NicLakes Geophysical & Coring Survey of Lake Nicaragua and Lake Managua, Nicaragua

A collaborative study by:

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(UTIG)

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Instituto Nicaragüense de Estudios Territoriales

(INETER)

Managua, Nicaragua

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Cruise Summary

The geophysical component of the 2006 NicLakes project acquired over 1,820 km of geophysical data over Lake Managua and Lake Nicaragua, Nicaragua, from May 6 – May 31, 2006. Both lakes occupy the Nicaraguan depression, an elongate intra-arc and back-arc basin trending approximately N45°W and parallel to the Pacific coast. Farther off the Pacific coast of Nicaragua the Middle America trench, where the Cocos plate subducts beneath the Caribbean plate at a rate of ~8 cm/yr (Demets et al., 1994) (Fig. 1). The obliquity of convergence varies from 0° in Costa Rica up to 15° in northern Nicaragua (Barkhausen et al., 2001).

Oblique subduction may result in detachment of part of the overriding Caribbean plate, referred to as a forearc sliver (Demets, 2001). The zone of detachment is thought to be within the Nicaraguan depression. Demets (2001) proposes that the forearc sliver is transported to the northwest along a major right-lateral strike-slip fault parallel to the Central American volcanic front (CAVF). The best modern analog for these processes is most likely the Sumatra forearc sliver, where a major strike-slip fault accommodates trench-parallel motion along a thermally weakened volcanic arc (Genrich et al., 2000). To test this hypothesis in Nicaragua, we collected several northeast trending track lines in both lakes that would cross the trend of this major strike-slip fault (Fig. 2).

An alternative hypothesis by La Femina et al. (2002) proposes that trench-parallel motion may be accommodated by bookshelf faulting. In this model, trench-normal faults strike to the northeast and accommodate left-lateral strike-slip (Fig. 3). These faults separate blocks which rotate in a clockwise direction about a vertical axis. The northeast striking faults may have formed from Miocene and older phases of deformation, and it is now preferential to reactivate these older structures than to form new ones. Some of our

Figure 1. The rate of subduction of the Cocos plate varies from 85 mm/yr in the south to 73 mm/yr in the north; obliquity of subduction varies from 0° in the south up to 15° possibly resulting in northwestward forearc sliver translation. Both lakes are within the Nicaraguan depression which stretches from Costa Rica to Honduras and El Salvador. Lake Managua and Lake Nicaragua were chosen as study areas because they covered large areas of the tectonically active Nicaraguan depression.

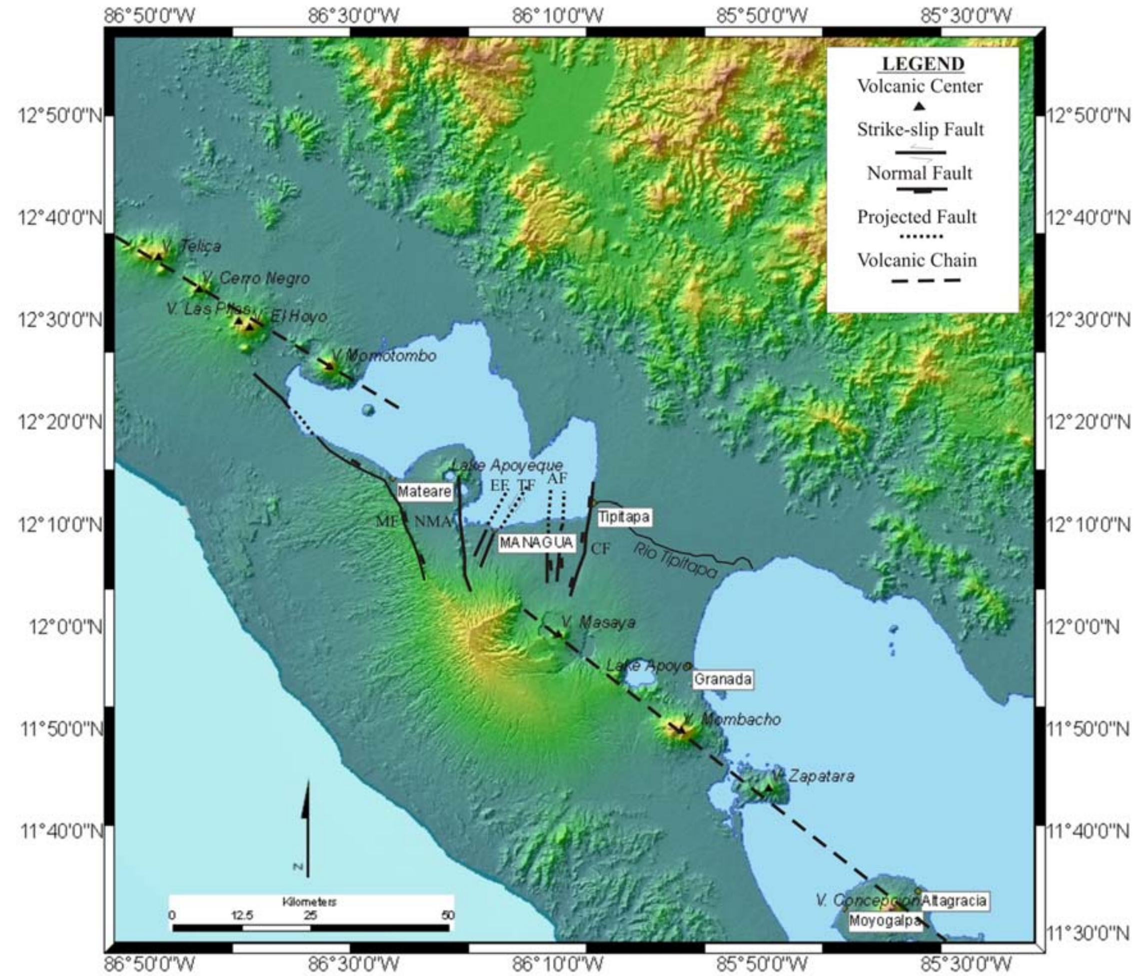


Figure 2. The model by Demets (2001) and Cowan et al. (2002) suggests dextral shear along a single fault zone parallel to the volcanic chain. Managua, capital city of Nicaragua, is located within a pull-apart basin where the strike-slip fault steps trenchward. The dotted line represents the alignment of volcanic segments located along the CAVF. Other structures along the Nicaraguan depression include: MF = Mateare fault; NMA = Nejapa-Miraflores-Apoyeque alignment; EF = Estadio fault; TF = Tiscapa fault; AF = Aeropuerto fault; CF = Cofradia fault.

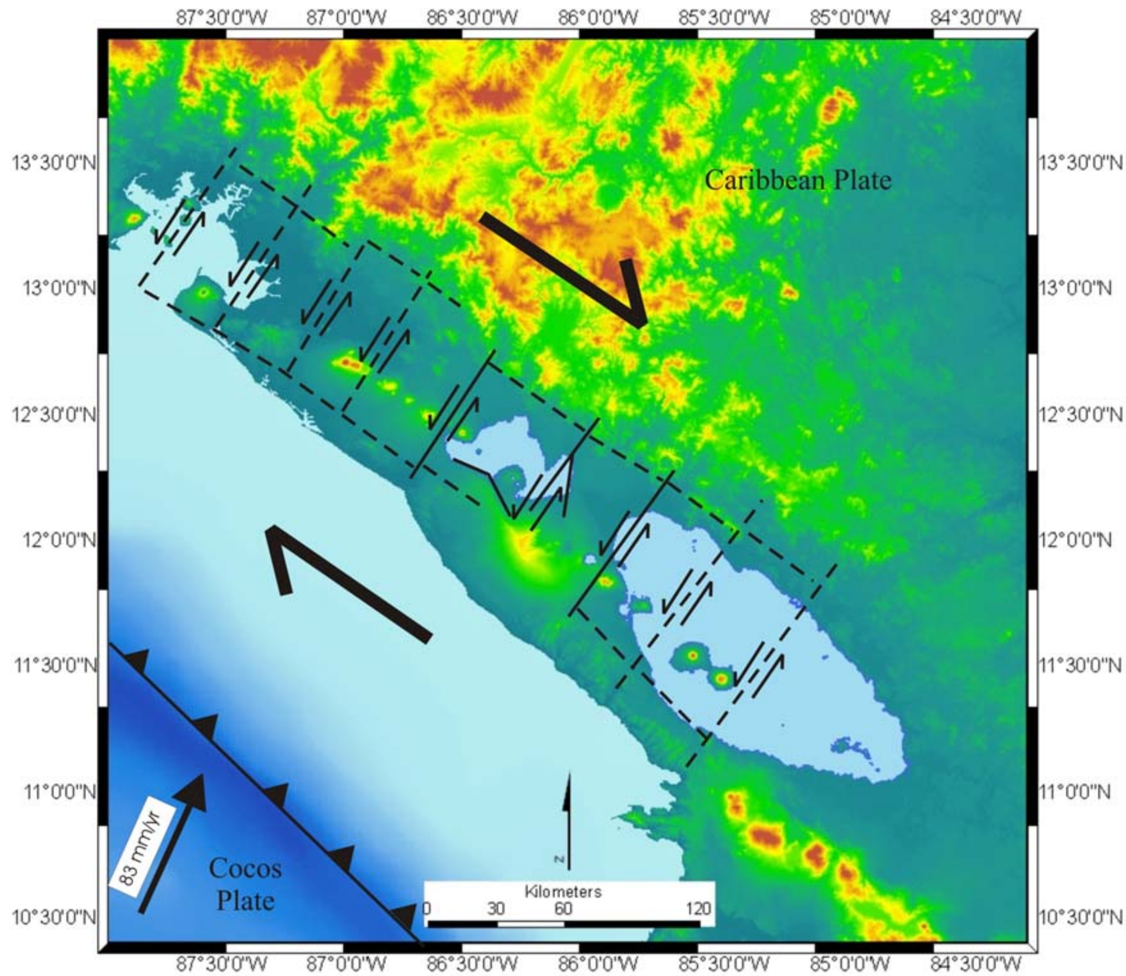


Figure 3. The bookshelf model proposes that in Nicaragua, the right-lateral shear zone concentrated along the volcanic front may be accommodated by left-lateral strike-slip faulting along trench-perpendicular faults. This process occurs by rotating blocks about a vertical axis along the shear zone. Minor extension may occur in an east-west orientation resulting in north-northwest trending normal faults within these blocks (La Femina et al., 2002).

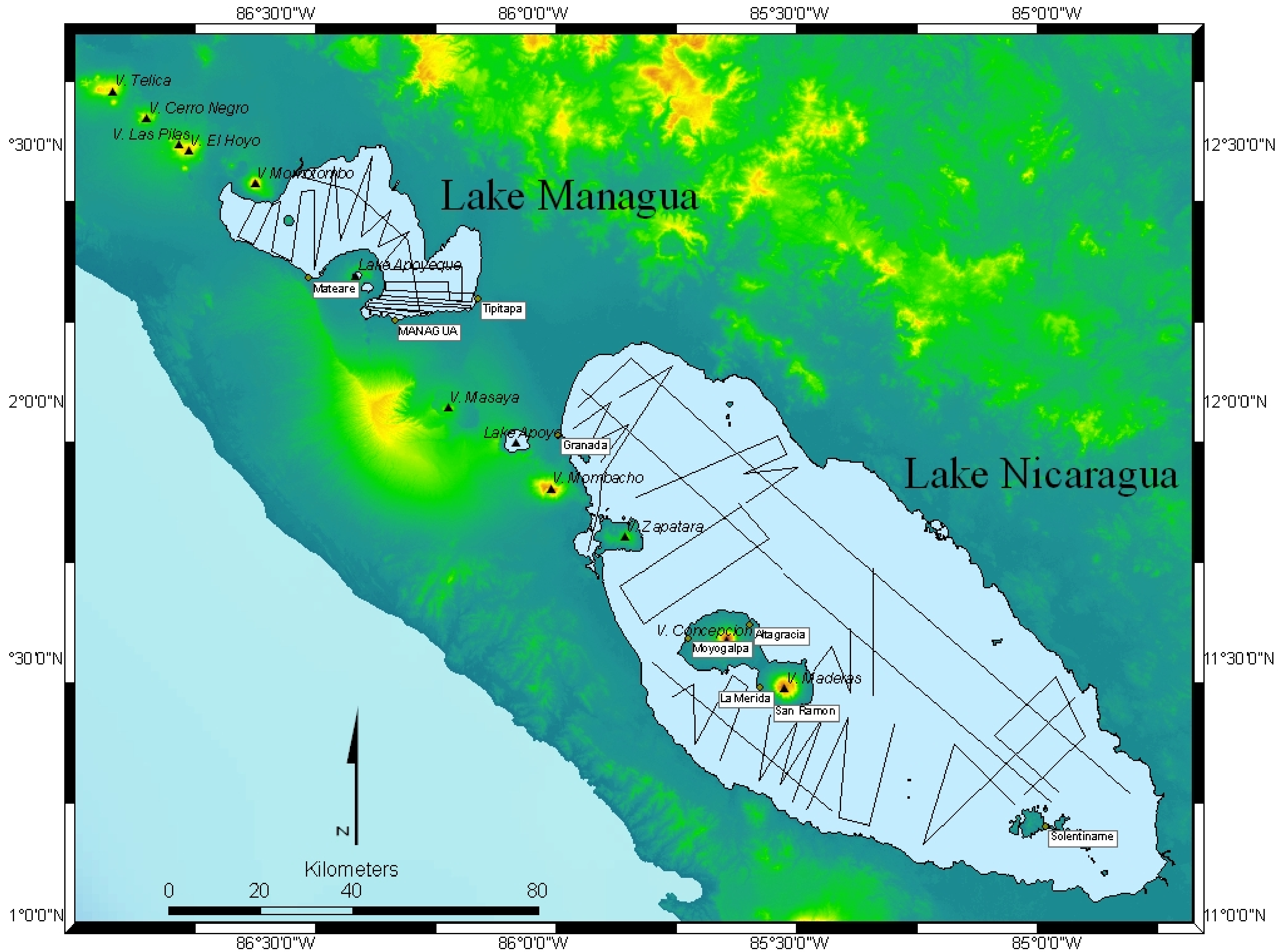
track lines were oriented in a northwesterly direction to determine if this style of deformation is active.

To test the above hypothesis', we proposed several track lines across Lakes Managua and Nicaragua (Fig. 4). However, due to the various complexities encountered while surveying the lakes, we had to alter our track positions daily and sometimes hourly. This resulted in survey profiles in less preferable locations and orientations. The acquired lines (1820 km) compares favorably in relation to the proposed lines (1000 km) due to the addition of Sidescan sonar and a 3.5 kHz subbottom profiler.

The purpose of the NicLakes project is to integrate multiple geophysical data sets to determine fault locations, orientation, and periodicity. This information will aid in developing a more constrained model for active deformation along the western Nicaraguan margin.

High resolution seismic data was used to image the upper 1 second of sedimentary fill within the depression (Fig. 5A). A 3.5 kHz subbottom profiler was used to image the upper few meters of sediment and acquire a high resolution image of the lake bottom (Fig. 5B). Sidescan sonar was used over Lake Managua to image a wide-angle view of the lake-floor features with the intention of correlating them with the seismic and 3.5 kHz data (Fig. 5C). One of the main outcomes from this study will be a more accurate bathymetric map for both lakes.

Figure 4. Map of western Nicaragua showing Lake Managua and Lake Nicaragua. The proposed track lines were based on the availability of ports across the lakes and predetermined areas of geologic interest. Ports used in the Lake Managua survey included the towns of Mateare and Tipitapa. Ports used for the Lake Nicaragua survey included Granada, Moyogalpa, La Merida, San Ramon, Altagracia, and Mancarun on Solentiname.



86°30'0"W
86°0'0"W
85°30'0"W
85°0'0"W
°30'0"N
2°0'0"N
°30'0"N
1°0'0"N
12°30'0"N
12°0'0"N
11°30'0"N
11°0'0"N
V. Telica
V. Cerro Negro
V. Las Pilas
V. El Hoyo
V. Momotombo
Lake Managua
Lake Apoyeque
Mateare
Tipitapa
MANAGUA
V. Masaya
Lake Apoyo
Granada
V. Mombacho
V. Zapatara
Lake Nicaragua
V. Concepcion
Altagracia
Moyogalpa
V. Maderas
La Merida
San Ramon
Solentiname
N
Kilometers
0
20
40
80

A.

B.

C.

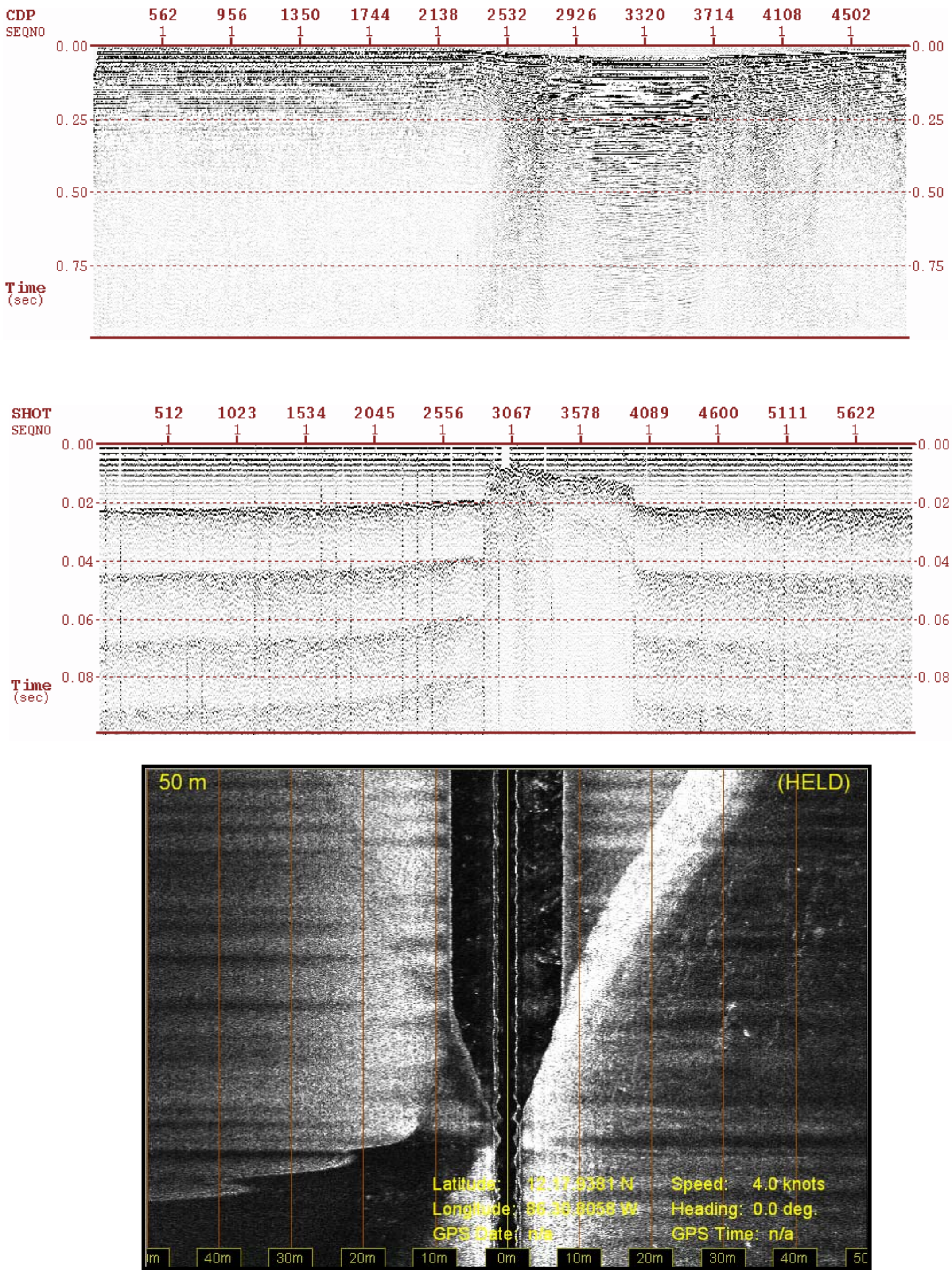


Figure 5. A) Example of multichannel seismic data acquired during the Lake Nicaragua survey. B) Example of 3.5 kHz subbottom profiler data also collected during the Lake Nicaragua survey. C) Example from a sidescan sonar image collected during the Lake Managua survey.

