed in putting the collected data on Exabyte-tapes, although we had the ability of an Exabyte tape drive. This would have reduced the amount of tapes to take home with us to only two, which would have been even more convenient.

## **Conclusions**

Whether or not the Puerto Rico trench is characterized by pure subduction, a pure left-lateral strike slip margin or a combination of both has been the overriding question of many scientists and was the question that was hoped to be answered on the *Ewing* 96-05 cruise. Even with the problems of the HMR1, lots of good data were collected that with further processing, will finally be able to give a clear picture of the tectonic activities in the Puerto Rico trench.

The main thing I learned by participating on this cruise was that I finally got to see that geophysics really works. I have studied geophysics in The Netherlands for several years and in those years I worked on processing of artificial data and some seismic data we collected ourselves during field trips. Somehow these data were always completely random, so you couldn't see the difference before and after stacking, before and after migration. It was a mess and stayed a mess. On this cruise, while working with SIOSEIS and with real professionally collected data, I saw that all the things I learned about in school, really work in practice, I was for example really amazed when I saw the first migrated section. The chance to work with these real data was a big challenge for

me and I think I was able to do a lot of work concerning processing and data quality control.

It was also a good learning experience to see and get to understand the working of other geophysical instruments like the HMR1, the gravity and magnetic measurements and the hydrosweep. This was also my first time I saw marine seismic data collection in practise and got an idea of the work which is going on on such a seismic ship.

I appreciate the financial support from UTIG that allowed me to participate in this Puerto Rico trench study. The next two semesters I will be working on the processing and interpretation of the seismic data, which I will also present at the AGU meeting in december and which I hope to conclude by writing a paper.

### **Acknowledgements**

First of all I would like to thank Paul Mann for inviting me on the cruise, which gave me the change to work with real data, get me introduced to the United States in general and the Institute of Geophysics in specific and indeed acted as "a good incentive to finish up my thesis study (in Holland) as quickly as possible".

Then I would like to thank all the people who were there on the ship, both ship crew members and special science staff for the help with my work and the fun we had. Finally I would like to thank Alison for her brief but clear two hour introduction to SIOSEIS and both her and Steffen for the answers on my questions I mailed them, although I realise it is hard to explain and solve a problem when you are not sitting behind the same screen.

Stefan Muszala  
9/5/96

### *Maurice Ewing* cruise EW96-05

#### **Introduction**

The purpose of the *R/V Maurice Ewing* 96-05 cruise was to gain a better understanding of the tectonic processes that are occurring at the Puerto Rico trench. The trench lies between the subduction-tectonics of the Lesser Antilles island arc and the Septentrional-Cayman trough left-lateral strike-slip fault system and thus exhibits oblique convergence. In order to study this process, as well as the time-transgressive deformational effects of fracture zone and aseismic ridge collisional effects, single channel seismic (SCS) data and HMR1 side-scan data were collected over a large portion of the Puerto Rico trench. Magnetic and gravity data were also collected throughout the cruise. The cruise occurred between the 15th of June and the 8th of July.

#### **Responsibilities**

The responsibilities that were given to me during the EW96-05 cruise consisted mainly of acting as a watch-stander. Watch standing duties included making sure the SCS data were being collected, checking that the magnetics, gravity and navigation data were being collected and overseeing the HMR1 data. Although I occasionally watched the SCS data collection, which included three line scan recorders and the magnetic tape drives, I acted mainly as a watch-stander

for the HMR1 system. Duties here included recording the latitude and longitude, recording the swath-width, fish depth as well as other data that would indicate that the HMR1 was collecting data and was still at the proper distance behind the ship.

Every day, around 4:00 in the afternoon, the science staff would hold meetings in order to discuss the geology and geophysics of the Puerto Rico trench. Although some of us may have grumbled from time to time about going to the meetings, they were instrumental in giving us a good feel for the study area, allowed us (the students) to take an active part in the research and allowed all of us to discuss various aspects of the research.

The last responsibility of the cruise was in writing portions of the cruise report. I either wrote or co-wrote the following sections: Single-Channel Seismic Reflection Operations, Airgun Configuration, Computer System, Navigation, Magnetic Data Acquisition, Review of Crustal Structure of the Study Area and Review of Shallow Structures in the Study Area.

What follows is a portion of the cruise report that I wrote on board and that gave me a good understanding of the background of the geology of the Puerto Rico Trench.

## **Geology of the Puerto Rico Trench**

### *Seismic Refraction*

There are four important seismic refraction lines that bear mentioning in relation to the Puerto Rico Trench. They are found in Bunce et. al. (1974), Officer

et. al. (1957) , Talwani et. al. (1959), and Treadgold (1985). All of the refraction lines contain similar cross-sections and compressional wave velocities.

Bunce et. al. (1959) using a Molnar and Sykes (1969) refraction line (fig. 1a & 1b), found that the layers with compressional wave velocities of 2.0, 5.2 and 6.6 km/s are continuous from the Nares Basin to the north slope of the trench. The 4.2 km/s layer pinches out at 21° 30' N. The 2.0 km/s each correspond to transparent sediments while the 4.2 km/s indicates stratified sediments. Both the 5.2 and 6.6 km/s layers are indicative of oceanic basement. Below this, the mantle is seen with compressional wave velocities of approximately 8.0 km/s. Under the trench itself, a different velocity profile is found. Here, there is a sedimentary layer with higher than 3.8 km/s velocities that overlays a section of 6.0 km/s layer (oceanic basement) Under this there is a layer of 7.2 km/s that lies over a 7.9 km/s layer. The 7.2 km/s layer has been found in other active orogenic regions such as mid-ocean ridges and some Pacific troughs and trenches (Bunce and Fahlquist, 1962).

Talwani et. al. (1959) found a similar velocity to that found in the Bunce et. al. (1974) paper (fig. 2a & 2b) Talwani et. al. (1959) find a 2.1 km/s layer (transparent sediments) that overlays a layer with 3.8 km/s compressional wave velocities. This could be interpreted as belonging to the layered sediments that Bunce et. al. had found. Below this, a 5.5 km/s layer is found. Although different from the 5.2 and 6.6 km/s layer found in Bunce et. al. (1974). this could be indicative of oceanic ba layers, there lie a 7.0 km/s layer and a 8.2 km/s layer. The 7.0 km/s layer is probably the intermediate layer found in Bunce et. al. (1974), while the 8.2 km/s layer is mantle material.

