Geoscientists Without Borders® Program

The Haiti Subsurface Imaging Project – Final Report

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Title: The Haiti Subsurface Imaging (HASI) Project: Helping build Haiti’s geoscience capability and searching for the 2010 earthquake fault

Project Location: Léogâne, Haiti

Lead Organization: University of Houston

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The Haiti Subsurface Imaging (HASI) Project:  
*Helping build Haiti’s geoscience capability and searching for the 2010 earthquake fault*

**OVERVIEW**

On January 12, 2010 Haiti suffered a major earthquake with subsequent and tragic human and infrastructural loss. Surface expression of the earthquake fault has not yet been unambiguously found. Thus, key geologic components of the devastating event are not well resolved. The Haiti Subsurface Imaging (HASI) Project aspires to find expression of this “blind” fault. In doing so, we are attempting to help with the building of geophysical capability and personnel development in Haiti.

This final report documents progress made on the HASI Project over the years 2012-2015 with the generous support of the Geoscientists Without Borders (GWB) program and SEG Foundation. As proposed in our 2011 submission to the GWB Program, a University of Houston (UH) team undertook an unfunded reconnaissance visit to Haiti in January, 2012 (Phase 1). Our team - Drs. Robert Stewart and Paul Mann, plus UH graduate students, Nathan Babcock and Li Chang - was able to coordinate our visit with a United Nations-sponsored Haiti Earthquake Memorial Conference in Port-au-Prince on January 12, 2012, exactly two years after the devastating 2010 earthquake. We met with a number of geoscience counterparts in the USGS, Haitian Bureau of Mines and Energy (BME), and other geosciences institutes. We then undertook a reconnoitering trip to the Léogâne Delta to find appropriate surveying sites near the earthquake epicentral area. We were accompanied and aided by Haitian colleagues from the BME, local professionals, and villagers at the survey site. We subsequently conducted geophysical (GPS, total station, gravity, and seismic) surveys in the Delta area. We established a solid working relationship with Haitian personnel. The geophysical data acquired were of good quality and the area was promising for further investigation.

Based upon these reconnaissance surveys, we returned to Haiti in February, 2013 (Phase 2). Global Geophysical of Houston kindly lent us 100 seismic station nodes for this effort. The US team included Drs. Stewart and Mann, UH staff members Li Chang and Anoop William, along with UH Ph.D. student, Eray Kocel. We encountered a number of logistical challenges in Haiti, but after several days were able to assemble our equipment, team, and transportation. We were joined by our Haitian colleagues from the BME. We next undertook GPS and gravity surveys near Port-au-Prince, then ten days of seismic, GPS, and gravity surveys in the Léogâne Delta. We were able to employ some 20 local villagers and provide instruction to them about seismic surveys, instruments, and deployment. We also encountered several aid groups in the Léogâne area and have offered them all of our survey information to assist with their development efforts. As a result of the
surveys, we have found some fascinating evidence of surface faulting. We have prepared and presented a number of abstracts, posters, and videos from this work.

Further east along the main Enriquillo-Plantain Garden Fault zone, lies Lake Enriquillo. Drs. Paul Mann and Matt Hornbach returned to Hispaniola in May, 2013 to undertake sonar measurements on the Lake. Their surveys produced a number of transects that provide exciting details of the main faults. With the usefulness and efficiency of lake surveys established, Dr. Mann and UH graduate student, Jiannan Wang returned to Haiti in July, 2014. They undertook a number of other sonar transects.

These four reconnoitering surveys have delivered excellent results relevant to our quest to image the subsurface in search for evidence of the 2010 earthquake. We anticipated that the top of the blind fault could be some several kilometers deep. While our shallow, short seismic lines show some evidence of faulting, the image is not clear and the discontinuities are not necessarily part of a larger fault system required to create the 2010 earthquake. Thus, as originally thought, a deeper imaging survey is required. This necessitates a larger seismic source (vibrating truck or heavier weight drop). We recommend a return to Haiti with this heavier seismic source. This type of survey would be much more expensive – in the neighborhood of $100,000. As part of Eray Kocel’s UH Ph.D. thesis (2015), we designed a survey to accomplish these deeper imaging goals. We hope that a follow-on project or further team can undertake this work and relationship with our Haitian counterparts.