Cruise diary kept by Justin Funk

April 30 – May 3: The geophysical team arrived from the USA to Managua. Some of the required equipment was purchased in Managua and the rest was shipped down separately. During this time, the team consisted of Mann, McIntosh, Steffen, Funk, Pratt, and Manuel Trańa from INETER. Hotel: Don de Panteleon, Managua.

May 4: One laptop and the Dr. Geo software (required for 3.5 kHz acquisition) were stolen from the team before leaving Managua. All other equipment was transported to Granada, our first port for the Lake Nicaragua survey. Hotel: Casa San Francisco, Granada.

Figure 6. The *San Luis* (left) is tied to the *Mozorola* (right) at the dock in Granada ready for equipment transfer (Photo by Steffen Saustrup)

May 5: The *Mozorola* was to be the main vessel for data acquisition on Lake Nicaragua, but was not available upon our arrival in Granada (Fig. 6). The *Mozorola* is normally used as a ferry to transport fruits and passengers between Granada and Altagracia, on Concepcion. As a solution, the survey equipment was loaded onto the *San Luis*, a much smaller vessel (Fig. 6). This day was spent preparing the *San Luis* for acquisition. Manuel Trańa went home to Managua for the weekend and never returned to the project. Hotel: Casa San Francisco, Granada.

May 6: First day of acquisition. The *San Luis* sailed for a couple hours to test the seismic equipment. There was a problem with the air gun after a few shots which required disassembling the gun and refitting its seals (Fig. 7). The GPS, streamer, shot box, and geode all worked fine. Hotel: Casa San Francisco, Granada.

May 7: The *San Luis* was positioned next to the *Mozorola* at the dock in Granada (Fig. 6). All equipment was transferred to the *Mozorola* and reconfigured for acquisition on the following day. The generator and two air compressors were strapped down on the upper deck while all other equipment was stored on the main deck below. The seismic air gun and streamer were deployed from the rear, while the 3.5 kHz transducer was rigged to the port side by a long plank reaching a couple inches below the water level. Hotel: Casa San Francisco, Granada.

May 8: For the first day of acquisition on the *Mozorola*, the seismic with a 20 in^3 air gun and 3.5 kHz bottom profiler worked well. Data was collected off the shores of Granada and the Las Isletas, which were formed by a sector collapse of Vulcan Mombacho. Hotel: Casa San Francisco, Granada.

May 9: We continued data collection from Granada. Both seismic and 3.5 kHz worked well. We discovered Manuel Trańa would not be returning to INETER, and now Pedro Perez from INETER would be working with us. Hotel: Casa San Francisco, Granada.

May 10: Continued seismic collection off the coast of Granada, but we could not collect data with the 3.5 kHz. A fuse blew in the 3.5 kHz transceiver and we did not have any spare parts. It required a 2 - 3 amp slow burning fuse, which couldn't be purchased in Granada. Hotel: Casa San Francisco, Granada.

Figure 7. Tom Pratt and Steffen Saustrup re-assemble the air gun aboard the San Luis. (Photo by Justin Funk)

May 11: No data was collected today as we spent all day at the dock. The 3.5 kHz still did not work, the sidescan sonar would not transmit data to the laptop, and the air gun had a leak requiring re-assembly (Fig. 7). Hotel: Casa San Francisco, Granada.

May 12: We acquired seismic and 3.5 kHz data as we traveled from Granada to Moyogalpa, a small town on Ometepe Island. Due to the absence of sidescan sonar, it was difficult to capture any orientations of features found with the 3.5 kHz. This was the first day of seismic acquisition with a 5 in^3 air gun instead of the 20 in^3 gun. Hotel: Moyogalpa Hotel, Ometepe Island.

May 13: We acquired seismic and 3.5 kHz data off the northeast coast of Vulcan Concepcion. Hotel: Moyogalpa Hotel, Ometepe Island.

May 14: Started acquiring seismic and 3.5 kHz data from Moyogalpa, while making our way to San Ramon on the southern side of Vulcan Maderas. The area between Ometepe Island and the western coast of Lake Nicaragua was surveyed today. We docked that night at La Merida and took a truck 3 km south to San Ramon. Hotel: Biological Reserve, Ometepe Island.

May 15 – 18: Thomas Pratt left the survey to return to Seattle, WA. We collected seismic and 3.5 kHz data around Vulcan Maderas. One day was spent on the northeast side exploring a deep trough in that area. The shelter for our compressors and generator was occupied by a swarm of African Killer Bees (problem resolved with a smoke bomb improvised from a coke bottle and diesel fuel). Several days were spent near the western shores of Lake Nicaragua and the southwest sides of the island. Hotel: Biological Reserve, Ometepe Island.

May 19: Pedro Perez took the ferry from Ometepe Island in to purchase some compressor belts for the large air compressor. He was also sent to Managua to get the new sidescan sonar unit which was being held in the Managua customs department. We left San Ramon to collect seismic and 3.5 kHz data as we traveled past the Zanate Islands to the Solentiname islands at the southeast end of the lake. Hotel: Mancarun, Solentiname Islands.

May 20: The purpose of this day's survey was to make certain there was nothing of interest in this part of the lake. Only 1 short seismic line was collected, the rest was 3.5 kHz data. Hotel: Mancarun, Solentiname Islands

May 21: We left Solentiname collecting only 3.5 kHz data. As we reached the middle of the lake, we collected some seismic lines through the deep trough we discovered days before. The crew was in good spirits because our destination was their hometown of Altagracia on Ometepe Island. Hotel: Hotel Central, Altagracia.

May 22 -23: Seismic was scarcely used the rest of the trip since we acquired little to no penetration and had to travel considerably slower to collect it. We relied mainly on 3.5

kHz data to gather accurate bathymetry readings and image small offsets in the lake floor. Hotel: Hotel Central, Altagracia.

May 24: This was our last day of acquisition on Lake Nicaragua. The only data collected was 3.5 kHz. We left Altagracia and finished acquisition at the pier in Granada. All the oil and gas was drained from the generator and compressors. The rest of the equipment was packed away for transfer to Lake Managua. Hotel: Casa San Francisco, Granada

May 25: The coring team took over the *Mozorola* once the geophysical equipment was removed. The equipment was transferred from the *Mozorola* on Lake Nicaragua to the *Morrito No. 2* on Lake Managua (Fig. 8). The *Morrito No. 2* was neither big enough nor sturdy enough to put the large compressor aboard, so the airgun used only the smaller compressor. Upon inspection, the fiberglass hull exhibited numerous basketball sized dents. Skepticism was at an all-time high. The boat was put into Lake Managua near the mouth of the Tipitapa

Figure 8. The *Morrito No. 2* was unloaded from a semi-truck into the mud flats of the Tipitapa River mouth in Lake Managua. This boat could maneuver shallow waters and mud flats powered by a 40-horse-power outboard motor. The dock consisted of two long planks set up on blocks. (Photo by Steffen Saustrup)

River and loaded on the southern shores (Fig. 8). Hotel: Las Mercedes Best Western, Managua.

May 26: Paul Mann left the survey today to return to the USA. The sidescan sonar arrived in time for the Lake Managua survey. Part of the day was used to ready the *Morrito No. 2* for data acquisition (Fig. 9). The 3.5 kHz was mounted on the port side about 1 meter from the stern of the boat. The sidescan was mounted on the starboard side more towards the middle of the boat. A long plank was wedged against the ceiling and hung down to the water where the sidescan fish hung. Seismic could be deployed from the stern port side while the outboard motor was moved to the starboard side. Hotel: Las Mercedes Best Western, Managua.

May 27 – 28: Acquired mainly 3.5 kHz and sidescan sonar data to the north of the capital city Managua. Seismic data was collected until the small compressor eventually malfunctioned which ended the possibility of collecting more seismic. Hotel: Las Mercedes Best Western, Managua.

Figure 9. The shores along the town of Tipitapa were used to dock the *Morrito No. 2* for several days. This is some of our geophysical equipment waiting to be loaded (Photo by Kirk McIntosh).

May 29-30: Sidescan sonar and 3.5 kHz data was recorded through the middle of Lake Managua and to the north near Vulcan Momotombo and Isla Momotombito. Hotel: Don de Panteleon, Managua.

May 31: This was our last day of acquisition on Lake Managua. We collected a detailed image of a scarp paralleling the most northwestern shore and in trend with the onshore Mateare Fault. Our dock was now near the town of Mateare which we commuted to in the mornings and evenings. Hotel: Don de Panteleon, Managua.

June 1-3: All geophysical equipment was packed up at the INETER office in Managua and shipped back to the USA by TRANSCARGO. McIntosh, Saustrup, and Funk returned to Granada to help the coring team unpack their equipment aboard the Mozorola. Hotels: Don de Panteleon, Managua; Hotel Posada, Granada; Las Mercedes Best Western, Managua.

June 4: Remaining team departs from Nicaragua to the USA and the NicLakes geophysical data acquisition is officially over.

RESEARCH VESSELS

Research Vessel 1: San Luis

The *San Luis* normally serves as a house boat for some of the local sailors on Lake Nicaragua (Fig. 10A). The original plan was to transfer this vessel to Lake Managua via a semi-truck for the second portion of the survey. This boat was considerably smaller than the *Mozorola* and seemed too vulnerable for the harsh weather endured on Lake Nicaragua. Due to the shallow waters of Lake Managua, the owner of the *San Luis* did not think it would be sufficient for the work on Lake Managua either. It was thus only used for two days on Lake Nicaragua while the *Mozorola* was unavailable. For our purposes it was used to test the functionality of our geophysical equipment before the survey. The back deck was used to deploy the seismic airgun and streamer, hold the high-pressured air tanks, and secure 3.5 kHz subbottom profiler (Fig. 10B). The cabin's upper deck held the small air compressor and the generator. The cabin housed remaining geophysical equipment including laptops, geode, shot-box, and storage bins (Fig. 10C). The cabin itself was extremely confined and fumes from the engine made it a difficult environment to work in.

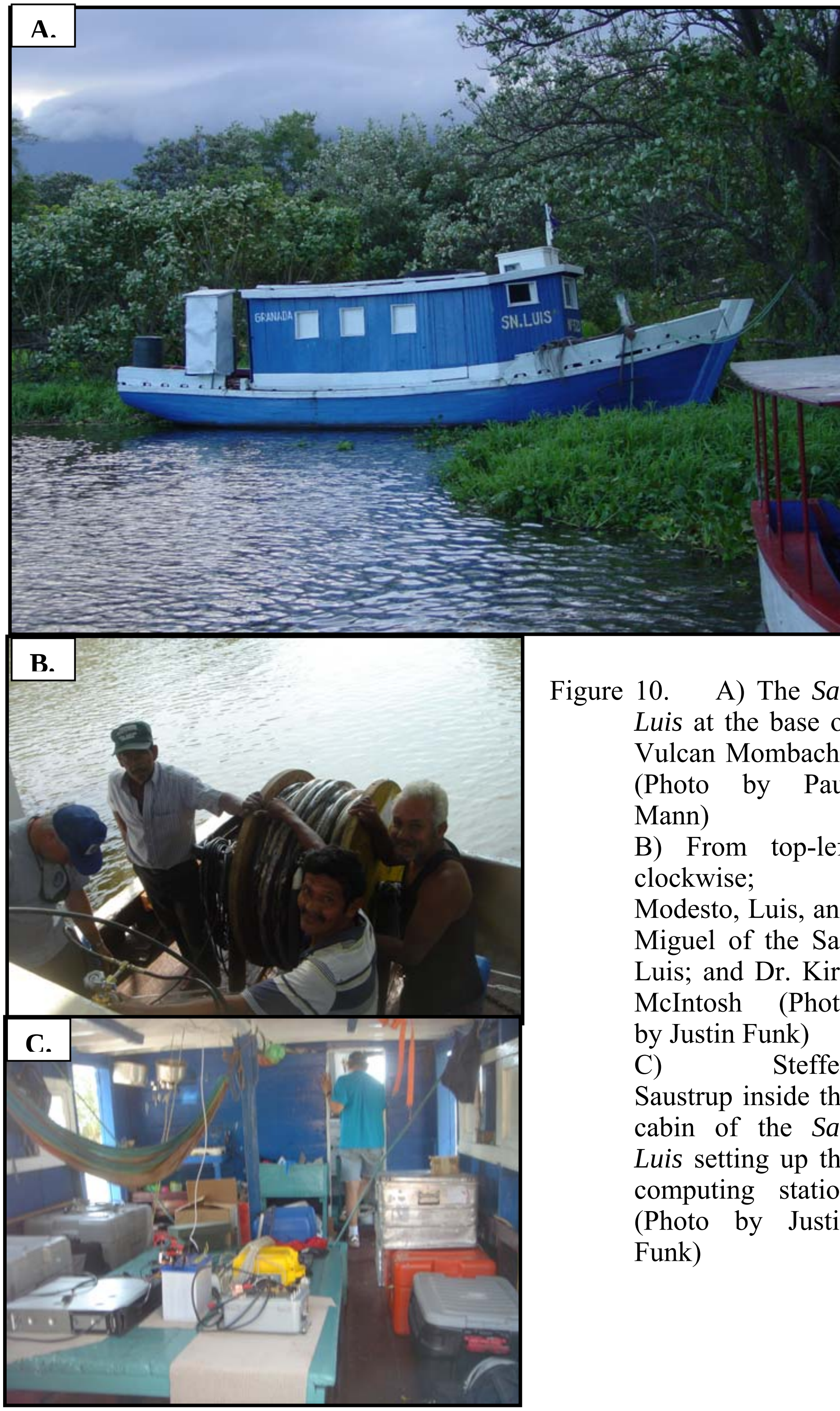


Figure 10. A) The *San Luis* at the base of Vulcan Mombacho (Photo by Paul Mann)
B) From top-left clockwise; Modesto, Luis, and Miguel of the San Luis; and Dr. Kirk McIntosh (Photo by Justin Funk)
C) Steffen Saustrup inside the cabin of the *San Luis* setting up the computing station (Photo by Justin Funk)

Platform 2: Mozorola

The *Mozorola* (Fig. 11) was our primary acquisition platform during the Lake Nicaragua survey from May 8 – May 24, 2006. It is normally used as a cargo ship transporting fruits, other various produce, and passengers between Granada on the mainland and Altagracia on Ometepe Island. The Mozorola is an 18.81 meter long ship with a 250 hp, six cylinder, diesel engine maintained by crewman Jose Anival Diaz-Lorio. The crew of the *Mozorola* consisted of six local Nicaraguan sailors, all from Altagracia. They provided excellent assistance when needed and the captain was extremely knowledgeable about Lake Nicaragua and its various bathymetric features. They were extremely resourceful with the materials aboard the ship. They made their quarters in the hull below deck where they cooked all their meals and slept each night when we made port. Their meals consisted of mainly rice, chicken, and fish they caught from the lake each morning. Each man was responsible for a unique job carried out every day. Tasks ranged from catching fish, cooking, swimming a tie rope to the dock, and swimming the anchor out from the ship.

The *Mozorola* had a top speed of ~15 km/hr and a cruising speed of ~6.5 km/hr during seismic acquisition. The heading was kept by a compass in the captain's bridge. A string ran from the captain's bridge back to the engine room and was used to signal the engineer forward, reverse, and velocity. The generator and compressors were stored on the upper deck and protected from the elements by a shelter constructed by the crew (Fig. 12 and 13). The remaining geophysical equipment was stored on the main deck.

Figure 11. The *Mozorola* leaving port in Granada, Nicaragua with its normal cargo of passengers and local merchandise headed for Altagracia on Ometepe Island.

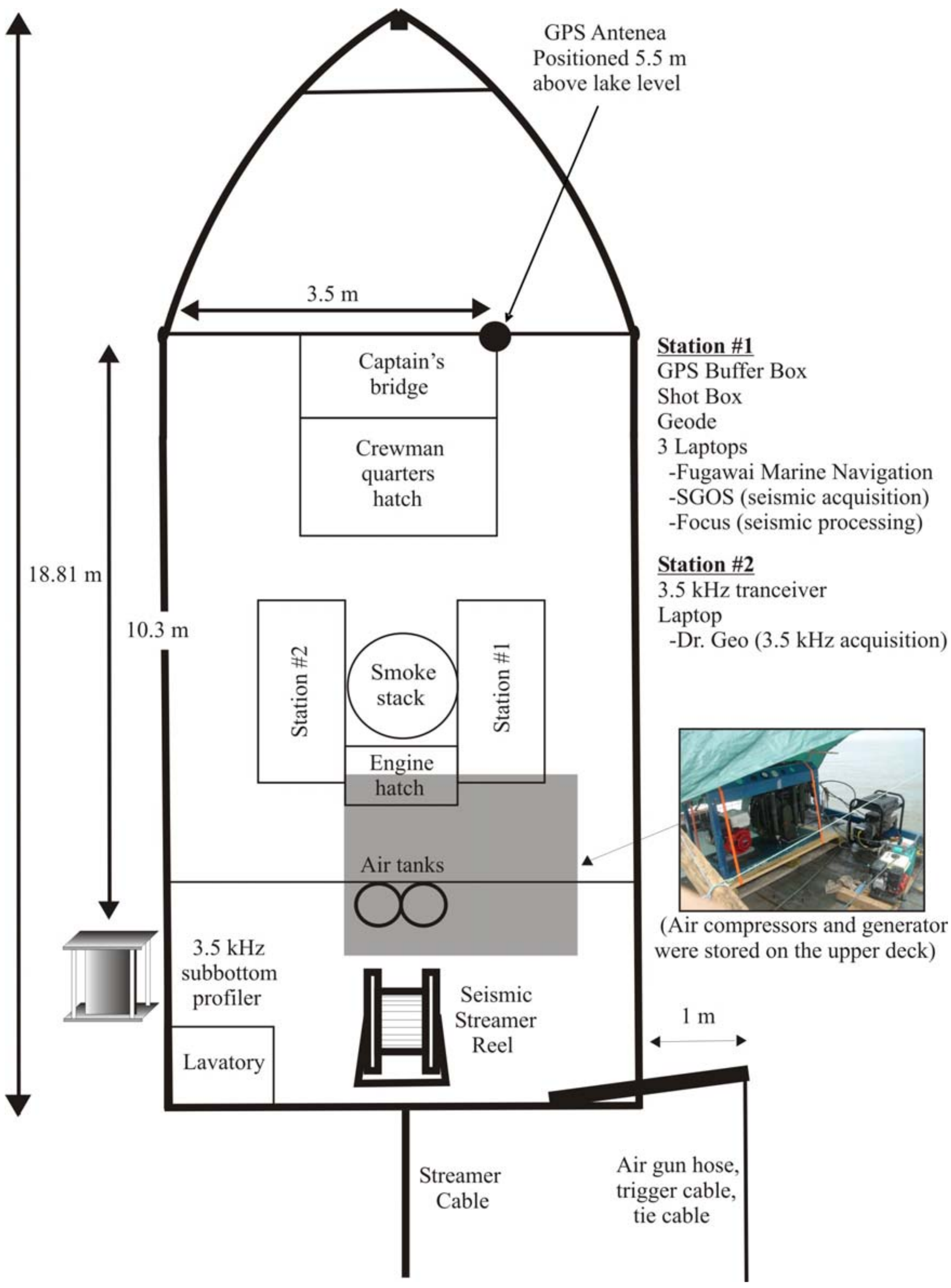


Figure 12. Configuration of the *Mozorola* during acquisition on Lake Nicaragua.