Officer et. al. (1957) conducted a series of seismic refraction lines that trended approximately east-west in the Puerto Rico Trench. Although the data had to be correlated to produce a north-south profile and data are therefore sparse, there exist certain similarities in the compressional wave velocities that Bunce et. al. (1974) and Talwani et. al. (1959) found. Officer et. al. (1957) finds a crustal velocity of 6.3 km/s and a mantle velocity of 8.0 km/s. Officer et. al. (1957) note that the crustal velocity in the Puerto Rico Trench is lower than the average 6.5 km/s compressional wave velocities of the Atlantic crust. A thickening of the crust from 4 km to 7 km was also found toward the deeper part of the trench.

Through the analysis of multichannel seismic (MCS) data, nineteen sonobuoys, and three expanding spread profiles (ESP's) Treadgold (1985), characterizes the crust found north of Puerto Rico. In his study of the Puerto Rico Trench, the Greater Antilles Outer Ridge and the Nares Abyssal Plain (fig. 3), Treadgold (1985) found that the NE-SW mantle ridge high is offset by a fracture zone. McCann and Sykes (1984) found an aseismic ridge trending northeast-southwest in their study of the Puerto Rico Trench (fig. 4). Figures 5, 6 & 7 show that the aseismic ridge is parallel to the Treadgold (1985) fracture zone and both the aseismic ridge and the fracture zone are perpendicular to the mantle high.

The general stratigraphy that Treadgold (1985) found is as follows: The uppermost layer is acoustically transparent material made up of a brown homogeneous silty clay with minor biogenic material. Underlying this is a layer of strongly reflective stratified sediments deposited by turbidity currents. Underneath these first two layers is the oceanic crust, which is divided into three distinct layers. They are a 3.8 km/s layer, a 5.1 km/s layer and a 6.0 km/s layer. The

average thickness of the crust was calculated to be 1.8 - 2.0 km. Beneath this, there is a layer with a velocity of 6.6 km/s and 7.2 km/s. This layer has an average thickness of 4.3 km and is composed of gabbro, matagabbro and some ultramafics. The last layer records velocities between 7.5 km/s and 8.2 km/s. This increase in velocity occurs at the Mohorovicic discontinuity and is thought to occur as the result of a petrologic change from serpentized ultramafics to unaltered ultramafics (Clague and Straley, 1977).

### *Shallow Structures*

Many different theories have been proposed to explain the relative motions of the Caribbean and North American Plate in the vicinity of the Puerto Rico Trench. Multi-Channel Seismic reflection data (Larue and Ryan, in press; fig. 8) and GLORIA side-scan sonar and single-channel seismic reflection data (Masson and Scanlon, 1991) help constrain these theories.

Larue and Ryan (in press) characterize the trench as a broad, flat-floored basin consisting of up to two seconds of sediment. They characterize the relative plate motion differently along the eastern and western portions of the Puerto Rico slope. In the west the lower slope exhibits abundant evidence of contractional deformation, whereas in the west it exhibits a combination of contractional and transcurrent motion. Due to the lack of a well developed accretionary prism, Larue and Ryan (1990) believe that the deformation along the trench is either very recent or occurring very slowly.

To the north of the trench, the seafloor is broken by numerous normal faults, while to the south of the trench there exist a series of terraces also broken by normal faults. The topography on the southern slope is due mainly to the 19° left-lateral strike-slip fault that in some regions makes up the boundary of the North American and Caribbean plates (Larue & Ryan, in press). In the eastern portion of the trench, there is an overall lack of sediment fill and the trench is narrower than elsewhere (MCS line LS 126 57; fig 9). In this region, a small accretionary sedimentary prism overlies undeformed sedimentary strata that are truncated along the top of a packet of gently south-dipping reflectors that are interpreted as the uppermost layers of underthrust oceanic crust (Larue and Ryan, in press). The truncated reflectors along this interface indicate that it is a fault contact with underlying strata.

The western portion of the trench can best be characterized by MCS line NAT 42 (fig. 10) Immediately south of the Puerto Rico Trench, Larue and Ryan (1990), find a layer of diffuse south-dipping reflectors that are interpreted as the boundary between the Atlantic oceanic crust and the rocks that underlie the south wall of the trench. It is in this portion of the trench that the valley of the south wall is in alignment with the 19° strike-slip fault that was found in the GLORIA side-scan study (Masson and Scanlon, 1991; described below).

West of MCS line NAT 42, Larue and Ryan (in press) describe the Puerto Rico Trench as strike-slip dominated. This is best shown on MCS line NAT 58 (fig 11). Here the north wall of the slope is bathymetrically smooth and discontinuously layered (Larue and Ryan, in press). The evidence for strike-slip motion in this portion of the trench is given by steeply dipping fault complexes

against which trench reflectors are deformed. Such structures are known as a contractional flower structures, and they are common features in areas where strike-slip motion is combined with some contraction (Larue and Ryan, in press).

GLORIA data presented by Masson and Scanlon (1991) show that the floor of the Puerto Rico Trench is easily recognized by a band of low back scattering due to recent turbidite sedimentation. On the lower Puerto Rico slope, a zone of ridges and sediment filled basins occurs between  $19^{\circ}\text{N}$  and  $19.5^{\circ}\text{N}$ . In deeper portions of the trench, the deeper strata are seen to tilt gently southward (fig. 12), suggesting that subduction in the trench has either stopped or is occurring extremely slowly (Masson and Scanlon, 1991). The ridges and basins trend  $095^{\circ}$ - $105^{\circ}$ , oblique to the axis of the  $085^{\circ}$  Puerto Rico Trench.

Several  $085^{\circ}$  to  $105^{\circ}$  trending lineaments extend for 250 km across the entire Puerto Rico slope. In the west, a similar lineament is found paralleling the main ridge and occurring just south of the Puerto Rico Trench. These lineaments are thought to be part of a large strike-slip fault system and are seen in figure 13 (Masson and Scanlon, 1991). Although no offset could be determined from the GLORIA data, the overall left-lateral nature of the North America and Caribbean plate boundary suggests that motion on the Puerto Rico slope fault complex is also left-lateral (Masson and Scanlon, 1991). In light of this, Masson and Scanlon (1991) suggest that the Main Ridge could have formed as the result of a right-step in of the left-lateral strike-slip fault system (Masson and Scanlon, 1991). In contrast, McCann and Sykes (1984) propose that the Main Ridge is a high-standing aseismic ridge that developed along the Atlantic oceanic fracture zone during seafloor spreading.

In the western-most portion of the GLORIA survey, some evidence of recent tectonic activity was found on the northern continental slope of Puerto Rico (McCann, 1985). Here Masson and Scanlon (1991) find numerous faults trending northwest-southeast. It has also been assumed that the Mona canyon, a box shaped canyon with extremely steep walls, is fault controlled. These faults have a north-south trend and are offset by the northeast-southwest-trending faults (Masson and Scanlon, 1991).