Geophysics has provided an excellent pathway for understanding Haiti’s geology and hazards, helping build technical capacity, further assisting in the development of Haitian personnel, and providing an intensely useful experience for an international group of students. The HASI Project has contributed a considerable body of work to help understand Haiti’s geology. And critically, the project has provided substantial technical and financial benefit to a full group of Haitians.
INTRODUCTION

The January 12, 2010 Haiti earthquake (Figure 1) caused enormous human loss and widespread destruction of buildings and infrastructure.

Figure 1. Map of the Haiti region with annotated epicenter of the January 12th, 2010 magnitude 7 Haiti earthquake (from the USGS Earthquakes website).

Haiti is still attempting to recover from that catastrophic event as seen in photos from our 2012 reconnaissance visit to Haiti (Figure 2).

Figure 2. The Haiti Presidential Palace (left) on January 14, 2012. The grounds have been cleaned, but the building is largely destroyed. Clean-up continues in Port-au-Prince (right). R. Stewart photos.

While much has been accomplished in humanitarian terms and technical understanding of the earthquake, there is much, much more to be done. The earthquake, itself, is somewhat of a mystery as it did not appear to rupture along the main Enriquillo-Plantain Garden Fault (Figure 3). As the
hypocentral rupture has no clear surface expression, it has been called a “blind fault”. Finding and imaging this fault would greatly assist in understanding Haitian tectonics as well as others like it worldwide. We are thus highly motivated to assist with the rebuilding and further development of Haiti’s technical capacity and personnel as well as understanding the nature of the fault system.

![Image showing the Leogane Delta and our geophysical survey lines.](image)

*Figure 3. Google image of the Leogane Delta (left) and our geophysical survey lines (right).*

Our objectives in the preliminary 2102 expedition were to:

1) establish contact and a working relationship with personnel at the Haitian Bureau of Mines, UN, National University of Haiti, local villages, and expediting groups;
2) scout the Léogâne Delta Fan (2010 Haitian earthquake epicentral) region for evidence of surface rupture and determine logistics for geophysical surveys;
3) undertake geophysical tests using shallow seismic and gravity techniques.

We chronicle the results of this expedition below.

**RECONNOITER - JANUARY, 2012**

We organized the Haiti reconnaissance mission over the period of September, 2011 to January, 2012. Armed with inoculations and geophysical equipment, we (Drs. Paul Mann, Rob Stewart and UH graduate students, Nathan Babcock – Figure 4 - and Li Chang) departed from Houston to Port-au-Prince via Fort Lauderdale. Due to time constraints, we flew all of our equipment with us as excess baggage. Fortunately, it did all arrive intact. We were able to import the equipment with minimal delay in Haiti due to sponsoring support and documentation from Dr. Dieuseul Anglade, General Director of the BME. On January 12, 2012, there was a 2010 Earthquake Memorial Conference in Port-au-Prince and major overview of the earthquake. Due to time constraints, we flew all of our equipment with us as excess baggage. Fortunately, it did all arrive intact. We were able to import the equipment with minimal delay in Haiti due to sponsoring support and documentation from Dr. Dieuseul Anglade, General Director of the BME. On January 12, 2012, there was a 2010 Earthquake Memorial Conference in Port-au-Prince and major overview of the earthquake. We were introduced to many of the individuals and organizations (USGS, UN, BME, NUH) who are involved in ongoing efforts to understand the earthquake and mitigate the effects of future events. Drs. Paul Mann and Rob Stewart made presentations at the Memorial Conference. We are currently corresponding with Dr. Carol Prentice of the USGS and Dr. Eric Calais of Purdue University who are involved in Haitian
tectonic studies. We also began coordinating with a major proposed French-Spanish marine cruise to be conducted off shore Haiti (currently delayed).

Figure 4. Geophysical team (Paul Mann, left; Nathan Babcock, center; and Rob Stewart, right) in Port-au-Prince, Haiti preparing to scout the epicentral area.

With the expert assistance of Haitian colleagues Alexander von Lignau and Savannah Savary, we established a working base near the Léogâne epicenter area. We spoke with the local villagers who have much of the Delta Fan area under cultivation and received permission to survey on their lands. We settled on a field (cattle grazing area) that was just onshore of a major offshore uplift (Figure 5) – thought to be located very close to the subsurface fault.