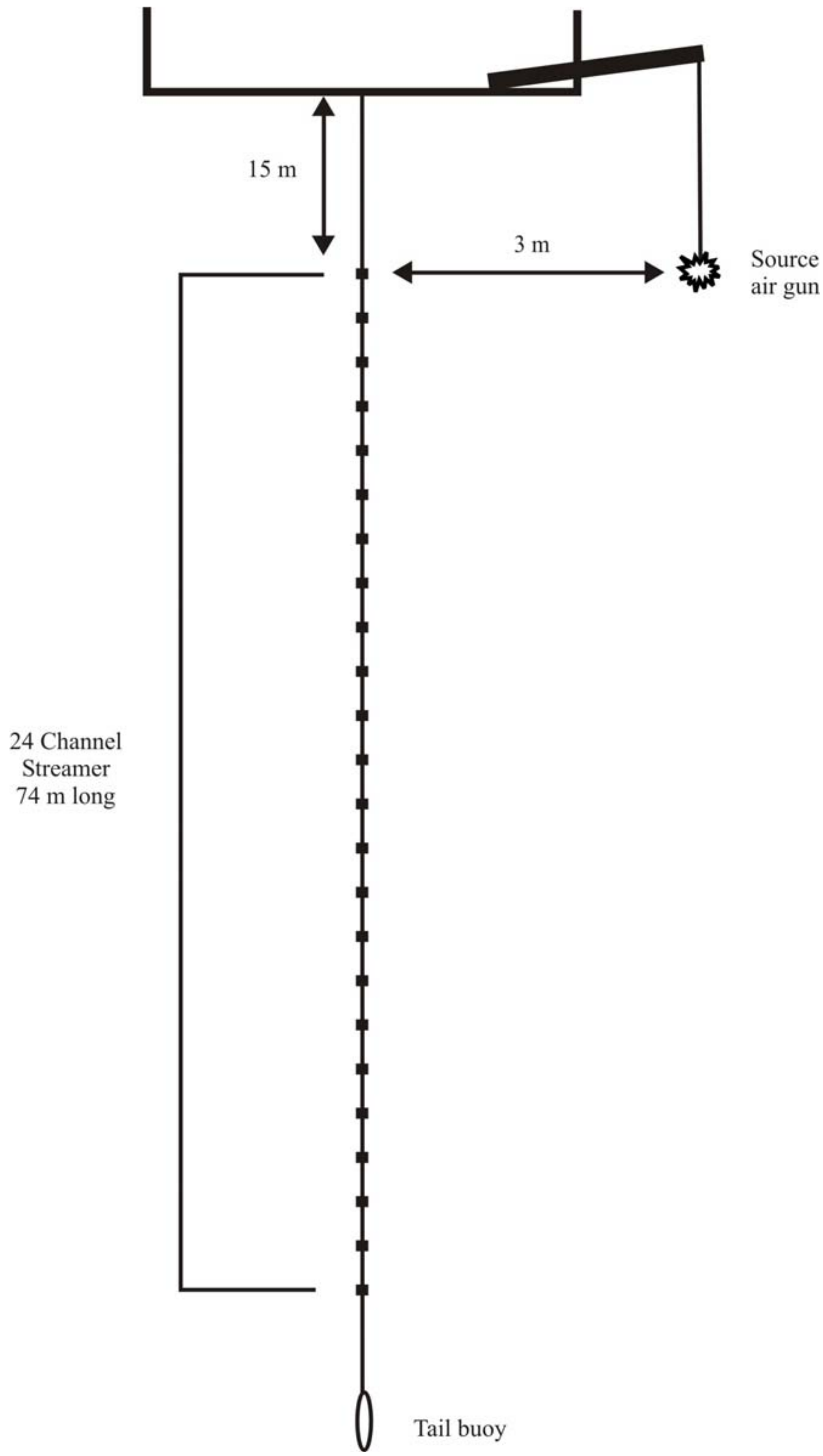


Figure 13. Seismic acquisition parameters for the *Mozorola* on Lake Nicaragua.

Platform 3: Morrito #2

Lake Managua is much smaller than Lake Nicaragua, much shallower, and much more polluted. For these reasons there are no boats that operate Lake Managua and thus no ports or boat ramps. We needed a ship that could be transported to the lake and also one that could navigate the shallow waters. The *Morrito No. 2* (Fig. 14 and Fig. 15) was chosen because of its shallow draft (<2 ft), a 40 horsepower outboard motor, and its ability to house all of our geophysical equipment. The only piece of equipment not brought on board was the larger air compressor because the upper deck was not strong enough to support it. The *Morrito No. 2* is 14 m long, 4 m wide fiberglass barge used for transporting sand and other products with loads up to 2,000 lbs. It was crewed by the same Nicaraguan men aboard the *San Luis*.

Figure 14. The *Morrito No. 2* was used for acquisition on Lake Managua. Here it is pictured along the shores of Lake Managua (Photo by Steffen Saustrup)

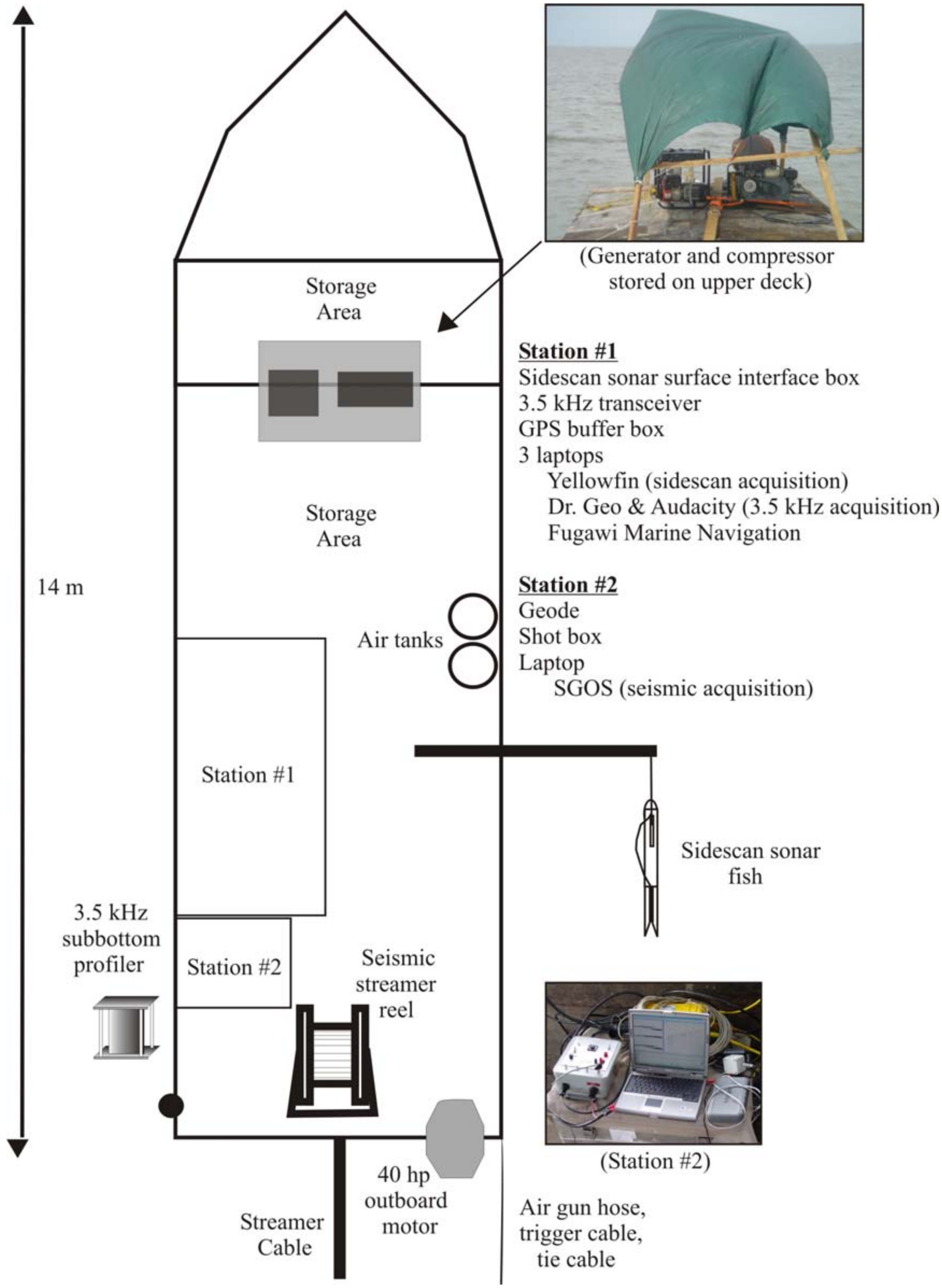


Figure 15. Equipment setup for the *Morrito No. 2* on Lake Managua.

Track Lines & Navigation

Survey track locations were determined using a Garmin GPS unit which was mounted at the top of the bridge 5.5 m above water level (Fig. 16). This fed into a GPS buffer box which was powered by a 12 V car battery. From the buffer box the signal was sent to a laptop and recorded once every second by the Fugawi Marine Navigation software. This created navigation text files every day which could be appended to headers in the seismic and 3.5 kHz profiler lines. Since the *Mozorola* was not previously equipped with any modern navigation system, the captain relied on a compass heading to steer for each track line. This lack of an accurate navigation system led to some deviations from our track lines.

Due to the GPS antennae height above lake level, strong wind and wave action caused high frequency oscillations in our position. When plotted, this gives our track lines a jagged appearance. The following text explains how the navigation data was processed to remove these high frequency oscillations. Once processed, this data was then appended to the headers of our seismic and 3.5 kHz profiler lines. The sidescan sonar included a separate navigation system which was attached directly to the upper deck of the *Morrito No. 2* for the Lake Managua survey.

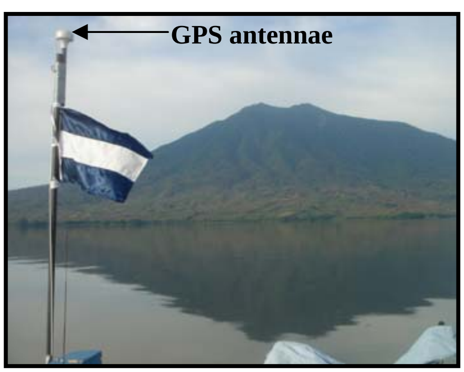
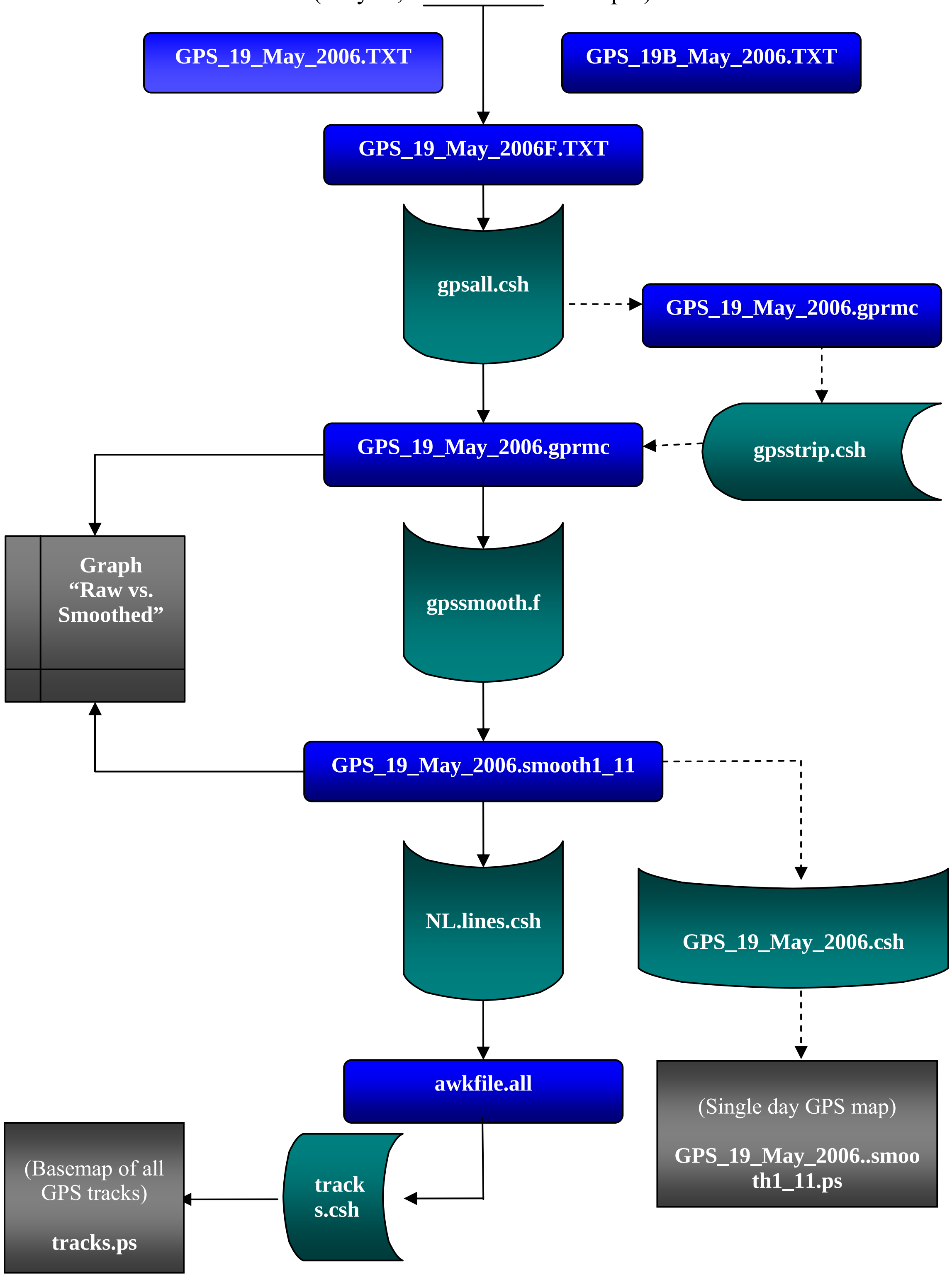


Figure 16. The GPS receiver was positioned 5.5 m above the lake level. It was taped to the top of the flag mast to provide an undisturbed signal at all times. The antenna was connected to laptops on the lower deck. In the background is Maderas volcano. (Photo by Justin Funk)

Navigation Processing Flow Chart for NicLakes Survey
(May19, 2006 used as example)



The flow chart above describes the processes required to smooth our navigation files to reduce noise. The GPS tracks for each day were stored as *.TXT files. If a particular day had several files, the first step was to combine these into a single text file. For example, GPS_19_May_2006.TXT and GPS_19B_May_2006.TXT both represent May 19th and are thus combined into a single file. The data for May 19, 2006 is used as an example in the following processing steps.

GPS_19_May_2006F.TXT

```
$PGRME,6.1,M,16.4,M,17.5,M*29
$GPVTG,301,T,301,M,002.9,N,0005.4,K*74
$PGRMB,0.0,200,,,,K,,W,W*31
$PGRMM,WGS 84*06
$GPRMC,112728,A,1124.9131,N,08532.5136,W,002.8,295.8,190506,000.3,E*6E
$GPGGA,112728,1124.9131,N,08532.5136,W,2,06,1.1,44.8,M,-0.2,M,,*7C
$GPGSA,A,3,02,04,05,09,10,17,,,,,,,2.7,1.1,2.5*3D
$GPGSV,3,3,11,28,18,148,48,29,06,194,45,48,34,260,49*49
$PGRME,6.1,M,16.4,M,17.5,M*29
$GPVTG,296,T,296,M,002.8,N,0005.2,K*73
```

These files were run though a program (gpsall.csh) that extracted the GPRMC strings from the raw GPS logs. If there was a problem with the file, individual logs could be run through the program (gpsstrip.csh) and produce the same output file.

GPS_19_May_2006F.gprmc

$GPRMC,112728,A,1124.9131,N,08532.5136,W,002.8,295.8,190506,000.3,E*6E

$GPRMC,112729,A,1124.9133,N,08532.5144,W,002.8,289.9,190506,000.3,E*64

$GPRMC,112730,A,1124.9135,N,08532.5153,W,003.0,286.6,190506,000.3,E*65

$GPRMC,112731,A,1124.9136,N,08532.5161,W,003.0,281.5,190506,000.3,E*62

$GPRMC,112732,A,1124.9136,N,08532.5171,W,003.2,274.9,190506,000.3,E*64

$GPRMC,112733,A,1124.9136,N,08532.5181,W,003.3,271.5,190506,000.3,E*62

$GPRMC,112734,A,1124.9136,N,08532.5191,W,003.4,270.7,190506,000.3,E*60

$GPRMC,112735,A,1124.9134,N,08532.5201,W,003.5,263.2,190506,000.3,E*6F

$GPRMC,112736,A,1124.9131,N,08532.5211,W,003.6,259.0,190506,000.3,E*60

$GPRMC,112737,A,1124.9130,N,08532.5222,W,003.7,262.0,190506,000.3,E*69

To reduce high frequency oscillations, each *.gprmc file was run through a smoothing program written in FORTRAN (gpssmooth.f). Several degrees of smoothing were tested until the maximum amount of smoothing occurred with the fewest number of smoothing points. The output frequency was 1 second and the best number of smoothing points was determined to be 11. The output smoothing file was plotted against a raw file to assure the smoothing was successful (Fig. 17).

GPS_19_May_2006.smooth1_11

```
Dy Mn Yr    GMT   Local      Lat              Lon          Spd  Crse
19  5 2006 112733  62733 11 24.9133 N  85 32.5182 W   3.3 273.1
19  5 2006 112734  62734 11 24.9132 N  85 32.5192 W   3.4 269.0
19  5 2006 112735  62735 11 24.9131 N  85 32.5201 W   3.5 265.6
19  5 2006 112736  62736 11 24.9128 N  85 32.5211 W   3.6 261.0
```

19 5 2006 112737 62737 11 24.9126 N 85 32.5221 W   3.7 257.5

19 5 2006 112738 62738 11 24.9122 N 85 32.5231 W   3.8 254.4

19 5 2006 112739 62739 11 24.9118 N 85 32.5241 W   3.8 250.1

19 5 2006 112740 62740 11 24.9113 N 85 32.5251 W   3.9 247.1

19 5 2006 112741 62741 11 24.9108 N 85 32.5261 W   4.0 243.6

Once the smoothed files were created, the GPS tracks for individual days could be displayed (Fig. 18). Each day was then through the program NL.lines.csh which created a master file (awkfile.all). This basically appended the track files for every day into a single master file that contained only latitude and longitudinal data.

awkfile.all

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930645 0

-85.939963 11.930647 0

-85.939962 11.930647 0

This file was then run through the program tracks.csh which created a post-script that would display every track line (Fig. 19 and 20).

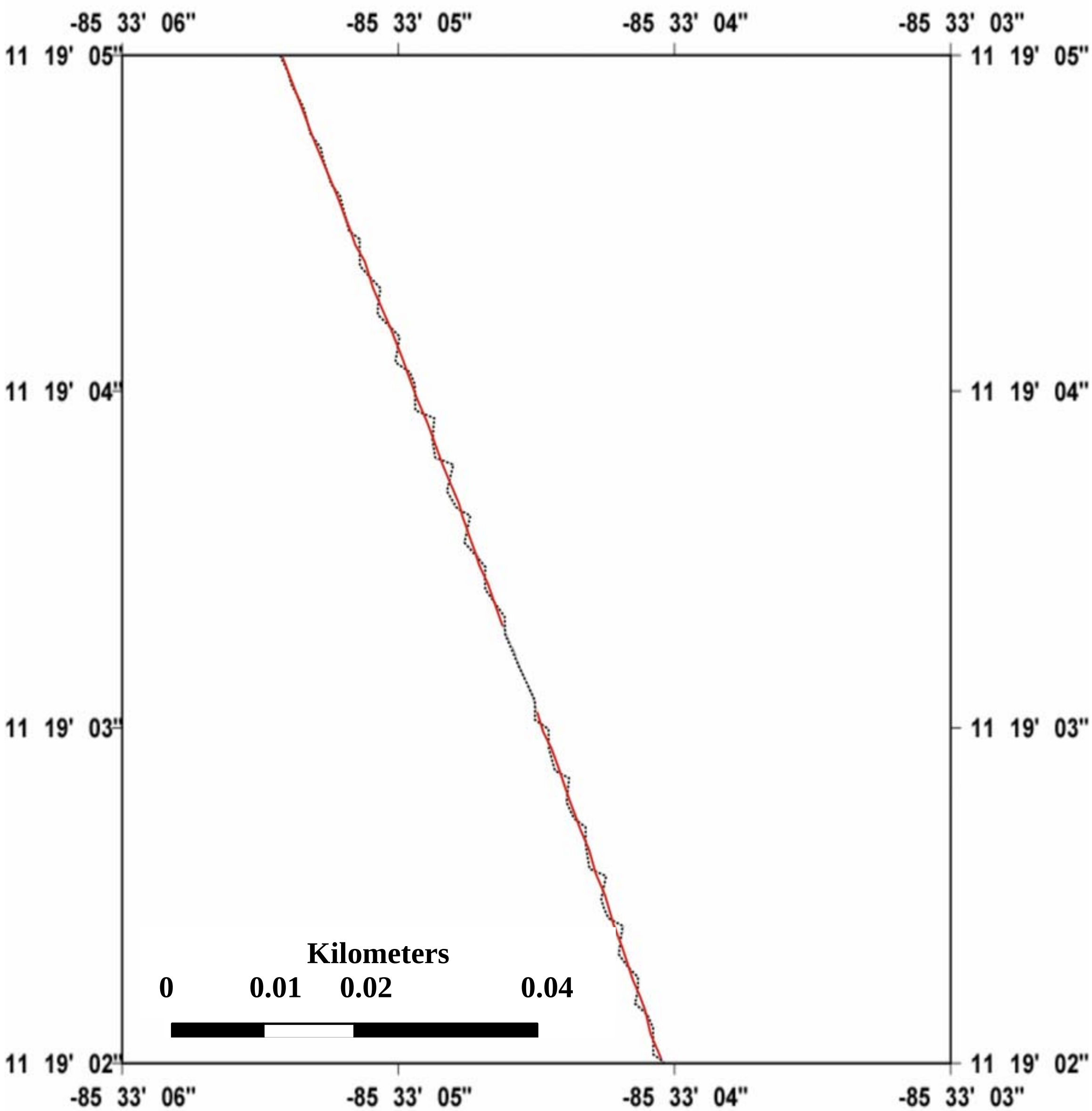


Figure 17. The raw GPS location (dotted black line) is plotted with the smoothed data (solid red line). The output frequency was kept at 1 second and the most efficient degree of smoothing occurred at 11 points.