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### Conclusion

Whether or not the Puerto Rico trench is characterized by pure subduction, a pure left-lateral strike slip margin or a combination of both has been the overriding question of many scientists and was the question that was hoped to be answered on the *Ewing* 96-05 cruise. Even with the problems of the HMR1, lots of good data were collected that with further processing, will finally be able to give a clear picture of the tectonic activities in the Puerto Rico trench.

When I was first introduced to geophysics I saw many slides of airgun arrays, streamers, magnetometers and almost every other imaginable piece of equipment used in geophysics. The pictures and descriptions meant little to me then and it was only this summer that I was able to put meaning to them and see everything in person. It was an enjoyable experience and I learned a great deal. It was like a crash course in applied marine geophysics and it gave me a much clearer picture of how everything on a cruise works from the hardware and software that make the equipment run and how they are fixed to the politics that goes along with cruises.

I appreciate the financial support from UTIG that allowed me not only to participate in the Puerto Rico trench study, but also in the North Slope aerogeophysical study with Larry Lawver. The magnetics data from the North Slope will form the basis of my PhD study and will allow me to combine geophysics and structural geology/tectonics. In order to gain experience in processing the North Slope data, I will be working on the Puerto Rico trench magnetic data with Paul Mann and Nancy Grindlay this semester in preparation for the spring AGU meeting.

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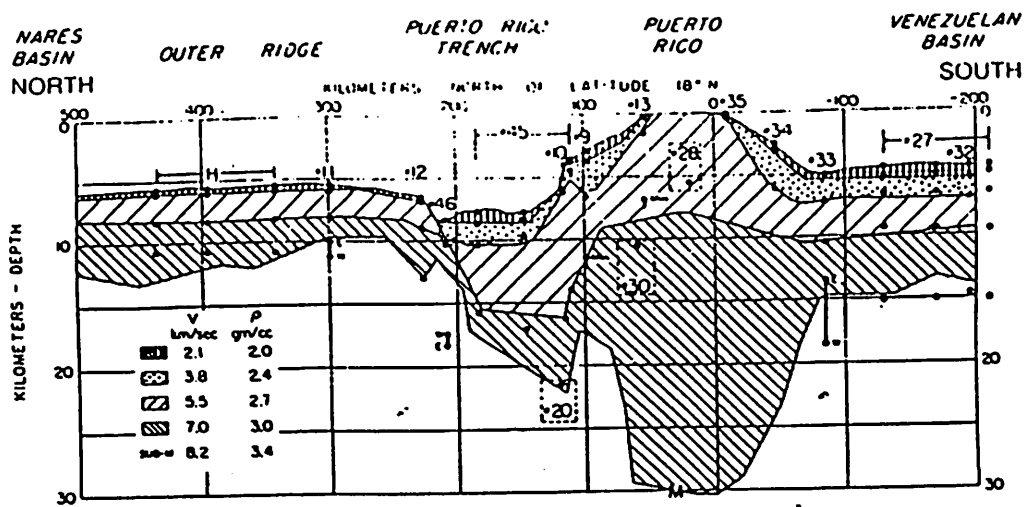


Figure 1a - Crustal cross section of the Puerto Rico Trench. Dashed lines indicate the Caribbean-Atlantic plate boundary (Modified from Molnar & Sykes, 1969, cited in Bunce et al., 1974).

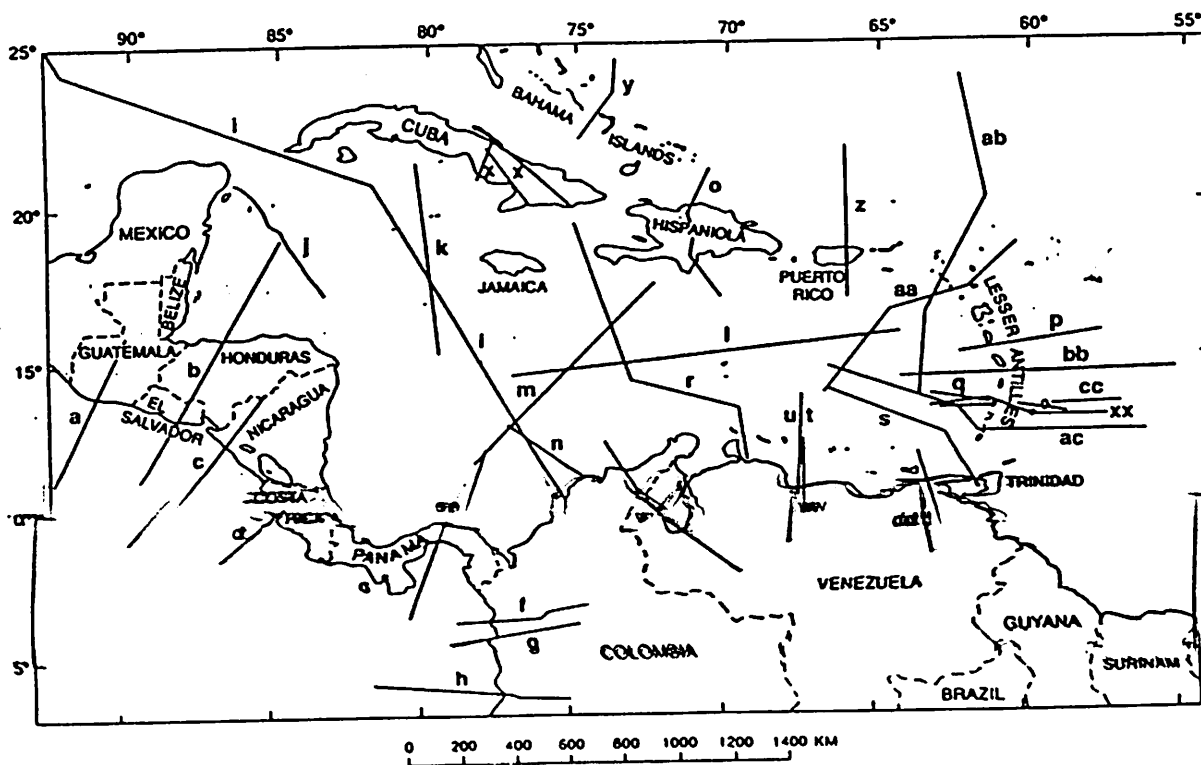


Figure 1b - Location of the Molnar & Sykes (1969) refraction line.