We first undertook total station surveys (with a Leica 60 laser theodolite) to give very precise relative locations. We also used a Trimble GPS system for absolute, but lower accuracy, locations. These surveys were of intense interest to local villagers as were subsequent seismic surveys (Figure 5). We employed some 20 local workers to help with equipment deployment and surveying. We conducted two gravity surveys (on the nearby beach with its post-earthquake uplift and in the grazing field) with the Scintrex CG-5 gravimeter. Most of our effort was spent with the hammer seismic source and Geometrics seismic recording units (60-channel Stratavisor plus a 24-channel Geode). One of the shot gathers from the hammer source is shown in Figure 6. There is evidence of refracting and reflecting data measured across the full spread.
A major portion of this project is dedicated to capacity building in Haiti as well as student engagement and education. Students at the University of Houston have processed these Haiti data and the seismic data are available online. Preliminary results are shown in Figures 7 and 8. We were very pleased that even with the relatively low energy hammer source, we can still see to about 400 m depth in the subsurface. There is even some indication of near-surface faulting at CMP 150. We are continuing to analyse and interpret these data. An accelerated weight drop source could perhaps image reflectors at 1000 m depth. Our mini-vibe (controlled vibratory truck) may well be able to image reflectors much deeper - at several kilometers depth. We were very excited that this Delta Fan is a good seismic data area.
Figure 7. Velocity analysis and NMO correction on CMP hammer seismic gather (left). Velocities range from 1200 – 2300 m/s. Stacking velocity section (right).

Figure 8. Brute stack section converted to depth. Note that there is evidence of reflections from about 400 m depth using the hammer seismic source.

We also undertook gravity surveys (Figure 9). Our hope with this method is to find some signature of discontinuous or displaced sediments across the blind fault. We made two traverses which both show a consistent response. We are currently modeling and interpreting these data.

Hazards working in Haiti include security, traffic, and illness. We are pleased to report that we concluded the geophysical operations and reconnoiter without injury or major incident. Several vehicles did suffer bumps and scrapes – which we settled with the rental agency. One team member had a mild internal plumbing episode which was assessed in Houston and passed in several days. We encountered no security nor theft problems.
SURVEYS - FEBRUARY and MAY 2013

In our second expedition to Haiti, we had considerably more equipment. This included numerous cases, of the generously loaned GSR seismic recording nodes from Global Geophysical. We were delayed in Port-au-Prince (PaP) for several days awaiting delivery and clearance of some of our equipment. We did make use of our wait time by undertaking gravity and GPS surveys in the PaP area (Figure 10).

Once again, there were reasonable concerns about health (especially cholera – see Figure 11) and safety, but we did not encounter any problems.
Figure 11. Alertness to health (Kolera toujou la – Cholera is still there) and security matters are important, but fortunately we encountered no problems.

After receiving all of our equipment and organizing vehicles and lodging, we departed for the Léogâne Delta. We met with our BME colleagues and hired over 20 local helpers to assist with equipment deployment (Figure 12).

Figure 12. We were able to employ several dozen local Haitian helpers in laying out the seismic lines and equipment near Léogâne under the diligent supervision of our Haitian Bureau of Mines and Energy colleagues.

We used two very different seismic recording systems: the autonomous nodes (GSRs generously loaned to us by Global Geophysical, Houston) and our Geometrics Geode cabled recorders. In addition, we had two sources: the GISCO slanted weight drop to excite both P and S waves as well as the Propelled Energy Generator (Figure 13).
Figure 13. We used two different seismic sources in the 2013 surveys: A GISCO slanted weight drop (left) and a PEG accelerated weight drop (right).

As with our previous surveys in 2012, there was a great deal of local interest in the effort. We were also able, especially with our Haitian colleagues, to provide ongoing educational discussions with villagers (Figure 14).

Figure 14. There are always many educational opportunities for discussion with the local villagers.