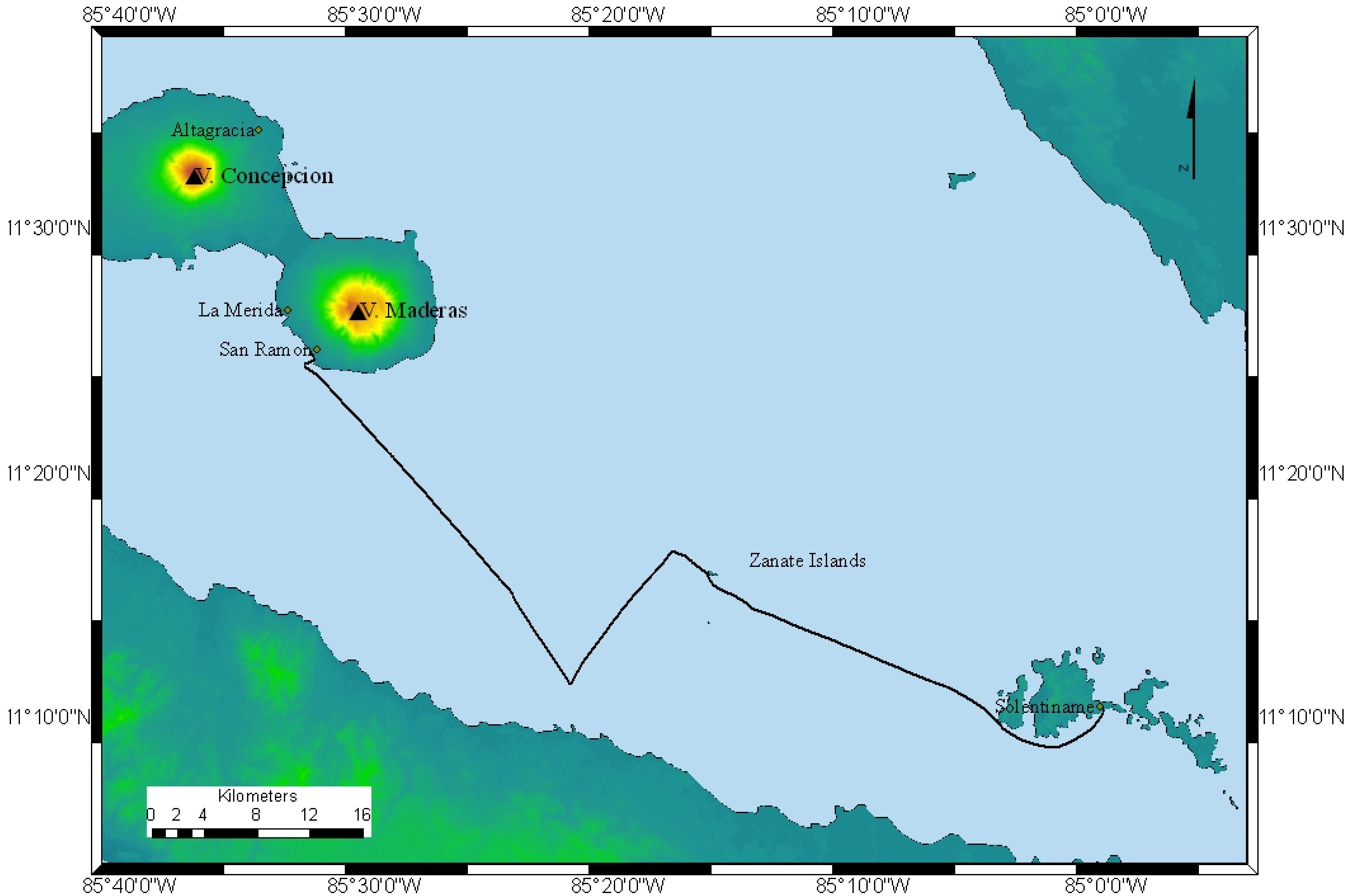


Figure 18. A plot of the smoothed track file for survey line May 19, 2006. with a total track distance of 26.5 km.

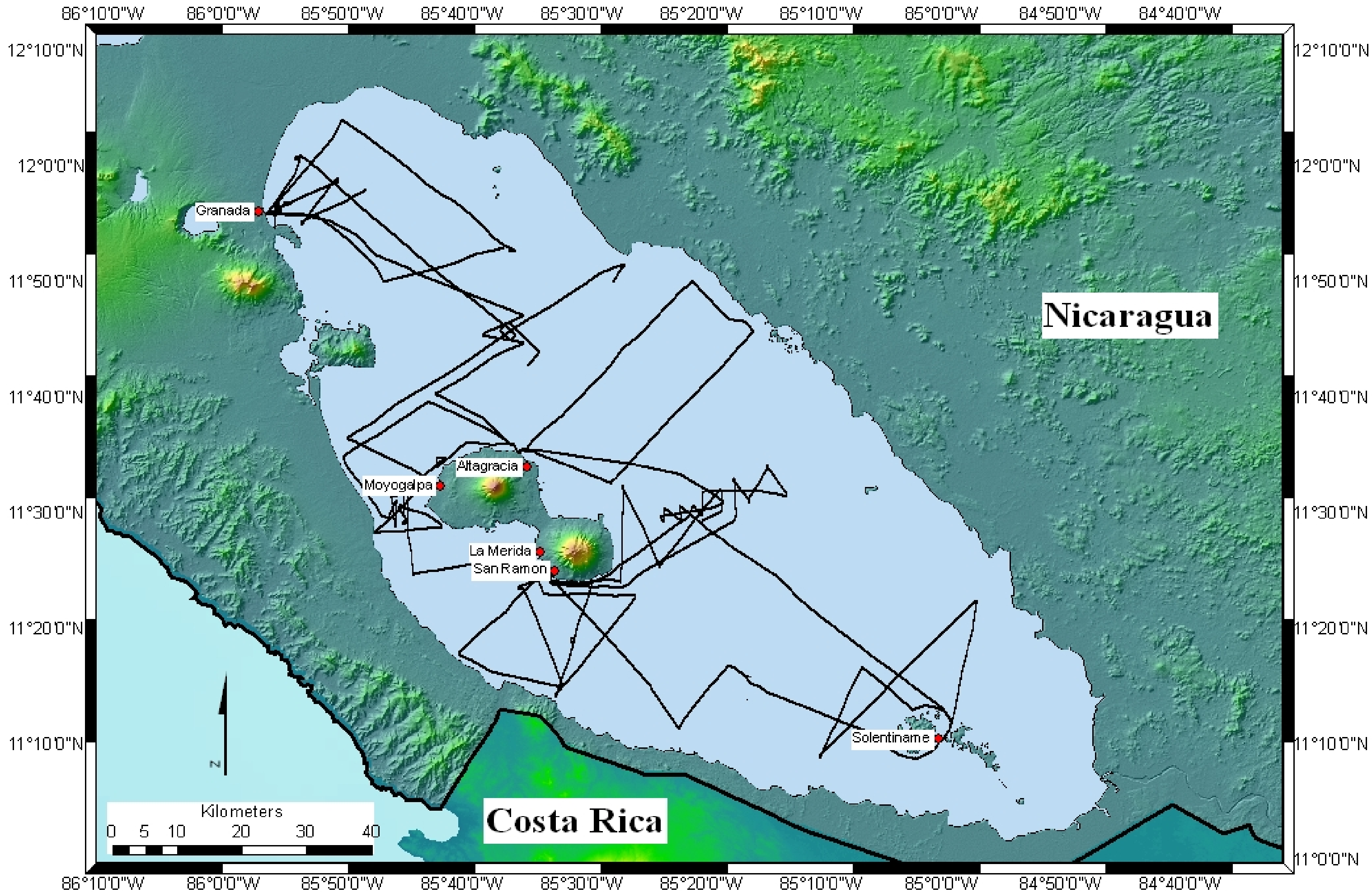


Figure 19. The survey in Lake Nicaragua took place over a 19 day period. Acquisition only occurred during the day, usually lasting from about 6:00 a.m. to 7:00 p.m. The survey tracks had to be adjusted daily and sometimes hourly to account for weather conditions and the availability of local ports. As the survey progressed across the lake, we docked at Granada, Moyogalpa, Altagracia, La Merida, San Ramon, and Solintename.

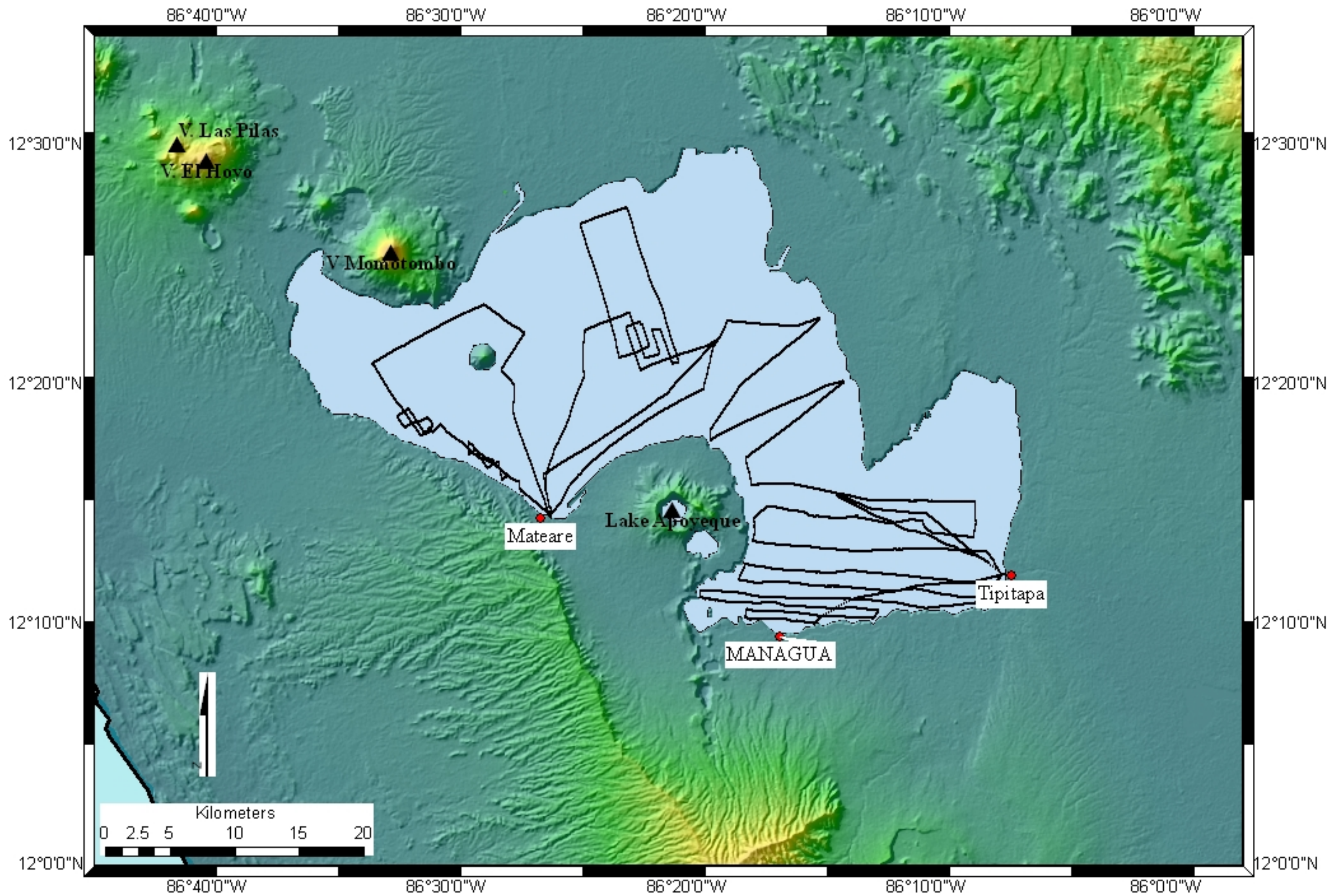


Figure 20. The survey in Lake Managua took 6 days to complete. Since this lake is considerably smaller, only 2 ports were needed. The first 3 days were based out of Tipitapa. This is near the Tipitapa River that connects Lake Managua to Lake Nicaragua. To cover the northwestern margins of the lake we docked at Mateare and commuted to and from a hotel in Managua. There were no docks or boat ramps in the capital city of Managua.

Seismic Acquisition

Seismic data was collected on all three ships used in the NicLakes survey. Only one line was collected aboard the *San Luis*, mainly to test functionality of the seismic equipment. The source for seismic acquisition was a Bolt 600 B airgun fired with a Bolt FC120 airgun firing box. The receiver was a 24-channel streamer with 3 hydrophones per channel, 1 meter hydrophone spacing and 3 meter channel spacing (Fig. 21). The total length was 74.1 meters and was towed less than a meter below the water surface (Fig. 22). Additional equipment included two air compressors, two holding tanks of compressed air with 3500 psi capacity, the air gun which could be fitted with a 20 in^3 or 5 in^3 chamber, geode, and a laptop running SGOS by Geometrics for data collection.
The *Mozorola (*Fig. 21a) was used for the survey of Lake Nicaragua which consisted of 49 lines. The *Morrito No. 2* (Fig. 21b) was used for the Lake Managua survey which only consisted of 4 lines. Initially the goal was to fire at ~1800 psi with a 4 second interval using the 20 in^3 air gun. Due to mechanical problems, the compressors could not keep up with that rate, thus firing pressure would sometimes drop down to 800 psi. Even after switching to the 5 in^3 air gun, the compressors could not keep pace with the firing rate. This resulted in the entire survey being shot at less than ideal pressure and shot interval.

The goal was to collect ~1000 km of high resolution seismic. Due to complications we only collected about 547 km. Table 1 is the data log for seismic acquisition and Fig. 23 shows a typical seismic line.

Seismic Acquisition Parameters

Number of Channels	24
Channel Length	3 meters
Shot Spacing	3 meters
Source to Near Channel	1 meter
Source Volume	5 in^3, 20 in^3
Source Pressure	800-1800 psi
Source Type	Air gun
Source Number	1
Source Depth	1 meter
Cable Depth	< 1 meter
Recording System	SGOS by Geometrics
Processing System	Focus
Navigation Type	Fugawi Marine Navigation

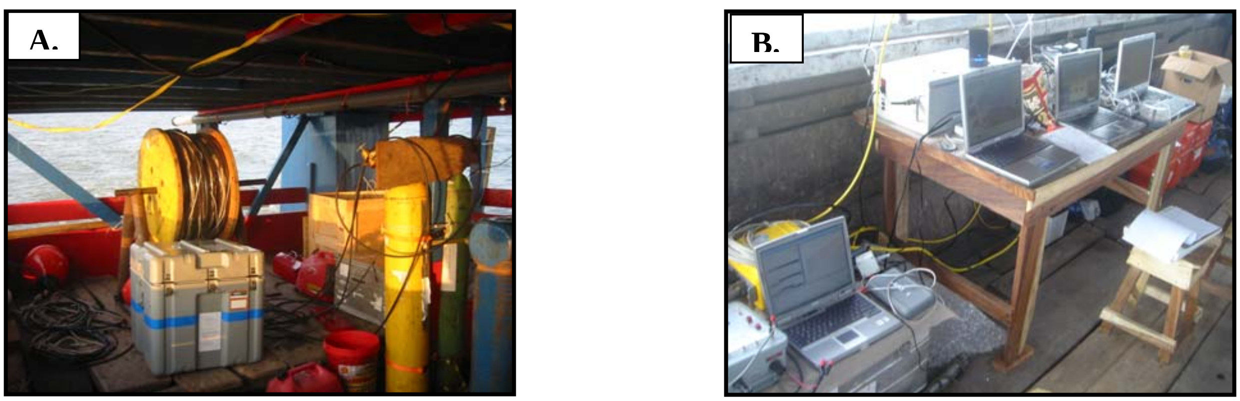


Figure 21. A) The streamer was set up in the middle near the stern of the *Mozorola*. Two high pressure holding tanks fed the air gun and were fastened to a center column of the ship. The air gun was positioned on the starboard side of the *Mozorola*, secured to a retractable plank. B) Aboard the *Morrito No. 2*, everything was wired to a central computing system positioned on the port side of the vessel.

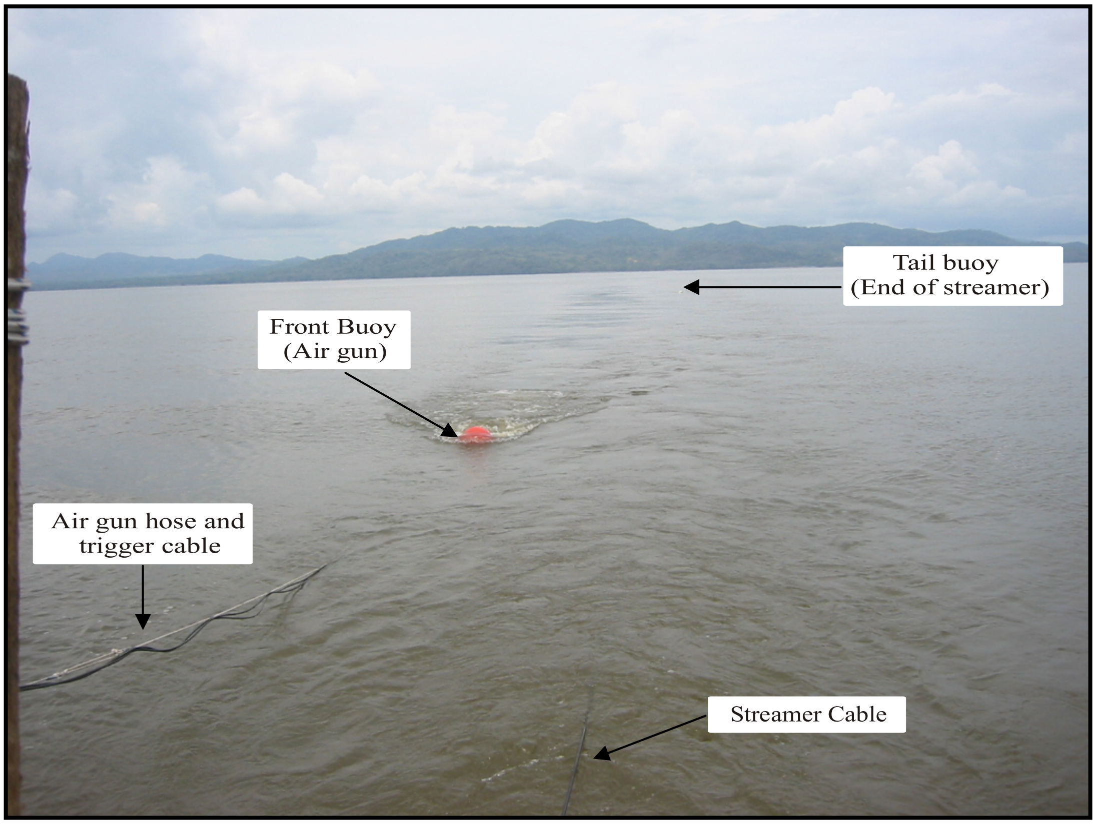


Figure 22. A view of the acquisition equipment towed behind the *Mozorola* on Lake Nicaragua. The source was a 5 in^3 air gun attached to the ships starboard side by a secure rope, attached to the high pressure air tanks by the black air hoses, and attached to the firing box by the other black line. The air gun was towed at ~1 m water depth which was held constant by the orange front buoy. The 24-channel streamer was towed directly behind the *Mozorola*; the end of the 74.1 m streamer is noted here by the white tail buoy.