**Figure 2a - Crustal cross section of the Puerto Rico Trench and nearby areas. Points indicate an inferred boundary (Modified from Talwani et. al. 1959).**

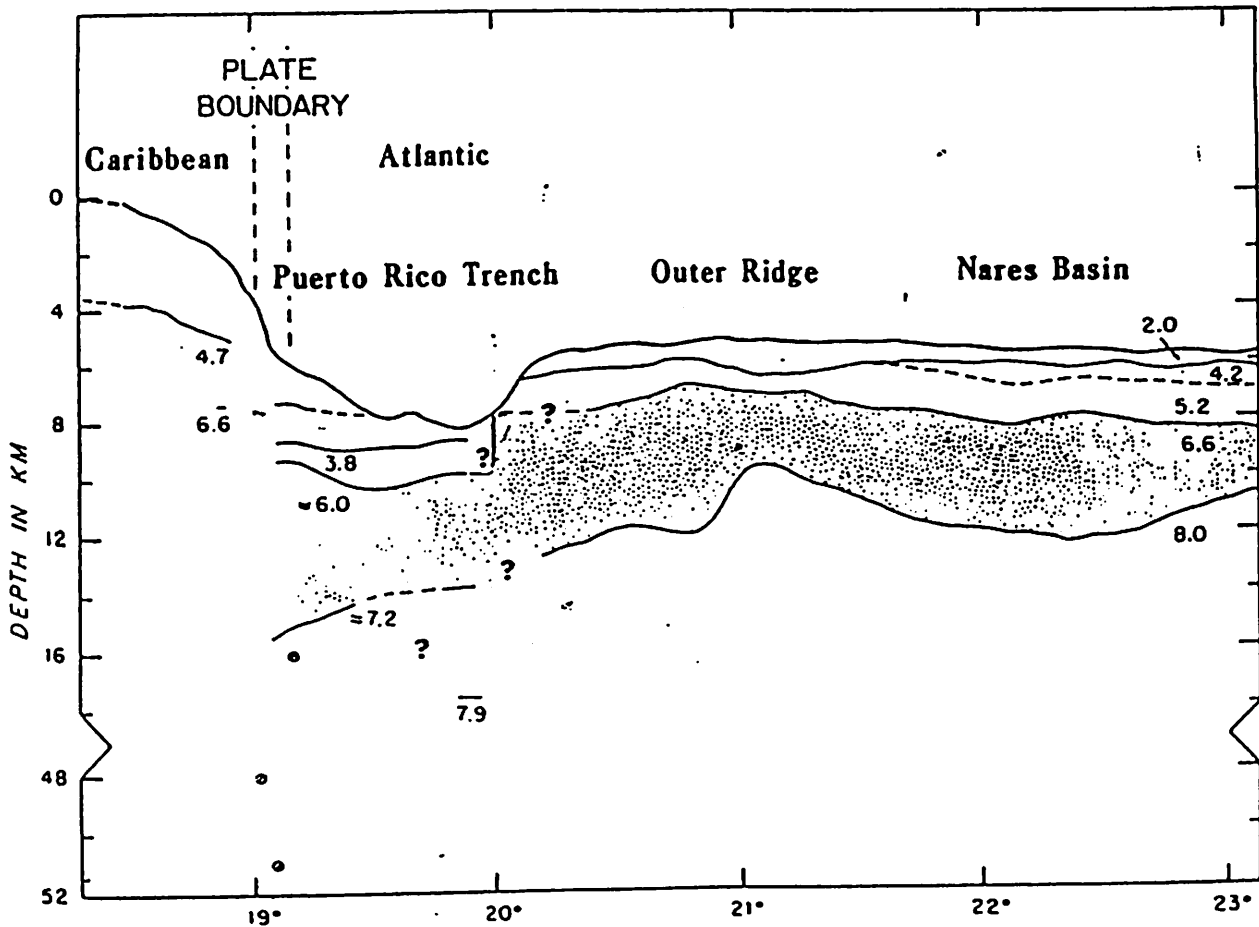


Figure 2b - Location of the Talwani et. al. (1959) refraction line. It is line 'z' on the map.