Drs. Paul Mann and Matt Hoenbach returned to Hispaniola (Figure 15) in May, 2013 to undertake test sonar surveys on Lake Enriquillo. This Lake has seen dramatic fluctuations in water level that are both scientifically puzzling and economically and socially hazardous.
Figure 15. Maps of Hispaniola and the sites of our 2012 and 2013 geophysical surveying work. We undertook the first geophysical lake surveys on Lake Enriquillo in May, 2013.

The early sonar images (Figure 16) show some fascinating details of the Lake’s subsurface – especially as it is on the main Eriquillo Plantain Garden Fault Zone.

Figure 16. Sonar results from the May 2013 Lake Enriquillo surveys.
JULY 2014 SURVEYS

On account of the successful sonar tests in May, 2013, we decided to return and undertake further surveys and imaging. In July 2014, we returned to Haiti and obtained a total of 94 km of high-resolution chirp profiles from the 129 km², brackish Lake Azuey (Box A in Figure 17) and 37 km of profiles from the 14 km², fresh water Lake Mirogoane (Box B in Figure 17) that both straddle the active trace of the Enriquillo-Plantain Garden fault zone (EPGFZ) of Haiti.

![Shake map of 2010 M7.0 Haiti earthquake.](image)

Figure 17: Shake map of 2010 M7.0 Haiti earthquake. The data is from USGS. Box A: Lake Azuey survey area. Box B: Lake Mirogoane survey area.

We used our University of Houston EdgeTech 216 chirp sonar to acquire acoustic high-resolution profile (Figure 18). The chirp sonar has one source, which sends out an acoustic sweep from 2 kHz to 10 kHz, and two receiver arrays (Figure 19).
Figure 18: EdgeTech chirp sonar. The sonar is towed under the water surface and is powered by an on-board electrical generator.

Figure 19: Source and receiver arrays on the underside of the EdgeTech 216 chirp sonar.

The signal received by the receiver arrays are stacked together to enhance S/N. A schematic diagram of chirp survey setting is shown in Figure 20. Because the distance between source and receiver arrays is very short comparing to the water depth, so the geometry setting can be considered as zero-offset (Figure 20).

Figure 20: Schematic diagram of the chirp sonar survey setup.
This sonar project was led in the field by Dr. Paul Mann. Jiannan Wang, a PhD student at UH, ran the sonar equipment and is using the data so acquired in his Ph.D. dissertation (to be completed in the Spring of 2016). During the survey, we received assistance from our local advisor: Alexander von Lignau. We also received financial assistance from Oxfam Italia (led by Alfredo Lo Cicero). The Haiti Bureau of Mines and Energy and Haiti Ministry of Economy and Finance provided assistance as well.

The chirp sonar was towed by a Boston Whaler boat (width: 1.8 m, length: 2.9 m) as shown in the photo in Figure 21. The average speed of the boat was 4 knots. A generator was carried onboard to power all the equipment: chirp sonar, processor, GPS, and the field computer. Navigation GPS was Lowrance Elite 5 and powered by 12 V battery.

![Figure 21: The boat (Boston Whaler) used for lake survey was towed to shore by a pick-up truck](image)

By using the reflected travel time of the acoustic wave in the water column, we generate the bathymetric map of the two lakes. Figure 22 shows the bathymetric map and structure map of the Lake Azuey area. The surrounding grey map is the Digital Elevation Map (DEM). The green lines in the map are the survey lines. The sub-bottom profiles reveal the near-surface structure beneath the lake bottom. Figure 23 shows one of the profile as example (from Line A4 in Figure 22). The EPGFZ locates at the south part of Lake Azuey and is buried about 0.7 m depth. A fold structure and several thrust faults can be seen clearly from this profile. We are currently preparing a paper to be submitted for publication in the SEG-AAPG Interpretation Journal.
Figure 22: Bathymetric and structure map of Lake Azuey. The green lines are survey lines.

Figure 23: Sub-bottom profile of Line A4.
The basic flow of our original proposed field work is outlined in Figure 24. We envisioned two field trips to Haiti given the original budget with three planning and reporting stages.

Figure 24. Original analysis and reporting timelines of HASI project (2012-2014).

We are very pleased to have finished the three Phases of effort and actually undertaken four field expeditions to Haiti including another set of lake surveys in July 2014 (Figure 25).

Figure 25. Timeline of field efforts from January, 2012 through July, 2014.