Table 1. Seismic Data Log for NicLakes Survey

Date	Boat	Line #	Time/start		Time/end		Start Lat	Start Lon	End Lat	End Lon	Start Shot	End Shot	Distance
5/8/2006	Mozorola	NLS_01	9:55	AM	11:44	AM	11.9255	85.923	11.97317	85.83667	89	1408	**10.8**
5/8/2006	Mozorola	NLS_02	12:54	PM	2:35	PM	11.98167	85.84017	11.9165	85.88917	1410	2645	**9.0**
5/8/2006	Mozorola	NLS_03	2:41	PM	4:30	PM	11.9185	85.88933	11.9615	85.80717	2646	3930	**10.1**
5/9/2006	Mozorola	NLS_04	1:17	PM	2:28	PM	11.83367	85.77283	11.84983	85.71133	4074	4891	**6.9**
5/10/2006	Mozorola	NLS_05	9:51	AM	3:33	PM	12.06533	85.83167	11.88083	85.59833	5032	9158	**32.6**
5/12/2006	Mozorola	NLS_06	7:48	AM	5:08	PM	12.01433	85.89017	11.7385	85.566	105	9438	**46.7**
5/13/2006	Mozorola	NLS_07	7:38	AM	3:18	PM	11.60833	85.82517	11.85783	85.44117	4	7629	**50.1**
5/14/2006	Mozorola	NLS_08	6:58	AM	8:51	PM	11.5415	85.72267	11.47233	85.7875	45	1915	**10.4**
5/14/2006	Mozorola	NLS_09	8:55	AM	10:35	AM	11.47217	85.78567	11.4805	85.69417	1980	3674	**10.0**
5/14/2006	Mozorola	NLS_10	10:40	AM	11:52	AM	11.483	85.6965	11.5105	85.75283	3739	4945	**6.9**
5/14/2006	Mozorola	NLS_11	11:48	AM	2:04	PM	11.50917	85.754	11.4115	85.82383	5004	7145	**13.2**
5/14/2006	Mozorola	NLS_12	11:48	AM	2:04	PM	11.50917	85.754	11.4115	85.82383	7145	10063	**13.2**
5/15/2006	Mozorola	NLS_13	8:14	AM	10:38	AM	11.403	85.445	11.53483	85.4425	40	2437	**14.6**
5/15/2006	Mozorola	NLS_14	10:38	AM	1:02	PM	11.53483	85.4425	11.42267	85.39133	2437	5775	**13.6**
5/15/2006	Mozorola	NLS_15	1:07	PM	3:26	PM	11.4285	85.3875	11.5335	85.30667	5863	8192	**14.6**
5/15/2006	Mozorola	NLS_16	3:30	PM	3:58	PM	11.53183	85.3055	11.50717	85.30467	8241	8698	**2.7**
5/16/2006	Mozorola	NLS_17	7:26	AM	9:10	AM	11.39633	85.4865	11.31117	85.51117	10	1734	**9.8**
5/16/2006	Mozorola	NLS_17A	9:47	AM	11:20	AM	11.316	85.51067	11.23667	85.515	1735	3290	**8.8**
5/16/2006	Mozorola	NLS_18	11:26	AM	2:39	PM	11.23983	85.53467	11.38	85.425	3350	5136	**19.6**
5/16/2006	Mozorola	NLS_19	4:55	PM	6:03	AM	11.38367	85.5515	11.4405	85.57633	5137	6288	**6.8**
5/17/2006	Mozorola	NLS_20	7:12	AM	10:22	AM	11.41317	85.55433	11.29783	85.6715	36	3190	**18.1**
5/17/2006	Mozorola	NLS_21	10:28	AM	1:15	PM	11.29483	85.66867	11.2495	85.529	3259	6049	**16.1**
5/17/2006	Mozorola	NLS_22	1:20	PM	4:05	PM	11.25183	85.52683	11.35667	85.58117	6052	8806	**13.0**
5/18/2006	Mozorola	NLS_23	10:18	AM	11:27	AM	11.491	85.2855	11.54817	85.28667	36	1192	**6.3**
5/18/2006	Mozorola	NLS_24	11:26	AM	12:20	PM	11.54617	85.2885	11.51667	85.266	1244	1971	**4.1**
5/18/2006	Mozorola	NLS_25	12:26	PM	1:27	PM	11.51883	85.26767	11.56567	85.23883	1972	2923	**6.1**
5/18/2006	Mozorola	NLS_26	X:XX	AM	2:25	PM	11.56267	85.23917	11.53133	85.21717	2994	3751	**4.2**
5/18/2006	Mozorola	NLS_27	3:41	PM	4:16	PM	11.5285	85.33217	11.49833	85.33633	3776	4400	**3.4**
5/18/2006	Mozorola	NLS_28	4:25	PM	4:38	PM	11.49983	85.48733	11.50933	85.34383	4500	4727	**15.7**
5/18/2006	Mozorola	NLS_29	4:42	PM	4:58	PM	11.5085	85.34533	11.496	85.34833	4756	5023	**1.4**

Table 1. (continued)

Date	Boat	Line #	Time/start		Time/end		Start Lat	Start Lon	End Lat	End Lon	Start Shot	End Shot	Distance
5/19/2006	Mozorola	NLS_30	9:14	AM	10:34	AM	11.24567	85.40217	11.18933	85.36483	25	1338	**7.4**
5/19/2006	Mozorola	NLS_31	10:37	AM	1:00	PM	11.19033	85.364	11.27933	85.296	1339	3605	**12.3**
5/19/2006	Mozorola	NLS_32	1:03	PM	2:16	PM	11.27917	85.294	11.24367	85.244	3606	4838	**6.7**
5/20/2006	Mozorola	NLS_33	8:22	AM	10:58	AM	11.21667	85.04067	11.277	85.109	60	1685	**10.0**
5/20/2006	Mozorola	NLS_34	X:XX	AM	12:38	PM	11.276	85.1105	11.153	85.16533	1714	4305	**14.9**
5/21/2006	Mozorola	NLS_35	10:51	AM	11:29	AM	11.48583	85.3355	11.50917	85.36267	4	576	**3.9**
5/21/2006	Mozorola	NLS_36	11:34	AM	11:53	AM	11.50683	85.3635	11.4905	85.36183	581	920	**1.8**
5/21/2006	Mozorola	NLS_37	11:57	AM	12:24	PM	11.49133	85.36417	11.65	85.3855	970	1449	**17.7**
5/21/2006	Mozorola	NLS_38	12:28	PM	12:46	PM	11.504	85.39917	11.4865	85.38833	1492	1810	**2.3**
5/21/2006	Mozorola	NLS_39	12:52	PM	12:57	PM	11.4895	85.388	11.49383	85.39033	1870	1968	**0.5**
5/21/2006	Mozorola	NLS_40	1:00	PM	2:28	PM	11.49533	85.389	11.50833	85.31433	2025	3480	**8.3**
5/21/2006	Mozorola	NLS_41	2:28	PM	2:42	PM	11.50833	85.31433	11.515	85.30233	3481	3715	**1.5**
5/21/2006	Mozorola	NLS_42	2:46	PM	3:58	AM	11.51833	85.30567	11.5545	85.36117	3790	4969	**7.3**
5/23/2006	Mozorola	NLS_43	X:XX	AM	8:02	AM	11.5985	85.59733	11.60133	85.65933	15	1217	**6.8**
5/23/2006	Mozorola	NLS_44	8:03	AM	9:01	AM	11.60133	85.65933	11.56717	85.7005	1218	2230	**5.9**
5/23/2006	Mozorola	NLS_45	9:07	AM	9:18	AM	11.56817	85.703	11.5785	85.70133	2278	2484	**1.2**
5/23/2006	Mozorola	NLS_46	9:22	AM	9:30	AM	11.57933	85.69867	11.58033	85.69083	2535	2682	**0.9**
5/23/2006	Mozorola	NLS_47	9:34	AM	10:55	AM	11.57783	85.6905	11.528	85.74217	2746	4092	**7.9**
5/23/2006	Mozorola	NLS_48	10:57	AM	11:41	AM	11.52633	85.7425	11.48667	85.742	4127	4854	**4.4**
5/27/2006	Mozorola	NLS_4M	12:31	PM	2:32	PM	12.18217	86.1755	12.17617	86.19917	5	1931	**2.7**
5/27/2006	Mozorola	NLS_6M	4:23	PM	5:22	PM	12.16867	86.28967	12.16867	86.2415	124	1117	**5.2**
5/28/2006	Morrito#2	NLS_11M	2:21	PM	3:49	PM	12.251	86.14183	12.25683	86.22817	3	1482	**9.4**
5/28/2006	Morrito#2	NLS_12M	3:52	PM	X:XX	PM	12.25517	86.22767	12.22117	86.15067	1483	2145	**9.2**
												Total Dist.	**546.9**

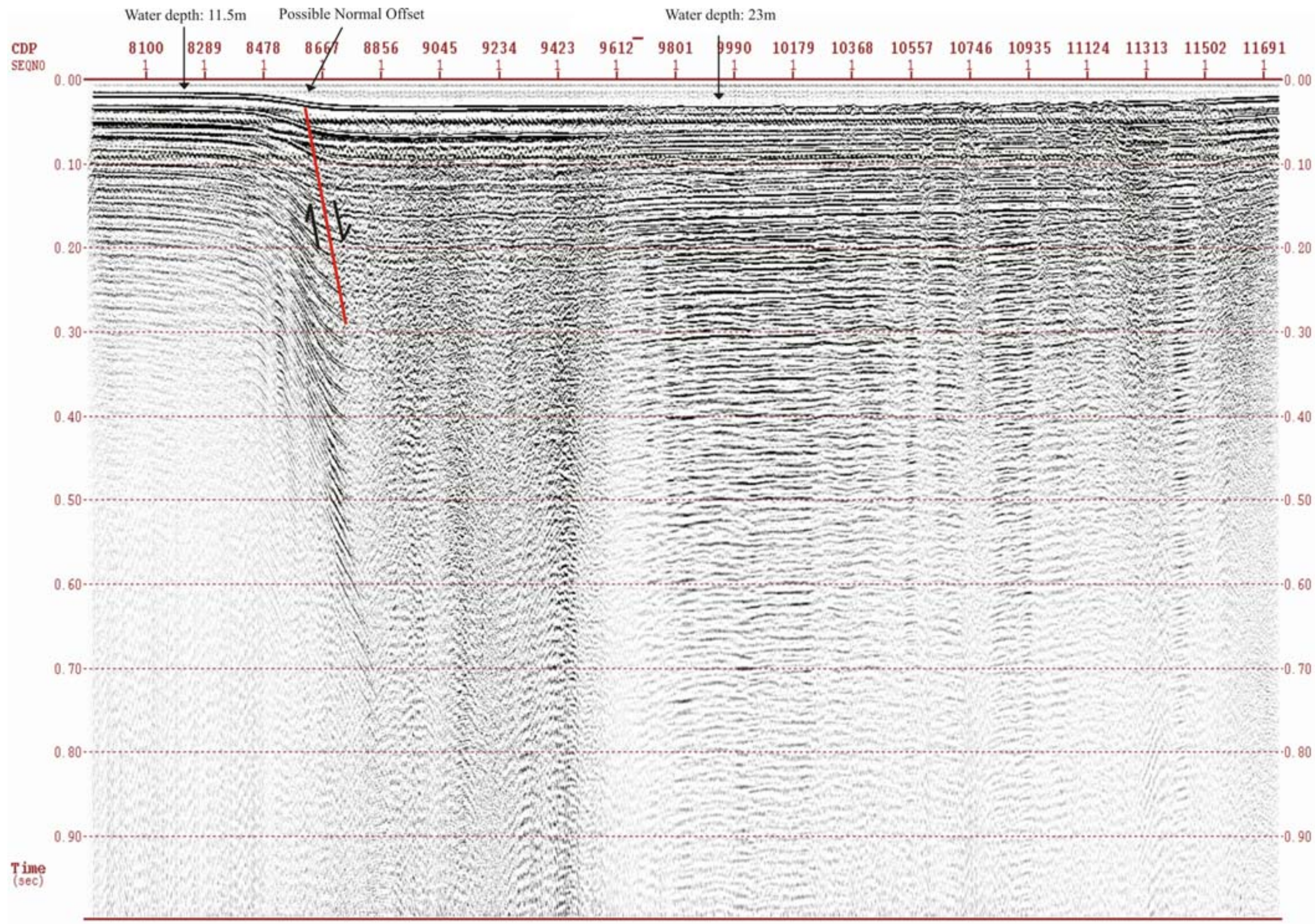


Figure 23. A typical seismic section collected on Lake Nicaragua. This line has undergone minimal processing including a bandpass filter, deconvolution, normal moveout velocity analysis, and an unmigrated stack. This line is from a deep trough found off the northeastern coast of Maderas volcano. A vast majority of the lines collected show a perfectly flat bottom with few and far scarps or surface displacements. There is almost no penetration in any line and reflections are mostly multiple energy.

3.5 kHz Subbottom Profiler Acquisition

Our best tool for exploring active deformation in the lakes was the DPS TECH 3.5 kHz Subbottom Profiler. This tool has been shown to provide high resolution imaging and good penetration worldwide. The system included a 3.5 kHz transceiver, a MASSA TR 1075A transducer, 2 kW power to the transducer, and Dr. Geo software for data acquisition and processing. The transmitter had a frequency of 3.5 kHz, ± 2%, variable 2 kW max power output, internal adjustable pulse repetition rate, selectable cycle pulse lengths, and +8V output for keying other instruments. The receiver had a switchable in/out 3.5 kHz center bandpass filter and selectable gain control at 3, 10, 20, and 40 dB. The transducer had an operating maximum depth of 2000 ft., directivity of 80° conical at -3 dB, and 4 kHz frequency.

The transceiver was connected via USB port to a laptop with Dr. Geo software. The transducer was positioned on the port side the *Mozorola* and *Morrito No. 2*, just below water level. The subbottom profiler was used to record very high resolution stratigraphy in the lake deposits. However, due to unusual circumstances it only recorded penetration in very isolated locations and otherwise displayed only surface features (Fig. 24). It became our main exploration tool in discovering active faulting (Data in Table 2).

Table 2. 3.5 kHz Subbottom Profiler Data Log for NicLakes Survey

Date	Boat	Line #	Time/start		Time/end		Start Lat	Start Lon	End Lat	End Lon	Distance
5/8/2006	Mozorola	NLP_02	12:53	PM	2:36	PM	11.98167	85.84017	11.9165	85.88917	**9.0**
5/8/2006	Mozorola	NLP_03	2:43	PM	4:33	PM	11.91867	85.88933	11.9615	85.80717	**10.1**
5/9/2006	Mozorola	NLP_04	1:24	PM	4:00	PM	11.93367	85.77283	11.87833	85.62167	**17.6**
5/10/2006	Mozorola	NLP_05	9:51	AM	10:15	AM	12.06533	85.83167	0	0	
5/12/2006	Mozorola	NLP_06	7:38	AM	5:08	PM	12.0115	85.89883	11.7385	85.566	**47.2**
5/14/2006	Mozorola	NLP_50	10:38	AM	11:41	AM	11.4805	85.69417	11.50667	85.74467	**6.2**
5/14/2006	Mozorola	NLP_51	11:54	AM	2:04	PM	11.51067	85.75367	11.50917	85.75417	**0.2**
5/14/2006	Mozorola	NLP_52	2:09	PM	X:XX	PM	11.41217	85.7315	0	0	
5/15/2006	Mozorola	NLP_53	7:07	AM	10:32	AM	11.41	85.546	0	0	
5/15/2006	Mozorola	NLP_54	10:35	AM	1:00	PM	11.53483	85.4425	11.42267	85.39183	**13.6**
5/15/2006	Mozorola	NLP_55	1:00	PM	3:28	AM	11.42267	85.39183	11.53367	85.30617	**15.4**
5/15/2006	Mozorola	NLP_56	3:28	PM	4:08	PM	11.53367	85.30617	11.503	85.30467	**3.4**
5/16/2006	Mozorola	NLP_58	6:45	AM	7:25	AM	11.40567	85.547	11.39817	85.48683	**6.6**
5/16/2006	Mozorola	NLP_59	7:25	AM	9:40	AM	11.39817	85.48683	11.31883	85.51333	**9.2**
5/16/2006	Mozorola	NLP_60	9:40	AM	11:19	AM	11.31883	85.51333	11.2355	85.536	**9.5**
5/16/2006	Mozorola	NLP_61	11:22	AM	2:40	PM	11.237	85.537	11.381	85.42617	**20.0**
5/16/2006	Mozorola	NLP_62	2:40	PM	4:55	PM	11.381	85.42617	11.38383	85.55283	**13.8**
5/16/2006	Mozorola	NLP_63	4:55	PM	6:16	PM	11.38383	85.55283	11.44867	85.57567	**7.6**
5/17/2006	Mozorola	NLP_64	6:59	AM	10:21	AM	11.4145	85.54133	11.298	85.67133	**19.2**
5/17/2006	Mozorola	NLP_66	10:21	AM	1:17	PM	11.298	85.67133	11.251	85.52667	**16.6**
5/17/2006	Mozorola	NLP_67	1.17	PM	4:04	PM	11.251	85.52667	11.3905	85.58133	**16.5**
5/18/2006	Mozorola	NLP_70	7:18	AM	10:18	AM	11.40867	85.54833	11.4905	85.2855	**30.1**
5/18/2006	Mozorola	NLP_71	10:18	AM	11:33	AM	11.4905	85.2855	11.54717	85.2895	**6.3**
5/18/2006	Mozorola	NLP_72	11:33	AM	12:19	PM	11.54717	85.2895	11.51633	85.26617	**4.3**
5/18/2006	Mozorola	NLP_73	12:19	PM	1:27	PM	11.51633	85.26617	11.56617	85.2405	**6.2**
5/18/2006	Mozorola	NLP_74	1:27	PM	2:33	PM	11.56617	85.2405	11.52567	85.21483	**5.3**
5/18/2006	Mozorola	NLP_75	2:33	PM	3:38	PM	11.53333	85.21483	11.5305	85.33133	**12.7**
5/18/2006	Mozorola	NLP_76	3:38	PM	4:22	PM	11.5305	85.33133	11.49833	85.33617	**3.6**
5/18/2006	Mozorola	NLP_77	4:25	PM	4:38	PM	11.49967	85.33733	11.50933	85.34383	**1.3**
5/18/2006	Mozorola	NLP_78	4:40	PM	5:07	PM	11.50883	85.34517	11.40683	85.35717	**11.4**
5/19/2006	Mozorola	NLP_80	6:26	AM	9:13	AM	11.41483	85.54167	11.24533	85.402	**24.2**

Table 2. (continued)