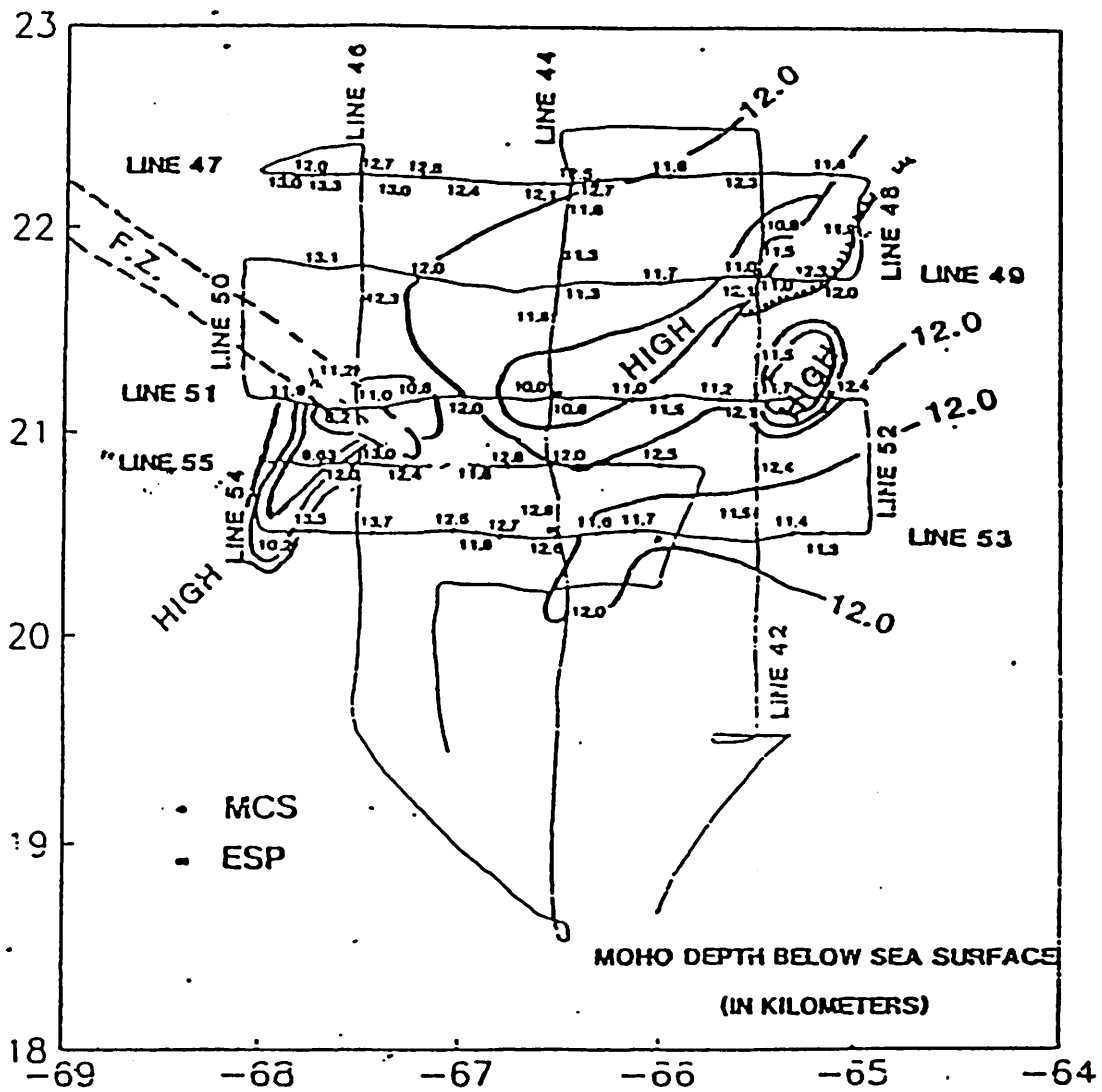
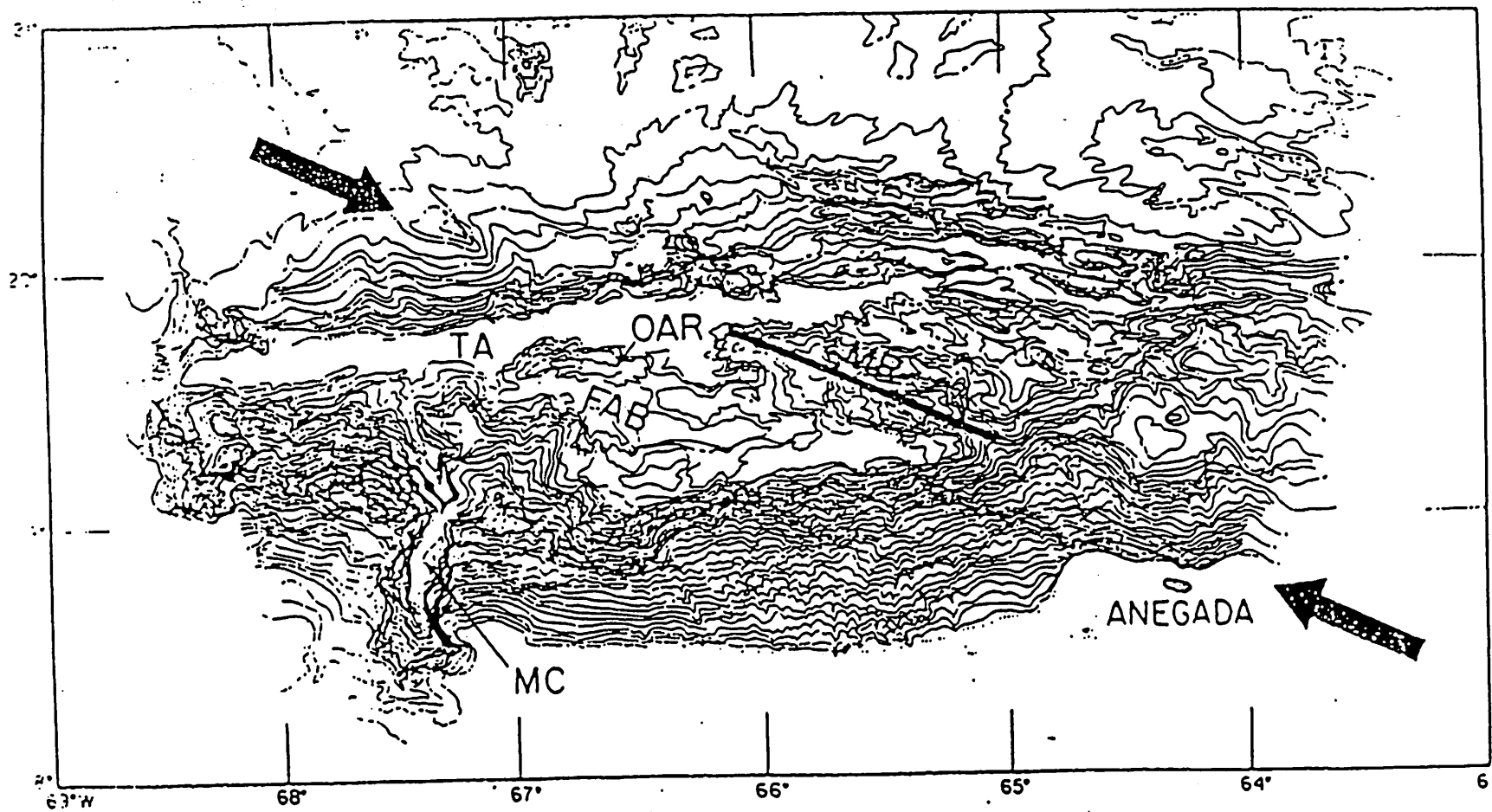
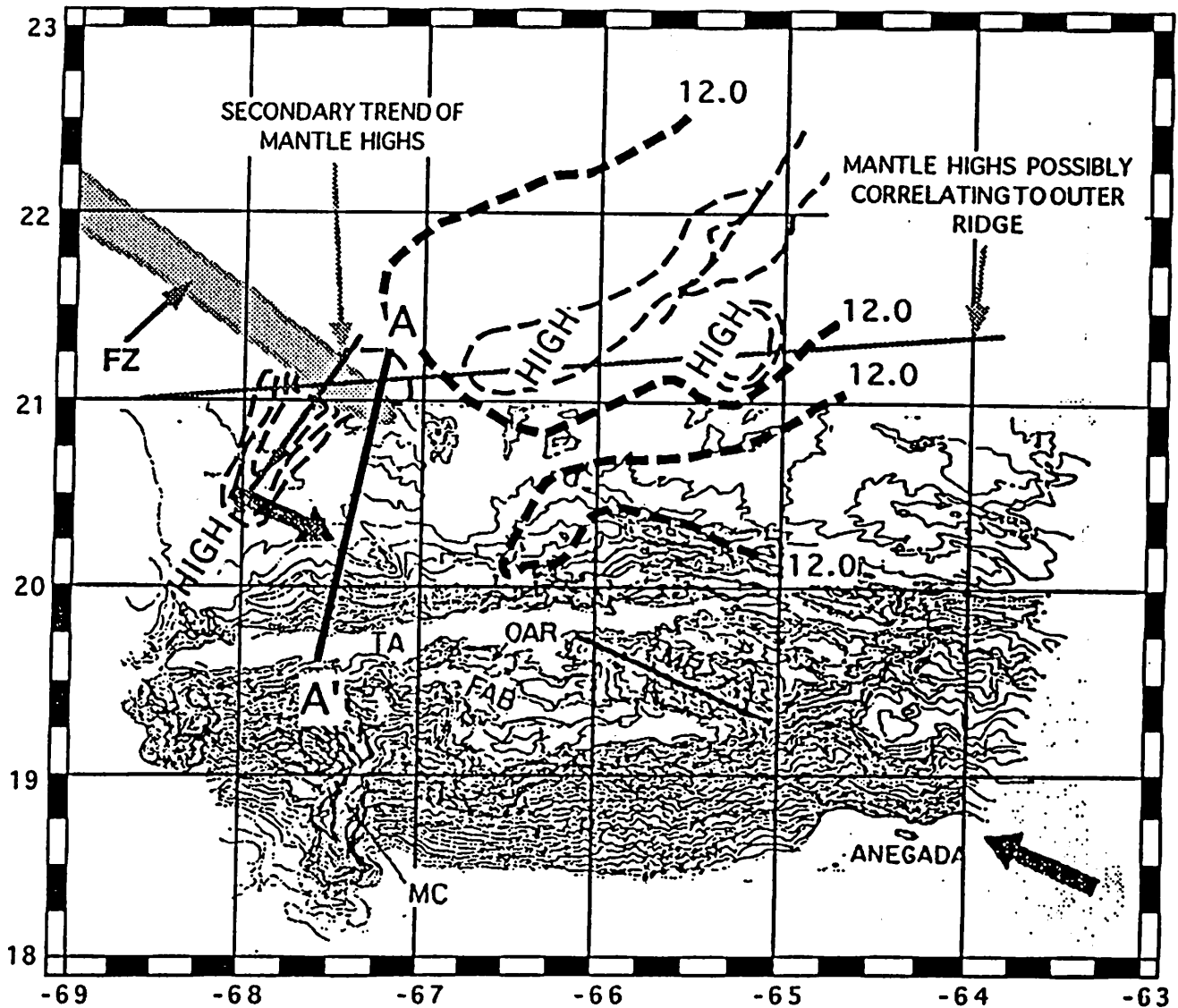


Figure 3 - Depth to the Moho showing NE-SW mantle ridge (contoured Moho high) offset by the fracture zone (dashed lines) and including the eastern mantle high (Threadgold, 1985).



**Figure 4** - Map showing the location of the aseismic ridge found by McCann and Sykes (1984).



**Figure 5 - Bathymetry** (A. Leonardi, unpublished data, 1981; published in McCann and Sykes, 1984) of the Puerto Rico trench north of Puerto Rico and the Virgin Islands (1 contour interval=1 fathom=1.829m). Depth to the MOHO is shown by the bold hashed lines. MR=Main ridge; TA=Trench Axis; OAR=outer arc ridge; FAB=forearc basin; FZ=fracture zone; MC=Mona Canyon. The reflection line from Savit et. al. (1964) that shows a crustal high that corresponds to the projection (dark arrows) of the Main Ridge by McCann and Sykes, 1984 is shown by the line A-A' (figs. 6 & 7). The main ridge and the fracture zone are oblique to the other tectonic structures in the trench. The depth to the Moho shows a mantle ridge that is orthogonal to the fracture zone and the Main Ridge (figure modified from McCann and Sykes, 1984 and from Treadgold, 1985).

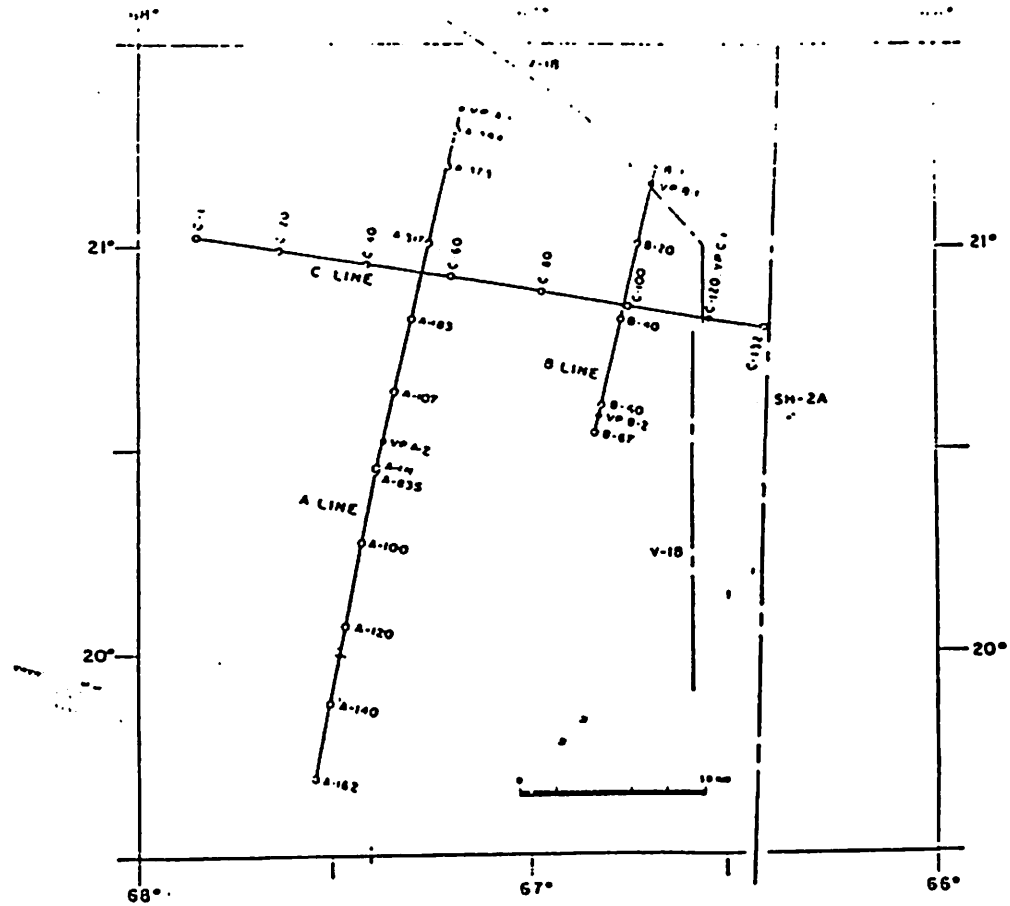


Figure 6 - Map showing the location reflection lines from Savit et. al. (1964).  
Line 'A' was superimposed on Figure 5.