Date	Boat	Line #	Time/s tart		Time/end		Start Lat	Start Lon	End Lat	End Lon	Distance
5/19/2006	Mozorola	NLP_81	9:13	AM	10:40	AM	11.24533	85.402	11.19367	85.36217	**7.2**
5/19/2006	Mozorola	NLP_82	10:40	AM	12:59	PM	11.19367	85.36217	11.27933	85.296	**11.9**
5/19/2006	Mozorola	NLP_83	1:02	PM	14:26	PM	11.27917	85.29433	11.24	85.23933	**7.4**
5/20/2006	Mozorola	NLP_84	7:20	AM	8:19	AM	11.172	84.99883	11.21567	85.03883	**6.5**
5/20/2006	Mozorola	NLP_85	8:19	AM	10:00	AM	11.21567	85.03883	11.277	85.1	**9.5**
5/20/2006	Mozorola	NLP_86	10:00	AM	12:49	PM	11.277	85.10967	11.148	85.16967	**15.7**
5/20/2006	Mozorola	NLP_87	12:49	PM	4:05	PM	11.148	85.16967	11.37283	85.82083	**75.3**
5/20/2006	Mozorola	NLP_89	4:06	PM	5:44	PM	11.1895	85.82083	0	0	
5/21/2006	Mozorola	NLP_90	6:30	AM	11:29	AM	11.17267	85.0015	11.50917	85.36267	**54.2**
5/21/2006	Mozorola	NLP_91	11:31	AM	11:54	AM	11.50833	85.364	11.48983	85.363	**2.0**
5/21/2006	Mozorola	NLP_92	11:56	AM	12:25	PM	11.491	85.3645	11.50633	85.38583	**2.9**
5/21/2006	Mozorola	NLP_93	12:25	PM	12:49	PM	11.50633	85.38583	11.48833	85.38717	**2.0**
5/21/2006	Mozorola	NLP_93	12:52	PM	12:57	PM	11.4905	85.3885	11.49417	85.3905	**0.5**
5/21/2006	Mozorola	NLP_94	12:58	PM	2:40	AM	11.49483	85.38983	11.514	85.30333	**9.7**
5/21/2006	Mozorola	NLP_95	2:40	PM	4:09	PM	11.514	85.30333	11.55717	85.36933	**8.6**
5/22/2006	Mozorola	NLP_101	6:29	AM	8:07	AM	11.58783	85.58667	11.54667	85.45633	**14.9**
5/22/2006	Mozorola	NLP_103	8:08	AM	11:08	AM	11.54667	85.45583	11.75383	85.261	**31.2**
5/22/2006	Mozorola	NLP_104	11:08	AM	12:21	PM	11.75383	85.261	11.833	85.34733	**12.9**
5/22/2006	Mozorola	NLP_105	12:21	PM	4:12	PM	11.833	85.34733	11.59717	85.57383	**35.9**
5/23/2006	Mozorola	NLP_106	6:42	AM	8:01	AM	11.5965	85.59317	11.60133	85.65967	**7.3**
5/23/2006	Mozorola	NLP_107	8:03	AM	9:01	AM	11.6005	85.66117	11.56717	85.7005	**5.7**
5/23/2006	Mozorola	NLP_108	9:01	AM	9:18	AM	11.56717	85.7005	11.57833	85.70133	**1.2**
5/23/2006	Mozorola	NLP_109	9:18	AM	9:30	AM	11.57833	85.70133	11.58	85.69017	**1.2**
5/23/2006	Mozorola	NLP_110	9:30	AM	10:54	AM	11.58	85.69017	11.506	85.74233	**10.0**
5/23/2006	Mozorola	NLP_111	10:54	AM	11:41	AM	11.506	85.74233	11.48617	85.74217	**2.2**
5/23/2006	Mozorola	NLP_112	11:41	AM	11:47	AM	11.48617	85.74217	11.48683	85.74683	**0.5**
5/23/2006	Mozorola	NLP_113	11:52	AM	12:39	PM	11.48683	85.74683	11.52383	85.765	**4.5**
5/23/2006	Mozorola	NLP_114	12:39	PM	1:08	PM	11.52383	85.76017	11.48083	85.76017	**4.8**
5/23/2006	Mozorola	NLP_115	1:08	PM	1:38	PM	11.48083	85.76017	11.5165	85.7585	**3.9**
5/23/2006	Mozorola	NLP_116	1:38	PM	1:55	PM	11.5165	85.7585	11.49417	85.76833	**2.7**

Table 2. (continued)

Date	Boat	Line #	Time/start		Time/end		Start Lat	Start Lon	End Lat	End Lon	Distance
5/23/2006	Mozorola	NLP_117	1:55	PM	2:03	PM	11.49417	85.76833	11.48783	85.77867	**1.3**
5/23/2006	Mozorola	NLP_118	2:03	PM	3:24	PM	11.48783	85.77867	11.58017	85.83167	**11.7**
5/23/2006	Mozorola	NLP_119	3:24	PM	4:57	PM	11.58017	85.83167	11.65983	85.71333	**15.6**
5/23/2006	Mozorola	NLP_120	4:57	PM	6:00	PM	11.65983	85.71333	11.5995	85.5995	**14.1**
5/24/2006	Mozorola	NLP_121	7:00	AM	8:14	AM	11.5895	85.58967	11.671	85.703	**15.3**
5/24/2006	Mozorola	NLP_122	8:14	AM	9:50	AM	11.671	85.703	11.74467	85.58117	**15.6**
5/24/2006	Mozorola	NLP_123	9:50	AM	10:28	AM	11.74467	85.58117	11.7565	85.638	**6.3**
5/24/2006	Mozorola	NLP_124	10:28	AM	11:10	AM	11.7565	85.638	11.78567	85.58333	**6.8**
5/24/2006	Mozorola	NLP_125	11:10	AM	3:21	PM	11.78567	85.58333	11.93	85.9395	**42.0**
5/26/2006	Morrito#2	NLP_01M	9:53	AM	1:01	PM	12.19517	86.11583	12.2075	86.29233	**19.3**
5/26/2006	Morrito#2	NLP_02M	1:01	PM	4:36	PM	12.2075	86.29233	12.18517	86.12217	**18.7**
5/27/2006	Morrito#2	NLP_03M	8:54	AM	12:10	PM	12.181	86.128	12.18867	86.32383	**21.3**
5/27/2006	Morrito#2	NLP_04M	12:15	PM	2:34	PM	12.18467	86.3225	12.17417	86.20017	**13.4**
5/27/2006	Morrito#2	NLP_05M	2:40	PM	4:13	PM	12.17033	86.20283	12.17567	86.29133	**9.6**
5/27/2006	Morrito#2	NLP_06M	4:20	PM	5:25	PM	12.17017	86.29167	12.17033	86.24017	**5.6**
5/28/2006	Morrito#2	NLP_07M	7:59	AM	10:44	AM	12.2165	86.12517	12.22367	86.2865	**17.6**
5/28/2006	Morrito#2	NLP_08M	10:44	AM	1:02	PM	12.22367	86.2865	12.23783	86.16883	**12.9**
5/28/2006	Morrito#2	NLP_09M	1:02	PM	1:42	PM	12.23783	86.16883	12.22633	86.13333	**4.1**
5/28/2006	Morrito#2	NLP_10M	1:42	PM	2:09	PM	12.22633	86.13333	12.25083	86.13217	**2.7**
5/28/2006	Morrito#2	NLP_11M	2:09	PM	3:49	PM	12.25083	86.13217	12.25667	86.22883	**10.5**
5/29/2006	Morrito#2	NLP_14M	8:31	AM	8:53	AM	12.226	86.14567	12.24317	86.17	**3.3**
5/29/2006	Morrito#2	NLP_15M	8:53	AM	10:18	AM	12.24317	86.17	12.2635	86.28817	**13.1**
5/29/2006	Morrito#2	NLP_16M	10:18	AM	10:30	AM	12.2635	86.28817	12.27967	86.2915	**1.8**
5/29/2006	Morrito#2	NLP_17M	10:30	AM	11:40	AM	12.27967	86.2915	12.3345	86.22367	**9.6**
5/29/2006	Morrito#2	NLP_18M	11:40	AM	12:54	PM	12.3345	86.22367	12.294	86.31667	**11.1**
5/29/2006	Morrito#2	NLP_18M	12:54	PM	2:45	PM	12.294	86.31667	12.37883	86.24083	**12.5**
5/29/2006	Morrito#2	NLP_19M	2:45	PM	3:34	PM	12.37883	86.24083	12.3765	86.3045	**6.9**
5/30/2006	Morrito#2	NLP_23M	10:50	AM	11:24	AM	12.34283	86.365	12.37517	86.36483	**3.6**
5/30/2006	Morrito#2	NLP_24M	11:24	AM	11:56	AM	12.37517	86.36483	12.3515	86.3795	**3.1**
5/30/2006	Morrito#2	NLP_25M	11:56	AM	1:14	PM	12.3515	86.3795	12.4425	86.40683	**10.5**
5/30/2006	Morrito#2	NLP_26M	1:15	PM	1:41	PM	12.44417	86.40683	12.45483	86.37717	**3.4**

Table 2. (continued)

Date	Boat	Line #	Time/s tart		Time/end		Start Lat	Start Lon	End Lat	End Lon	Distance
5/30/2006	Morrito#2	NLP_27M	1:41	PM	3:19	PM	12.45483	86.37717	12.34833	86.33833	**12.5**
5/30/2006	Morrito#2	NLP_30M	4:03	PM	4:39	PM	12.35383	86.3515	12.38233	86.3725	**3.9**
5/30/2006	Morrito#2	NLP_31M	4:39	PM	5:08	PM	12.38233	86.3725	12.3695	86.40367	**3.7**
5/30/2006	Morrito#2	NLP_32M	5:08	PM	6:29	PM	12.3695	86.40367	12.269	86.4305	**11.5**
5/31/2006	Morrito#2	NLP_33M	7:39	AM	9:31	AM	12.24067	86.42783	12.36833	86.44533	**14.3**
5/31/2006	Morrito#2	NLP_34M	9:31	AM	9:57	AM	12.36833	86.44533	12.388	86.4775	**4.1**
5/31/2006	Morrito#2	NLP_35M	9:57	AM	11:01	AM	12.388	86.4775	12.34433	86.549	**9.2**
5/31/2006	Morrito#2	NLP_36M	11:01	AM	11:55	AM	12.34433	86.549	12.30417	86.50917	**6.2**
5/31/2006	Morrito#2	NLP_37M	11:55	AM	12:23	PM	12.30417	86.50917	12.31017	86.53417	**2.8**
										Total Dist.	**1110.8**

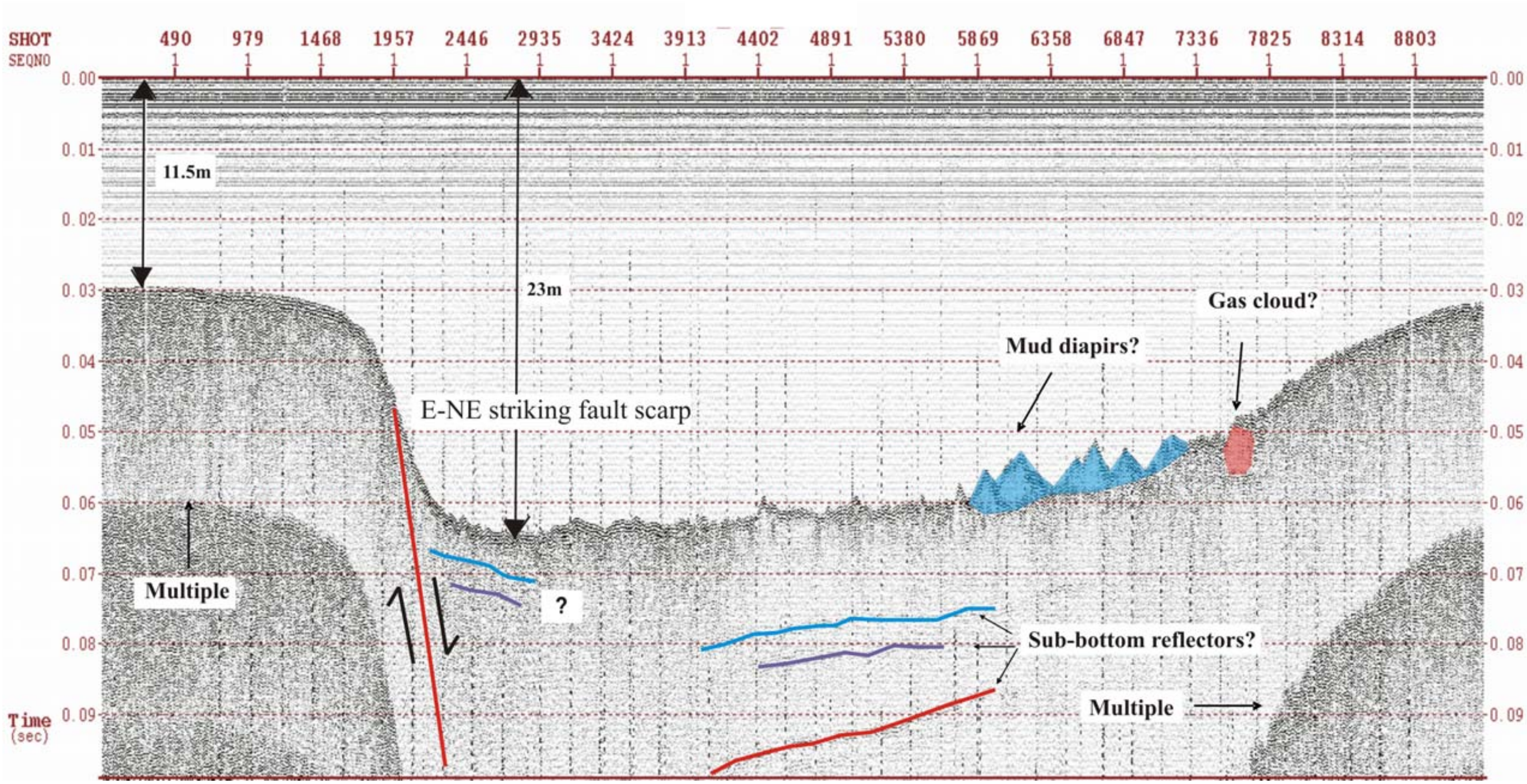


Figure 24. This 3.5 kHz line is in a similar location to the seismic section shown in Fig. 23, which crosses a known trough to the northeast of Vulcan Maderas. The 3.5 kHz subbottom profiler became the primary investigation tool in searching for recent or active faulting in Lake Managua and Nicaragua.

Sidescan Sonar Acquisition

Sidescan sonar was used to record features on the lake floor. It could then be correlated with features imaged on seismic or the 3.5 kHz that broke the surface. This would indicate recent activity or seismicity. Unfortunately, technical problems with the equipment and shipping problems prevented its use on Lake Nicaragua. The only sidescan sonar data available is from the Lake Managua survey (Data in Table 3).

A long board was wedged between the ceiling and the railing of the *Morrito No. 2* (Fig. 25). The fish then hung from a clip bolted into the wood and was approximately 1 m below the water surface in order to reduce noise from the ship's roll (Fig. 25). We were able to image several features, including possibly active faults and paleo-stream channels (Fig. 26).

<u>Sidescan Sonar Specs</u>**:**

Transducer	-1 transducer per side, tilted down 20°
Transducer frequency and beam width:	260 kHz: 2.2° x 75°
	330 kHz: 1.8° x 60°
	770 kHz: 0.7° x 30°
Max. Operating Depth:	300m
Interface:	Analog Telemetry
Weight:	5.4 kg

Figure 25. Steffen Saustrup is maintaining the laptops aboard the *Morrito No. 2* during the Lake Managua survey. The board wedged against the upper deck in the top left of the picture extends out into the water, supported the sidescan sonar “fish”. The “fish” hung by a carabineer from the plank at ~1 m water depth.

Table 3. Log for Sidescan Sonar collected aboard the Morrito No. 2 on Lake Managua (May 26 – May 31, 2006)

Date	Boat	Line #	Time/start	Time/end	Start Lat	Start Lon	End Lat	End Lon	Distance
5/26/2006	Morrito#2	NL_01M	10:00 AM	1:15 PM	12.19433	86.1205	12.1965	86.2955	**19.0**
5/26/2006	Morrito#2	NL_02M	1:15 PM	4:36 PM	12.1965	86.2955	12.18517	86.12217	**18.9**
5/26/2006	Morrito#2	NL_03M	4:36 PM	4:57 AM	12.18517	86.12217	12.20017	86.11333	**1.9**
5/27/2006	Morrito#2	NL_03M	8:54 AM	12:10 PM	12.181	86.128	12.18867	86.32383	**21.3**
5/27/2006	Morrito#2	NL_04M	12:10 PM	2:32 PM	12.18867	86.32383	12.17617	86.199	**13.7**
5/27/2006	Morrito#2	NL_05M	2:32 PM	4:16 PM	12.17617	86.29183	12.17317	86.29183	**0.3**
5/27/2006	Morrito#2	NL_06M	4:16 PM	5:28 PM	12.17317	86.29183	12.172	86.238	**5.9**
5/27/2006	Morrito#2	NL_07M	5:28 PM	7:01 PM	12.172	86.238	12.19917	86.1175	**13.5**
5/28/2006	Morrito#2	NL_07M	7:59 AM	10:44 AM	12.2165	86.12467	12.22383	86.2865	**17.6**
5/28/2006	Morrito#2	NL_08M	10:44 AM	11:09 AM	12.22383	86.2865	12.24733	86.2765	**2.8**
5/28/2006	Morrito#2	NL_09M	11:09 AM	1:03 PM	12.24733	86.2765	12.2375	86.16867	**11.8**
5/28/2006	Morrito#2	NL_10M	1:03 PM	1:43 PM	12.2375	86.16867	12.22667	86.133	**4.1**
5/28/2006	Morrito#2	NL_11M	1:43 PM	2:11 PM	12.22667	86.133	12.251	86.13333	**2.7**
5/28/2006	Morrito#2	NL_12M	2:11 PM	3:49 PM	12.251	86.13333	12.25683	86.22817	**10.3**
5/28/2006	Morrito#2	NL_13M	3:49 PM	5:58 PM	12.25683	86.22817	12.20783	86.12233	**12.7**
5/29/2006	Morrito#2	NL_14M	8:13 AM	8:53 AM	12.20883	86.126	12.24317	86.16883	**6.0**
5/29/2006	Morrito#2	NL_15M	8:53 AM	10:18 AM	12.24317	86.16883	12.26333	86.288	**13.2**
5/29/2006	Morrito#2	NL_16M	10:18 AM	10:31 AM	12.26333	86.288	12.27967	86.2915	**1.8**
5/29/2006	Morrito#2	NL_17M	10:31 AM	11:40 AM	12.27967	86.2915	12.33467	86.22367	**9.6**
5/29/2006	Morrito#2	NL_18M	11:40 AM	3:35 PM	12.33467	86.22367	12.37617	86.3045	**9.9**
5/29/2006	Morrito#2	NL_20aM	4:19 PM	5:46 PM	12.32933	86.32	12.24383	86.426	**14.9**
5/30/2006	Morrito#2	NL_21M	7:49 AM	10:02 AM	12.25583	86.43	12.363	86.31117	**17.5**
5/30/2006	Morrito#2	NL_22M	10:02 AM	11:24 AM	12.363	86.31117	12.37567	86.36533	**6.1**
5/30/2006	Morrito#2	NL_24M	11:24 AM	11:57 AM	12.37567	86.36533	12.353	86.38	**3.0**
5/31/2006	Morrito#2	NL_33M	7:59 AM	9:31 AM	12.265	86.43667	12.36833	86.44533	**11.5**
5/31/2006	Morrito#2	NL_34M	9:31 AM	12:16 PM	12.36833	86.44533	12.30283	86.52883	**11.6**
5/31/2006	Morrito#2	NL_35M	12:16 PM	4:02 PM	12.30283	86.52883	12.24067	86.42767	**13.0**
								Total Dist.	**274.6**

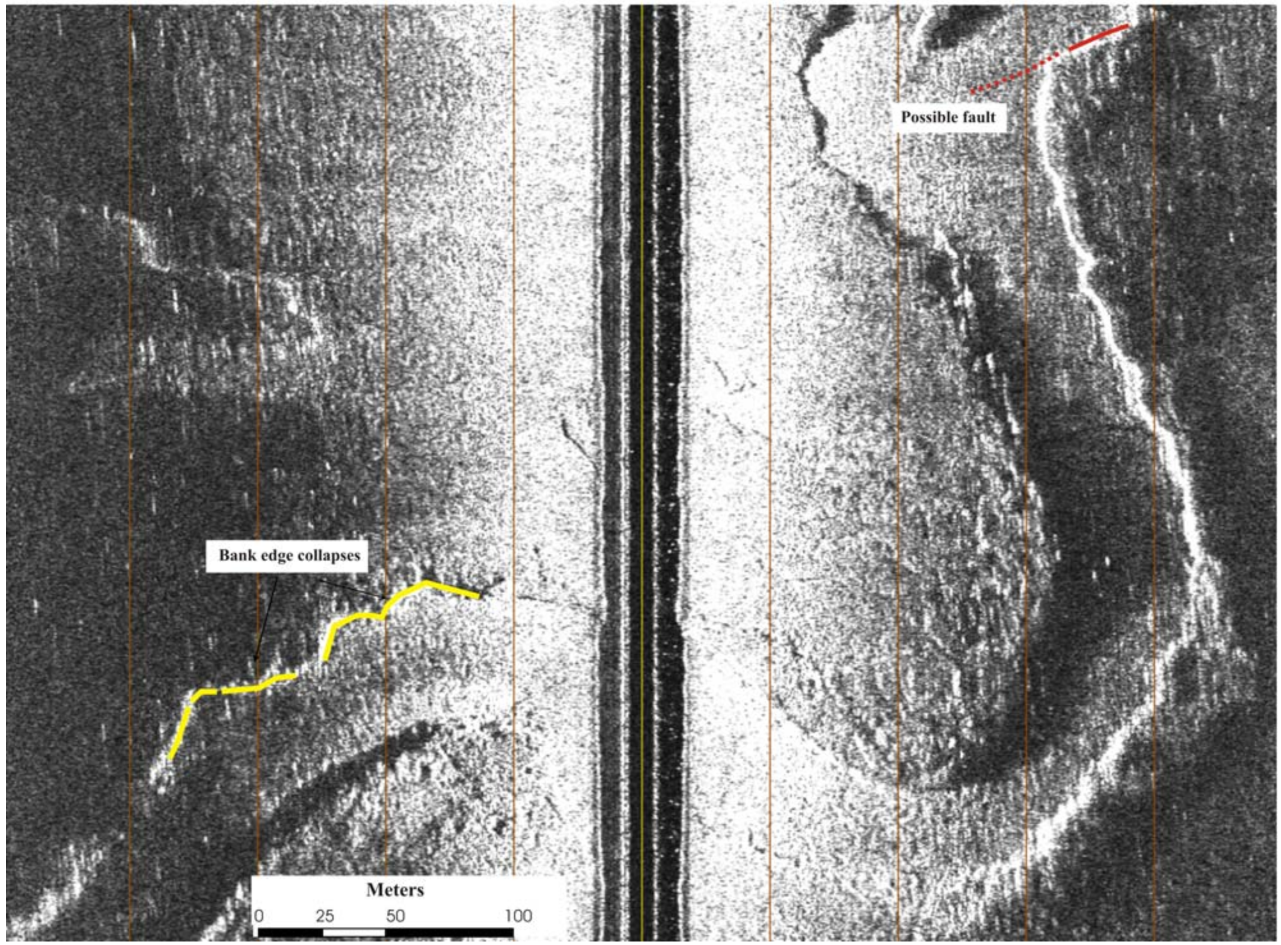


Figure 26. This raw, unprocessed image from sidescan sonar data displays a sinuous feature, indicative of a stream channel. This could represent a paleo-stream channel of the Tipitapa River which could have flowed here during lower lake levels. Offsets in the river can help determine timing and location of active faults.

SECTION 2: CORING SURVEY

Cruise Summary

A seismically-guided coring program in Lake Nicaragua was carried out to help establish a time series of volcanic activity, which can be used for determining the eruptive histories, volumes of erupted magma, and eruptive intensities (as recorded by grain size and thicknesses of tephra layers of locally explosive volcanoes, with the focus on the more recent activity (Fig. 27). These data, in combination with geochemical analyses on volcanic ash layers, will serve to develop models for the petrologic evolution of magmatic systems and better hazard indications of potential eruptive behavior. In addition, detailed paleoclimate studies on the lacustrine sediment records will help to reconstruct past climate variability and to determine factors which are responsible for it. Tephra layers will be used for dating the sediment sequences and linking with terrestrial deposits (Fig. 28).

Figure 27. Schematic map of locations of major Nicaraguan volcanoes.

Figure 28. (Left) Mombacho volcano (Right) Tephra deposit from the northern flank of Mombacho volcano (photos: Sabine Wulf).

The coring cruise in Lake Nicaragua was carried out from May 24 to June 04, 2006. A total of 35 short sediment cores were recovered from the boat using a gravity corer (Aquatic Research Instruments). Each core was retrieved in a single 6 cm diameter polycarbonate tube (Fig. 29). Core lengths ranged from 12 cm to 100 cm. Five long cores were extracted from the lake using a modified manual square rod piston corer. The long cores were taken primarily from the northern and southwestern part of the lake. Coring was carried out from a small raft constructed of two inflatable boats lashed together by two extendable aluminum scaffolding planks. Maximum penetration depth was 496.5 cm (composite depth). Additionally, five lake bottom grab samples were taken from areas where penetration and/or retrieval by the gravity corer were not possible.

Figure 29. Detailed images of the gravity corer used (source: http://www.aquaticresearch.com).

Coring Cruise Diary

May 24: Since the whole coring crew (Robert Dull, Sabine Wulf, Catherine Spruance and Zachery Baker) has arrived the evening before, this day was used to purchase additional coring equipment (WD40, batteries, paper rolls, foods etc.), receive the coring equipment from INETER (Managua) and to load the rented boat "*Mozorola*" (Fig. 30). Hotel: Casa Capricho, Granada.

May 25: We departed with the *Mozorola* from Granada heading ENE to test the gravity coring equipment. Three gravity cores (GC) were taken: the first one (GC-1) was located WSW of Isla La Flor where water depth was ~7m; the other two (GC-2 and GC-3) were taken on the way back to Granada from ~9 m water depth. Retrieval lengths ranged from 52 to 59 cm. Sediments consisted of dark to light grayish-brown gyttja and were generally homogeneous in appearance, although one distinctive change in color and texture was noted in two of the cores (GC-1, GC-3). This abrupt change from brown in the upper sediments to gray below was noted in core GC-1 in 34 cm and reversed in GC-3 in 30 cm sediment depth. The watery and/or gelatinous upper 12 cm of each core was sub-sampled in 1cm increments using a core plug and extruder. Problems with the GPS occurred during the second half of day, and a manual GPS was used afterwards. Arrival in Granada was at 7 pm. Hotel: Casa Capricho, Granada.

Figure 30. Retrieval of cores and sub-sampling procedures (photos: Robert Dull)

May 26: Starting from Granada we headed towards the NE section of the lake basin. Gravity core GC-4 was taken from 5.8 m water depth in a position roughly 4 km from the northeastern shoreline. The sediments were difficult to penetrate due to a shallow gravel horizon. The upper ~11.5 cm of the core consisted of brown-greenish organic sediments underlain by a layer of coarse (<3cm) igneous rocks. The impact of the corer on the gravel lens resulted in the destruction of the end of the polycarbonate core barrel and precluded the sampling of any sediment underlying this impenetrable layer. Grab sample #1 was taken at the same site in order to gather samples of the volcanic rock fragments. The entire core GC-4 was sub-sampled with the extruder. Next we proceeded southeast towards Isla La Flor (see position GC-1). Coring conditions became increasingly difficult due to high wind and waves. Gravity core GC-5 was taken from 7.6 m water and exhibited similar stratigraphy to GC-1, but contained more abundant charcoal fragments. A long piston core (LC1) with a composite length of 4.35m was recovered from the same position (Fig. 31). Sediments consisted mainly of brownish-gray gyttja. The upper 16 cm of sediments were discarded due to the high water content, with the knowledge that the surface sediments had already been carefully sampled with the

Figure 31. A) Preparation of coring raft used for the retrieval of piston cores. B) Extrusion procedure of piston cores (photos: Robert Dull)

gravity corer. A sharp transition occurred at 4.10 m depth to gray-blue dense clay sediments. Deeper penetration failed due the high bulk density and the cohesive properties of these sediments.

We returned to Granada at 8 pm. Hotel: Casa Capricho, Granada.

May 27: Starting from Granada we headed southeast towards Ometepe Island (Fig. 32). It was moderately windy in the morning, and got worse in the afternoon. Four gravity cores were recovered from 8.8 to 12 m water depth: GC-6, located 2 km to the eastern coast of Zapatera Island, consists of 48 cm of sediment with loose sandy volcanic material (tephra) at the bottom. GC-7, GC-8 and GC-9 were taken from a Fault zone northwest and west of Concepcíon volcano. GC-7 is stratified and contains abundant pieces of charcoal in the upper part of the core. GC-8 is homogenous and contains bivalves at the top and in the middle of the core. GC-9 is made up of a mix of tephra and organic sediments at the top and brown-greenish mud at the base. Grab sample #2 was taken close to the GC-9 coring position. The grab sample consisted primarily of black

Figure 32. A) Maderas volcano, western flank (photo: Sabine Wulf. B) Gravity core preservation on Ometepe Island (photos: Robert Dull)

coarse tephra material (sand to small gravel size).

Arrival time at Ometepe Island was 6.30 pm. Hotel: Biological Reserve, San Ramon.

May 28: Departing from Ometepe Island we proceeded to the north amidst windy conditions. We retrieved two gravity cores (GC-10 and GC-11) and grab sample #3 in the embayment just west of the Isthmus of Istian on Ometepe between Concepcíon and La Maderas volcanoes. Several tephra layers were observed in GC-10. GC-11 is made up of homogenous mud with no visible stratigraphy. Five more gravity cores were taken from 10 to 15 m water depth in the basin southwest of Ometepe Island. All sediment cores were homogenous and showed no obvious stratigraphy except of GC-12 and GC-15.Visible tephra layers occurred in cores GC-12, GC-13 and GC-14, while missing in cores GC-15 and GC-16. A grab sample from 8.6 m water depth in a position between GC-13 and GC-14 turned up a couple of volcanic rocks (no sampling). Penetration with the gravity corer was not possible due to the crumpling of barrel. Core GC-17 was recovered from a 21 m water depth in a fault zone south of La Madera, and consisted of greenish-brown sediments (see GC-9).

We returned to Ometepe Island at 6.30 pm. Hotel: Biological Reserve, San Ramon.

May 29: Starting from Ometepe Island and proceeding towards the southeast, we again encountered extreme windy conditions in the morning. The wind persisted until the afternoon as we approached the Archipelago of Solentiname (Fig. 33). Three gravity cores, GC-18, GC-19 and GC-20 were retrieved en route from Ometepe to Solentiname Islands. Sediments were observed to be generally organic-rich and homogeneous with respect to color and texture, except for GC-19, which exhibited one major change in

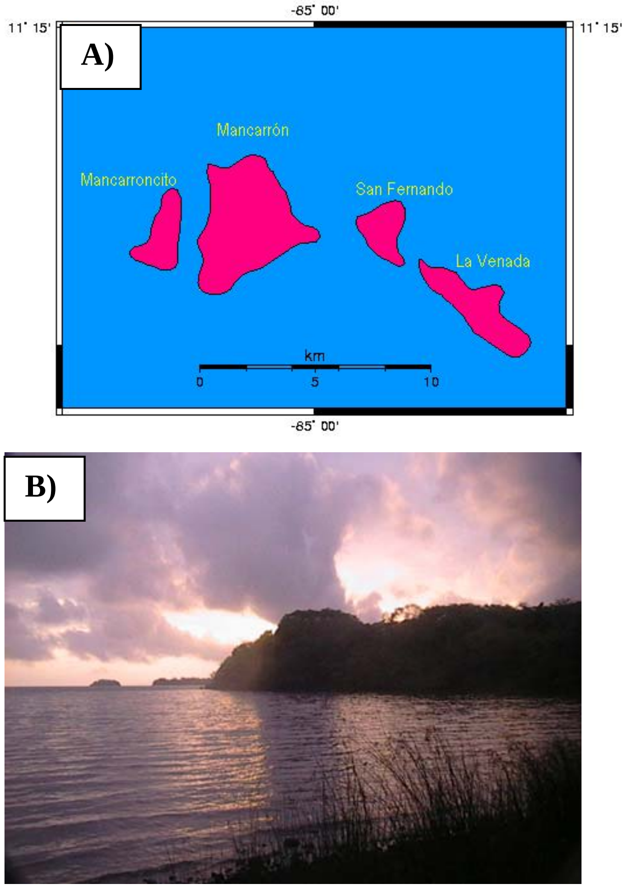


Figure 33. A) Schematic map of the Solentiname archipelago. B) Sunset at the embayment of the northern part of Mancarun Island (photo: Sabine Wulf)

lithology (see discussion regarding GC1). Core GC-20 contains snails at the sediment surface and coarse organic plant macrofossils in 65cm sediment depth. Penetration from 1.9 m water depth near the Southwest Costa Rican coast (river delta) failed. Grab sample #4 at the same location turned up black-brownish pyroclastic material mixed with gastropod shells. Gravity core GC-21 and Piston core LC-2 were taken from 5 m water depth south-southwest of Mancarroncito Island. The composite length of both cores is 2.50 m. Coring conditions were extremely difficult due to strong winds and high waves. Gravity core GC-22 was recovered from 3.7 m water depth near the southern coast of Mancarun Island. GC-21, GC-22 and LC-2 are made up of brown-grayish mud and show no obvious stratigraphic changes.

Arrival time at the Mancarun Island was 6 pm. Hotel: Mancarun.

May 30: Departing from Mancarun Island, we headed towards the southeast. On this morning perfect coring conditions were encountered: nearly no wind, and a calm water surface. It became more windy in the afternoon. Gravity core GC-23 and Piston core LC-3 were retrieved from 4.3 m water depth just south of San Fernando / La Venada Islands. Composite length is 4.965 m. GC-23 shows stratification from medium to light gray-brownish mud. LC-3 contains a 10cm thick, dark and sandy tephra layer in 7.25 m push depth (Fig. 34). A sharp transition occurs in 8.35 m push depth from brown organic-rich mud to gray-blue dense clay. Problems with the coring equipment occurred during drive #7 and #8 (broken cables, loss of Piston corer) because of the cohesive properties of the bottom clay.

We returned to Mancarun Island at 5 pm. Hotel: Mancarun.

Figure 34. A) Transition from dark brown organic sediments to blue-gray clay in Piston core LC-3-5, 8.35 m push depth (photo: Robert Dull)

May 31: Embarking from Mancarun Island we set out on a northerly route. Winds were light in the morning, but strong in the afternoon. The first gravity core GC-24 was recovered from shallow water (4.6m) at the western shore of San Fernando Island (Solentiname). This core is nicely stratified and contains two ash layers at 8 and 34 cm

sediment depth, respectively. We continued our cruise towards the Northwest. Gravity cores GC-25 and GC-26 were taken from 9.6 and 11.1 m water depth between Ometepe Island and the Eastern coast of Lake Nicaragua (Fig. 35). Both cores exhibited a marked change in color from medium brownish gray at the top to a light brownish gray at the bottom. GC-26 in addition contains gastropods between 4 and 6 cm sediment depth. GC-27 and GC-28 from 12.9 m and 21.7 m water depth show no obvious stratigraphy. Core GC-28 is exceptionally long (100 cm) which might indicate an inclined (<90°) penetration angle. Coring in 29 m water depth in a fault zone east of Ometepe Island failed. Grab sample #5 turned up gray-bluish clay nodules which are altered/oxidized at the surface (reddish-orange rinds) indicating recent hydrothermal activity. Gravity core GC-29 was recovered from ca 21.5 m water depth (drifting boat) and close to the locations of the grab sample and GC-28 exhibited 17 cm of gray-brownish mud at the top and 3 cm of gray-blue clay at the base. The contact zone is characterized by a 1 cm sandy layer (tephra?). GC-30 and GC-31 are taken from 14.2 m water depth east of Concepcíon volcano and contain grayish-brown lake sediments with no obvious stratification.
We arrived at the eastern coast of Ometepe Island at 6 pm. Hotel: Altagracia.

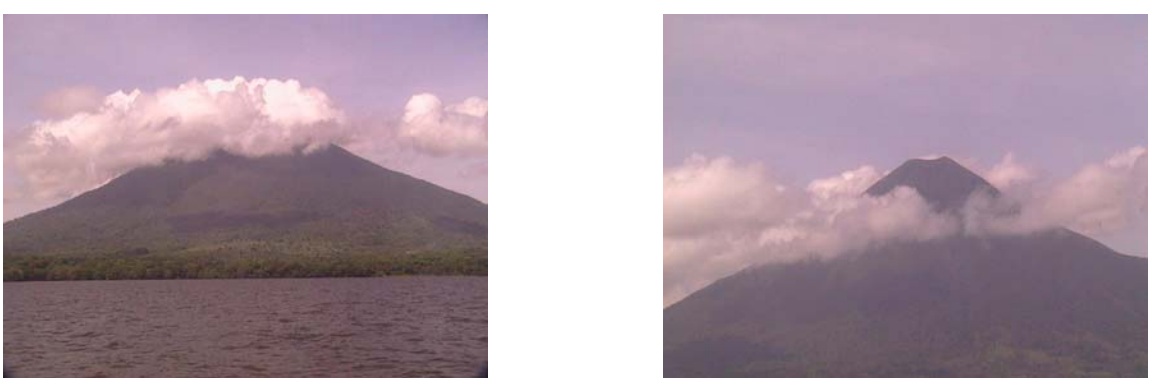


Figure 35. Concepcion volcano, eastern flank (photos: Sabine Wulf)

June 1: Starting from Altagracia, Ometepe Island, we set out on a northwesterly course towards Zapatera Island. The wind was moderate. Gravity core GC-32 was taken from 15.8 m depth and showed no obvious stratigraphy. GC-33 and GC-34 were recovered 500 m from the northwestern shoreline of Zapatera Island. GC-33 is stratified from light at the top to medium gray-brownish at the bottom. Datable wood occurred in 39 cm depth. GC-34 consists of homogenous lake mud. Piston core LC-4 was retrieved at the same position from 3.4 m water depth. Coring took place from the boat in extremely calm water conditions. Total length of core was 4.4 m. A change from dark brown to medium brown occurred at 6.09 m push depth. A tephra horizon was observed at 6.57 m push depth and coarse organic material between 6.89 and 6.90 m.

Accompanied by a spectacular sunset we returned to Granada at 8 pm (Fig. 36). Hotel: Casa Capricho, Granada.

Figure 36. A) Sunset on Lake Nicaragua. B) Center of the city of Granada with Mombacho volcano in the background (photos: Sabine Wulf). Concepcion volcano, eastern flank (photos: Sabine Wulf)

June 2: Embarking from Granada, we took a NNE route towards the Tipitapa river delta and inlet from Lake Managua. Light winds prevailed throughout the day. Gravity core GC-35 and Piston core LC-5 were taken from 3.3 m water depth. The top 10 cm of GC-35 are characterized by dark brownish sand and bivalves. The basal section of GC-35 and the piston core sections were characterized by homogenous brown gyttja. Total retrieval length was 4.15 m. Loss of important Piston coring tools (T-bar, rods, and broken cables) during the last two drives precluded any further coring.

We returned to Granada in the late afternoon. Hotel: Casa Capricho, Granada.

June 3 to June 4: The coring campaign on Lake Nicaragua was officially finished. We unload the boat and used the following two days to clean and pack the coring equipment. The boxes were transported back to INETER in Managua, where it was shipped to Austin three weeks later.

Hotel: Casa Capricho, Granada.