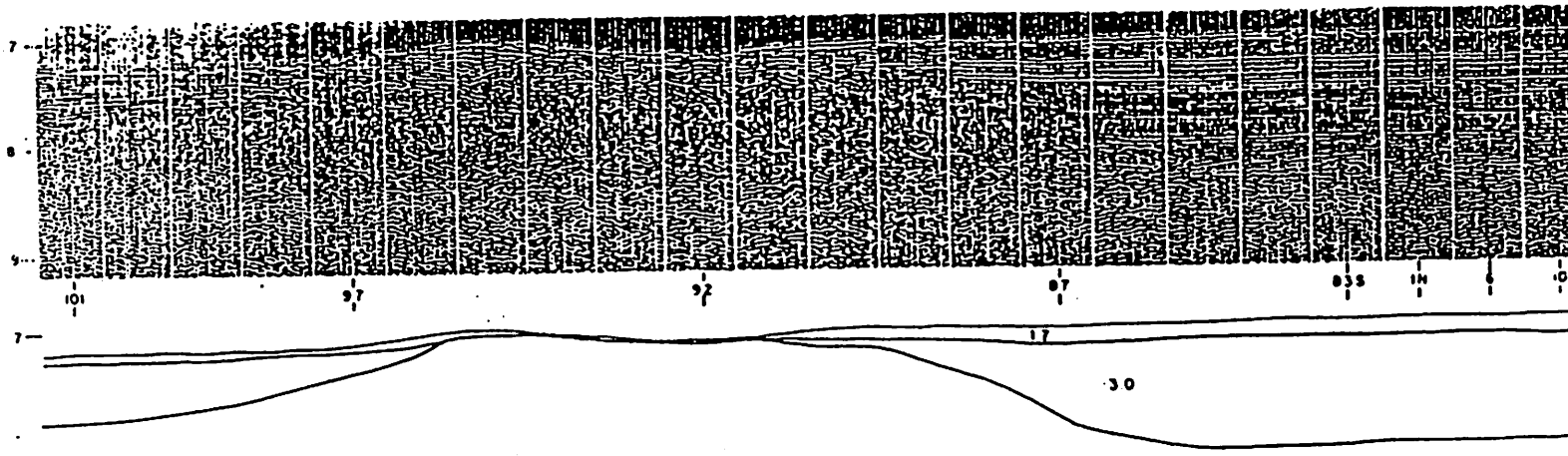


Figure 7 - Portion of Savit et. al. reflection line 'A' that shows the crustal high in the same trend as the Main Ridge projection of McCann and Sykes (1984).



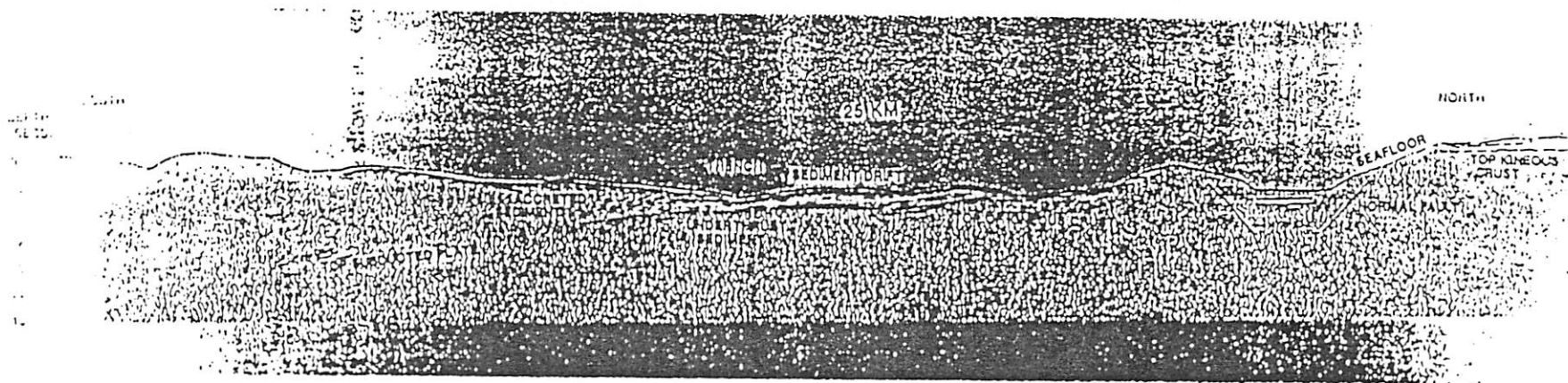


Figure 9- MCS line LS 126 57 (from Larue and Ryan, 1991).

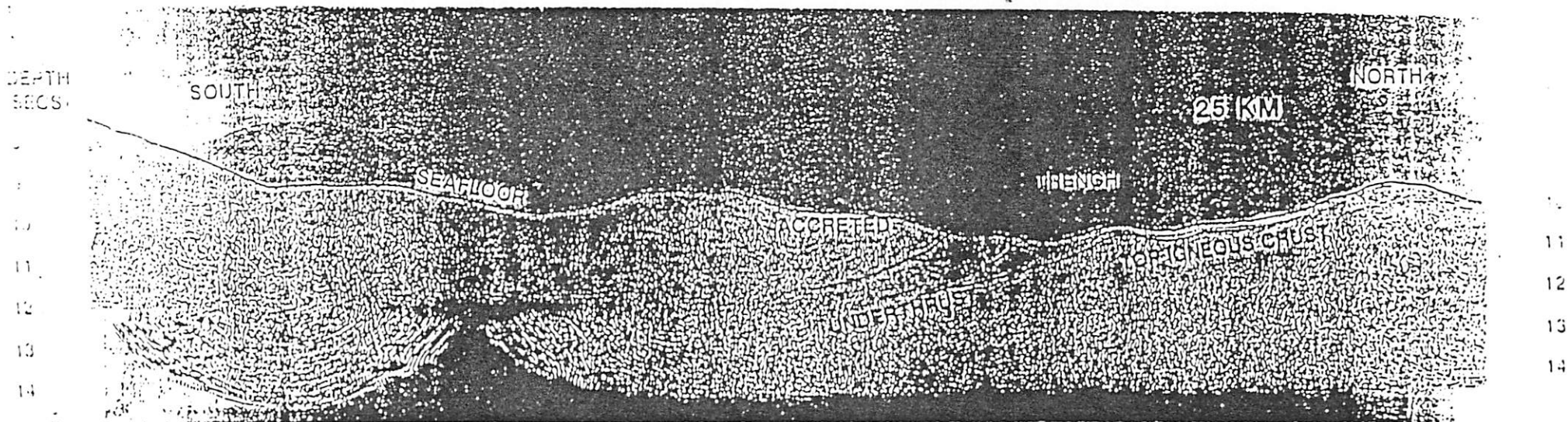


Figure 10 - MCS line NAT 42 (from Larue and Ryan, 1991).