Coring Data

Table 4: Location, water depth and gravity core (GC) retrieval length data of coring sites in Lake Nicaragua

Core #	Date	N dec. Degrees	W dec. Degrees	Water depth (m)	GC-Retrival length (cm)
GC-1	5/25/2006	12.0062883	-85.6933783	7.1	54
GC-2	5/25/2006	11.9913522	-85.7746754	9.2	52
GC-3	5/25/2006	11.9632754	-85.8548049	9.15	58.5
GC-4, Grab-S-1	5/26/2006	12.05921	-85.73399	5.8	11.5
GC-5, LC-1	5/26/2006	12.01343	-85.69428	7.6	54
GC-6	5/27/2006	11.7256129	-85.7715202	9	48
GC-7	5/27/2006	11.5699137	-85.7490578	11.8	50
GC-8	5/27/2006	11.5132829	-85.7463837	12	46
GC-9	5/27/2006	11.5074032	-85.7378962	8.8	39
Grab-S-2	5/27/2006	11.5073756	-85.7378958	2.5	-
GC-10	5/28/2006	11.4728333	-85.5670467	4	32
Grab-S-3	5/28/2006	11.4731923	-85.5668624	4	-
GC-11	5/28/2006	11.4769717	-85.6098883	10	55
GC-12	5/28/2006	11.4292	-85.6550067	13.6	61
GC-13	5/28/2006	11.3829983	-85.7095267	10.4	38
GC-14	5/28/2006	11.3321817	-85.66385	15.1	70
GC-15	5/28/2006	11.3198633	-85.63243	13.8	50
GC-16	5/28/2006	11.3198644	-85.6324291	13.8	46
GC-17	5/28/2006	11.376300	-85.512338	21	64
GC-18	5/29/2006	11.3078333	-85.3519734	16.7	59
GC-19	5/29/2006	11.2501616	-85.2655945	7.6	72
GC-20	5/29/2006	11.1664733	-85.2139534	9.5	72
Grab-S-4	5/29/2006	11.1198533	-85.1881734	1.9	-
GC-21, LC-2	5/29/2006	11.1372433	-85.0813934	5	45
GC-22	5/29/2006	11.1607733	-85.0096533	3.7	71
GC-23, LC-3	5/30/2006	11.1222892	-84.9697041	4.3	53.5
GC-24	5/31/2006	11.18847	-84.98756	4.6	42
GC-25	5/31/2006	11.3630556	-85.1203611	9.6	49
GC-26	5/31/2006	11.4664167	-85.2390278	11.1	46
GC-27	5/31/2006	11.5365278	-85.32775	12.9	52
GC-28	5/31/2006	11.5250006	-85.3193373	21.7	100
Grab-S-5	5/31/2006	11.5176673	-85.3006429	29	-
GC-29	5/31/2006	11.5076395	-85.3197818	21.5	21
GC-30	5/31/2006	11.556278	-85.467917	14.2	65
GC-31	5/31/2006	11.589194	-85.54825	14.2	71.5
GC-32	6/01/2006	11.675917	-85.685889	15.8	67
GC-33	6/01/2006	11.783389	-85.863417	10.6	76.5
GC-34, LC-4	6/01/2006	11.762583	-85.872528	3.4	52.5
GC-35, LC-5	6/02/2006	12.063056	-85.861861	3.3	24.5

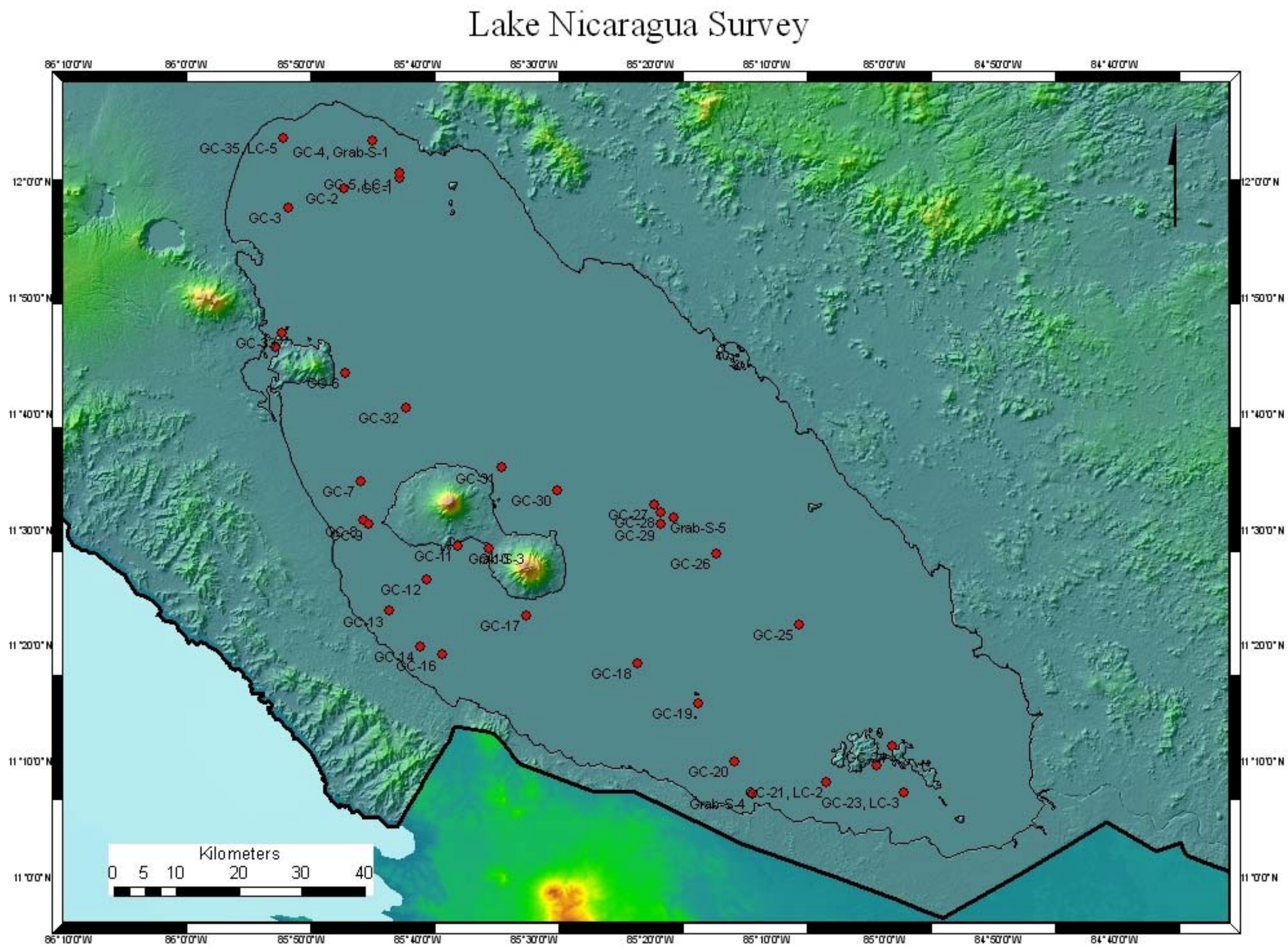


Figure 37. Coring sites of Lake Nicaragua

Lake Nicaragua Survey

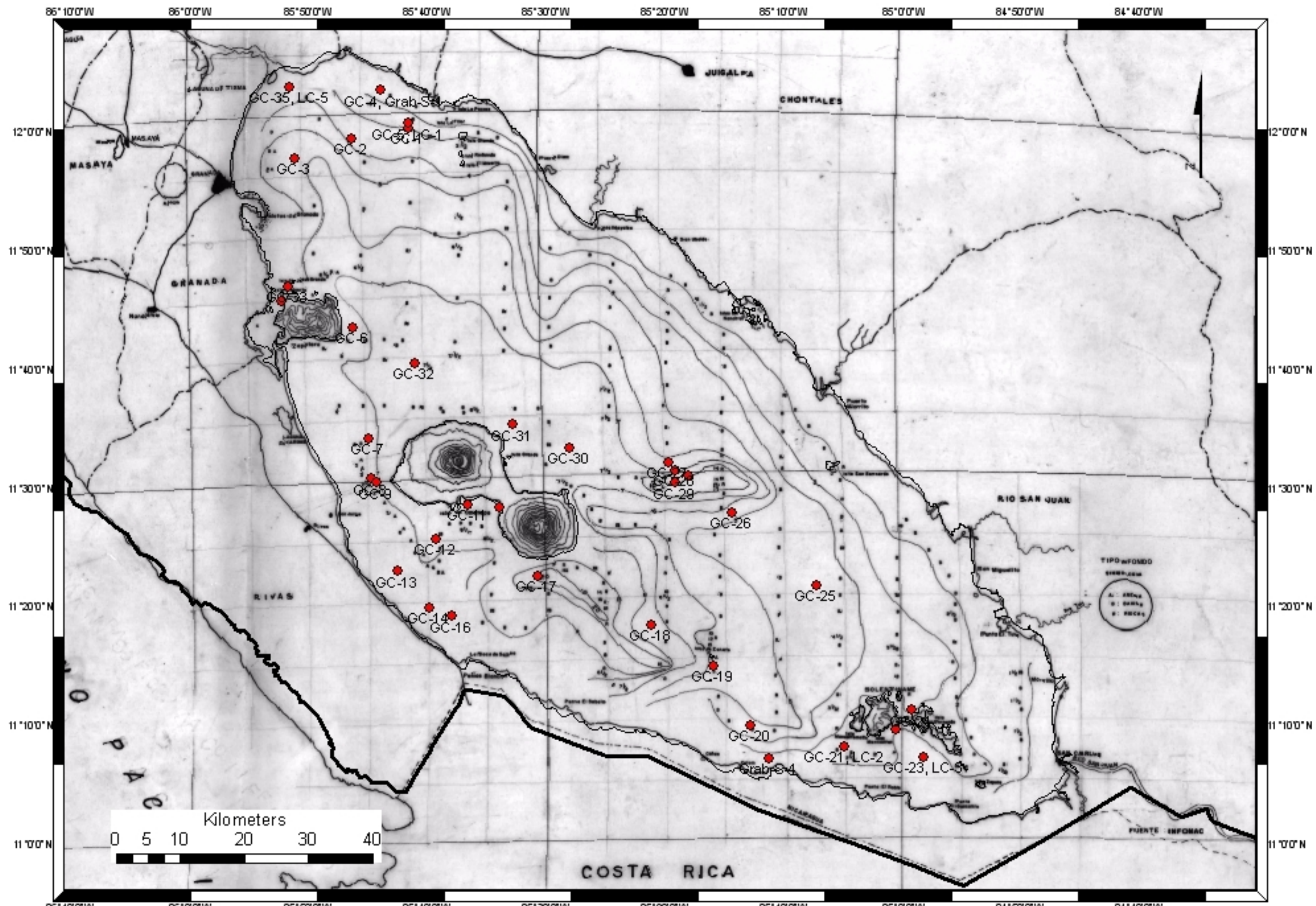


Figure 38. Bathymetric map of Lake Nicaragua with coring sites.

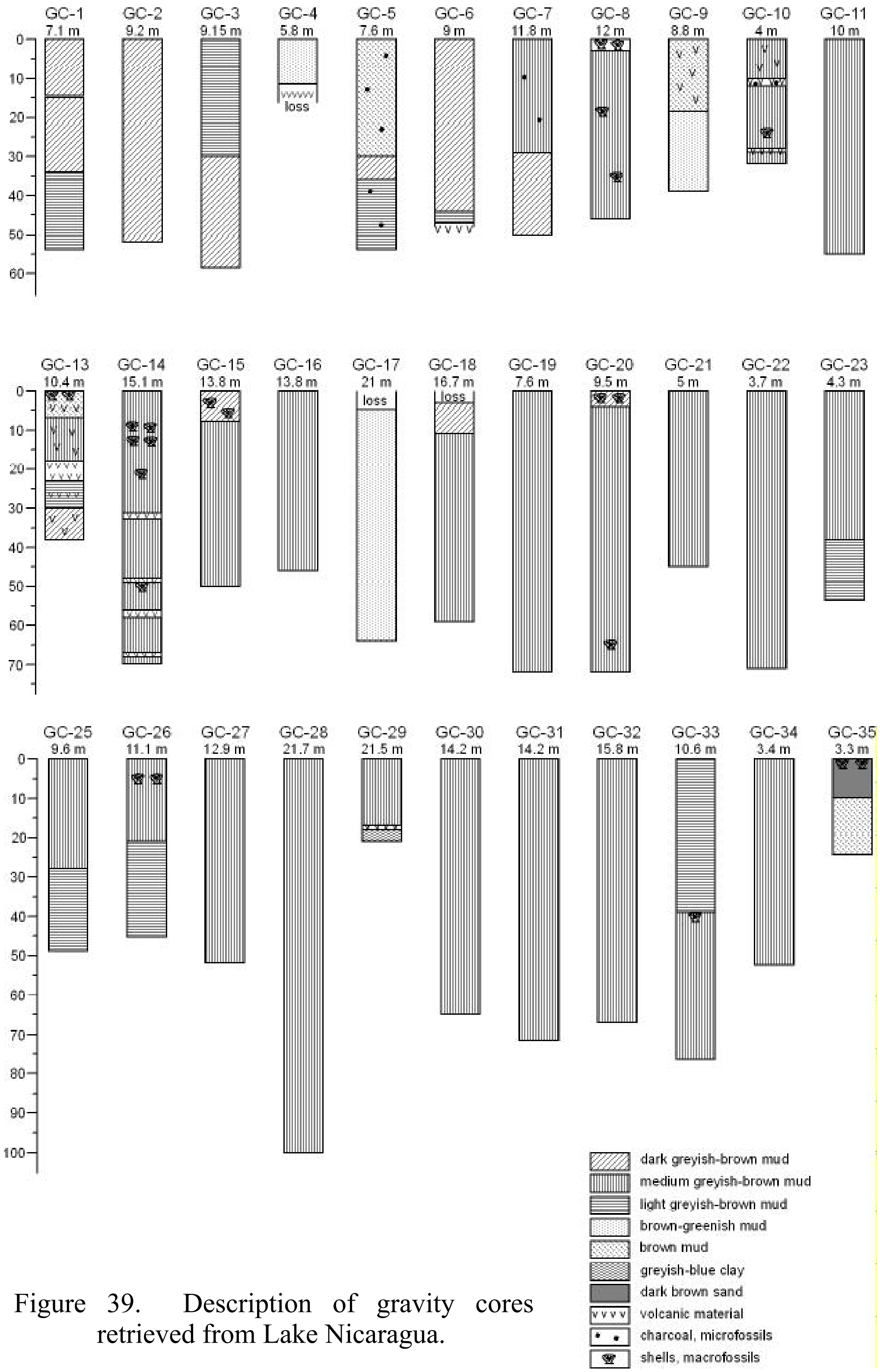


Figure 39. Description of gravity cores retrieved from Lake Nicaragua.

Table 5: Description of gravity cores retrieved from Lake Nicaragua Lake Nicaragua

Core	Top (cm)	Bottom (cm)	Sediment description
GC-1	0.0	34.0	dark greyish brown mud
	34.0	54.0	light grey mud
GC-2	0.0	52.0	dark greyish-brown mud
GC-3	0.0	30.0	light greyish-brown mud
	30.0	58.5	dark greyish-brown mud
GC-4	0.0	11.5	brown-greenish mud
	11.5	?	Tephra (lost)
Grab S-1			volcanic rock fragments (tephra/ignimbrite?)
GC-5	0.0	30.0	brown organic-rich mud with scattered charcoals (dating)
	30.0	36.0	dark grey mud (Transition Holocene/Pleistocene?)
	36.0	54.0	light to medium grey mud with charcoals (dating)
GC-6	0.0	44.0	dark grey-brownish mud
	44.0	48.0	light grey mud/silt (Tephra?)
GC-7	0.0	29.0	light to medium grey-brownish mud with scattered charcoals (dating)
	29.0	50.0	dark brown mud
GC-8	0.0	3.0	shells
	3.0	46.0	medium grey-greenish mud with scattered shells
GC-9	0.0	18.5	black tephra (recent Concepcion eruption 2006?) mixed with brown mud
	18.5	39.0	brown-greenish mud
Grab S-2			black tephra material
GC-10	0.0	10.0	grey-brownish mud mixed with black tephra
	10.0	12.0	tephra?, charcoals, microfossils (dating)
	12.0	28.0	grey-brownish mud
	at	24.0	plant material, wood (dating)
	28.0	29.0	beige tephra?
	29.0	32.0	grey-brownish mud
Grab S-3			grey-brownish mud mixed with black tephra (see GC-10)
GC-11	0.0	55.0	grey-brownish mud (no obvious stratigraphy)
GC-12	0.0	17.0	brown mud mixed with black tephra
	17.0	31.0	grey-brownish mud
	31.0	61.0	medium grey mud

Core	Top (cm)	Bottom (cm)	Sediment description
GC-13	0.0	1.0	gastropodes and bivalves
	1.0	7.0	brownish mud mixed with black tephra
	7.0	18.0	medium grey mud mixed with sand sized tephra, plant material at top (dating)
	18.0	23.0	black tephra
	23.0	27.0	light grey-brownish mud
	27.0	28.0	black tephra
	28.0	30.0	light grey-brownish mud
	30.0	38.0	dark grey organic sediments mixed with black tephra
Grab S-X			volcanic rock fragments (no sampling)
GC-14	0.0	7.0	grey-brown mud
	7.0	15.0	greyish-brown mud with shells
	15.0	27.0	grey-brown mud with medium sized macrofossils (<5mm)
	27.0	32.0	brown-greyish mud
	32.0	33.0	light coloured laminated tephra
	33.0	48.0	brown-greyish mud
	48.0	49.0	black tephra
	48.0	51.0	large piece of wood (dating)
	49.0	56.0	brown-greyish mud
	56.0	58.0	black tephra
	58.0	67.0	brown-greyish mud
	67.0	68.0	possible tephra
	68.0	70.0	brown-greyish mud
GC-15	0.0	8.0	dark grey mud with shells
	8.0	50.0	medium grey mud
GC-16	0.0	46.0	grey-brownish mud (no obvious stratigraphy)
GC-17	0.0	5.0	thrown out because of mixing
	5.0	64.0	grey-brown-greenish mud (no obvious stratigraphy
GC-18	0.0	3.0	loss
	3.0	11.0	dark brown mud
	11.0	59.0	grey-brownish mud
GC-19	0.0	72.0	grey-brownish mud (no obvious stratigraphy)
GC-20	0.0	4.0	grey-brownish organic mud with snales
	4.0	72.0	medium grey mud
	at	65.0	organic matter (dating)
Grab S-4			black-brownish pyroclastic material mixed with snales

Core	Top (cm)	Bottom (cm)	Sediment description
GC-21	0.0	45.0	grey-brownish mud
GC-22	0.0	71.0	brown-greyish mud (no obvious stratigraphy)
GC-23	0.0	38.0	medium grey-brownish mud
	38.0	53.5	light grey-brownish mud
GC-24	0.0	8.0	dark grey-brownish mud, tephra at bottom
	8.0	21.0	brownish mud
	21.0	34.0	medium brown-greyish mud
	34.0	35.0	tephra
	35.0	42.0	light greyish mud
GC-25	0.0	28.0	medium grey-brownish mud
	28.0	49.0	light grey-brownish mud
GC-26	0.0	21.0	grey-brownish mud with gastropodes between 4 and 6 cm
	21.0	46.0	light grey-brownish mud
GC-27	0.0	52.0	grey-brownish mud (no obvious stratigraphy)
GC-28	0.0	100.0	grey-brownish mud (no obvious stratigraphy)
Grab S-5			grey-blue clay nodules with red-orange surface, hydrothermal activities?
GC-29	0.0	17.0	grey-brownish mud
	17.0	18.0	tephra?
	18.0	21.0	grey-blue clay
GC-30	0.0	65.0	grey-brownish mud (no obvious stratigraphy)
GC-31	0.0	71.5	grey-brownish mud (no obvious stratigraphy)
GC-32	0.0	67.0	grey-brownish mud (no obvious stratigraphy)
GC-33	0.0	39.0	light grey-brownish mud
	at	40.0	wood (dating)
	39.0	76.5	medium grey-brownish mud
GC-34	0.0	52.5	grey-brownish mud (no obvious stratigraphy)
GC-35	0.0	1.0	bivalves
	1.0	10.0	dark brownish sand
	10.0	24.5	brownish mud

Sample	Date	Time	Drive	Push depth top (cm)	Push depth base (cm)	Push length (cm)	Retrieval length (cm)	Water depth (cm)	Notes
Piston core #1									**WSW of Isla La Flor**
GC-5	5/26/2006	3pm - 6.30pm					54	760	medium windy, wavy water surface
LC-1-1			1	760	850	90	79		top 16cm removed, basal 3cm sub-sampled
LC-1-2			2	842	942	100	97		
LC-1-3			3	930	1030	100	99		
LC-1-4			4	1016	1116	100	100		
LC-1-5			5	1110	1175	65	53		
LC-1-6			6	1170	1195	25	25		change in sediments (brown -> grey-blue)
Total length							435		
Piston core #2									**River delta SW of Solentiname**
GC-21	5/29/2006	3pm - 5pm					45	500	medium windy
LC-2-1			1	550	650	100	98		5cm gap between GC-21 and LC-2-1
LC-2-2			2	650	750	100	106		
Total length							250		

Sample	Date	Time	Drive	Push depth top (cm)	Push depth base (cm)	Push length (cm)	Retrieval length (cm)	Water depth (cm)	Notes
Piston core #3									**SE of Mancarron Island (Solentiname)**
GC-23	5/30/2006	9.30am - 2pm					53.5	430	calm water, more windy after noon
LC-3-2			2	530	630	100	96		
LC-3-3			3	620	720	100	100		bottom 5cm tephra
LC-3-4			4	710	810	100	100		top 10cm tephra
LC-3-5			5	800	847	47	47		835 cm: change in sediments (brown -> grey-blue)
LC-3-6			6	830	870	40	39		856 cm: change in sediments (see LC-3-5)
LC-3-7			7	870	890	20	20.5		cable broken
LC-3-8			8	890	913	23	23		basal 1m in sampling bag
			9	920					piston corer lost
Total length							496.5		

Sample	Date	Time	Drive	Push depth top (cm)	Push depth base (cm)	Push length (cm)	Retrieval length (cm)	Water depth (cm)	Notes
Piston core #4									**W of Zapatera Island**
GC-34	1/6/2006	2.22pm - 5pm					52.5	340	calm water
LC-4-1			1	360	460	100	106	340	
LC-4-2			2	450	550	100	113		
LC-4-3			3	540	640	100	102		609cm: change dark brown to medium brown
LC-4-4			4	630	695	65	65		657cm: tephra
LC-4-5			5	690	730	40	36		689-690cm datable organic matter
LC-4-6			6	720	750	40	28		
LC-4-7			7	750	780	30	27		
Total length							440		
Piston core #5									**River delta NE of Granada**
GC-35	2/6/2006	12am - 5pm					24.5	330	slightly windy
LC-5-1			1	400	495	95	93	390	
LC-5-2			2	490	541	51	51		
LC-5-3			3	540	590	50	38		
LC-5-4			4	580	625	45	40		
LC-5-5			5	620	670	50	43		
LC-5-6			6	660	700	40	31		
LC-5-7			7	690	730	40	37.5		
LC-5-8			8	725	770	45	36		
LC-5-9			9	760	805	45	39		cable broken, loss of hammering rod
Total length							415		