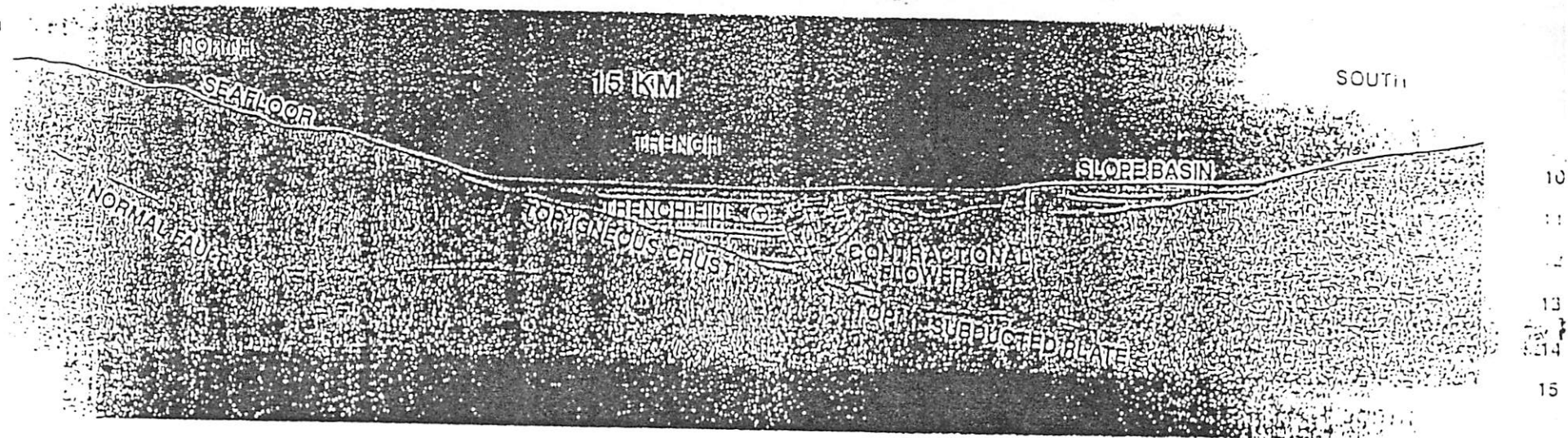


Figure 11- MCS line NAT 58 (from Larue and Ryan, 1991).

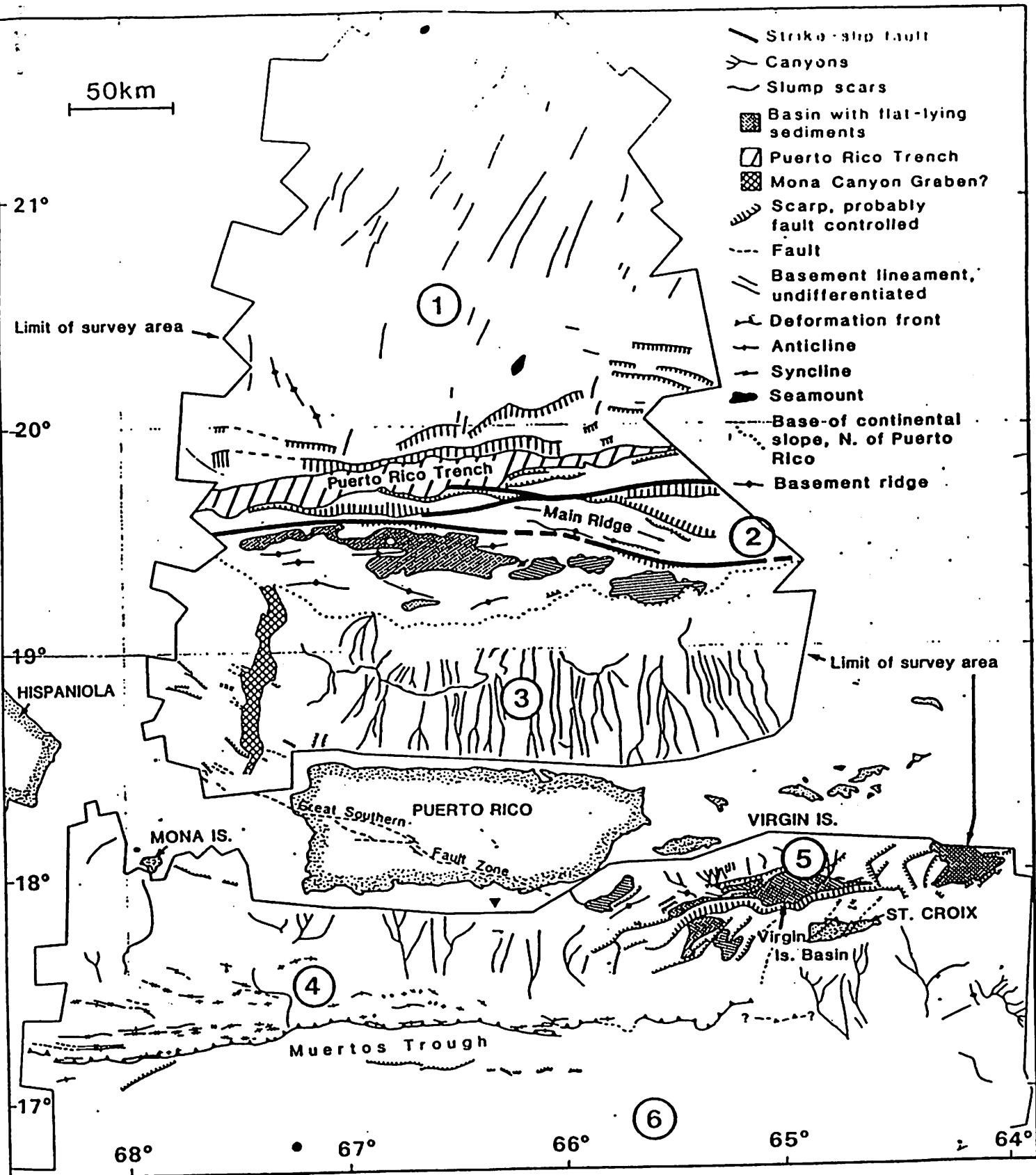


Figure 12 - Generalized interpretation of tectonic elements mapped in the GLORIA side scan survey (From Masson and Scanlon, 1991).