HASI Project contributions: Presentations and publications

As noted above, it has been very satisfying and productive to have undertaken and completed four expeditions to Haiti under the auspices of this Geoscientists Without Borders Project. We worked with many Haitian people and established numerous solid working relationships. All of the Haiti work was accomplished without injury or major illness. To continue analysis of the Project’s data and to prepare presentations, we received a no-cost extension of the project until Summer 2015.

A summary of the abstracts, posters, and presentations based on the HASI Project to date is provided in Table 1. In addition, there is considerable geophysical data available on the site plus photos and references.
<table>
<thead>
<tr>
<th>Type</th>
<th>Topic</th>
<th>Venue</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publication (in review)</td>
<td>Geophysical investigation of the 2010 Haiti epicentral region.</td>
<td>Interpretation (SEG-AAPG) 2015</td>
<td>Eray Kocel, Robert R. Stewart, Paul Mann, and Jiannan Wang</td>
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<tr>
<td>Expanded Abstract</td>
<td>Integrated geophysical investigation of the 2010 Haiti earthquake.</td>
<td>85th SEG Annual Meeting (2015), New Orleans, Louisiana, USA.</td>
<td>Eray Kocel, Robert R. Stewart, Paul Mann, Jiannan Wang, and Li Chang</td>
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<tr>
<td>Invited Luncheon Talk</td>
<td>People and Program of the Geoscientists Without Borders Haiti Subsurface Imaging Project</td>
<td>SAGEEP 2015 Conference, Austin, Texas, USA.</td>
<td>Robert R. Stewart</td>
</tr>
<tr>
<td>Abstract and presentation</td>
<td>Definition and Paleoseismology of the Active, Left-Lateral Enriquillo-Plantain Garden Fault Zone Based on High-Resolution Chirp Profiles: Lakes Azuey and Mirogoane, Haiti.</td>
<td>AGU 47th Annual Fall Meeting, San Francisco, USA, Poster Presentation</td>
<td>Jiannan Wang, Paul Mann, and Alexander von Lignau</td>
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Table 1. Summary of abstracts, posters, and presentations resulting from the HASI Project.

**Recommendations**

The HASI Project has established many fundamental geophysical properties in the epicentral and neighboring regions of Haiti. We have developed good logistical operating procedures and created the positive bases for further investigations. However, there remains much more to do geophysically in the country and especially as regards better understanding Haiti’s earthquake mechanisms and future hazards.

We recommend another investigative program (for a future project) that would include:

1) A land surveying component again in the Léogâne Delta with a larger seismic source (vertical vibrator or accelerated weight drop) - and a Haitian and student crew - that would be able to image down 4 km.

2) Sonar and marine seismic (Boomer) transects close to the western coast of the Léogâne Delta to search for ocean-bottom deformations and evidence of the Fault.
In addition, we suggest:

3) Further development of working relationships with Haiti personnel at the Bureau, National University, and other aid agencies
4) Assistance with University geophysical programs in Haiti.
5) Procurement of geophysical equipment for the Haiti programs.
6) Development and support of additional Haitian graduate students.

SUMMARY

A geophysical team from the University of Houston undertook a reconnaissance expedition to Haiti on January 10-17, 2012. We were able to participate in the Haiti Earthquake Memorial Conference in Port-au-Prince on the second anniversary of the 2010 event. We met there with a number of members of Haitian and international aid and geosciences organizations. We established a good working relationship with members of the Bureau of Mines and Energy as well as a number of local logistics experts. We reconnoitered the epicentral region of the 2010 earthquake and selected a site on the Léogâne Delta Fan for our surveys. We undertook detailed total station, GPS, gravity, and seismic surveys in the Fan area. There was a productive and pleasant interaction with local villagers in receiving access to survey areas and assistance with operations. The quality of the 2012 data provided promise for more detailed surveys that we undertook in February 2013. Again, we had excellent relations with our Haitian colleagues and local people. Good GPS, gravity, and seismic data were acquired. There is some evidence of faulting in the seismic sections from the Léogâne area. Another mission in May, 2013 to the puzzling and hazardous Lake Enriquillo produced compelling sonar images illuminating the the major faults zone. To further develop Haitian geophysical capabilities and create more detailed sections across fault zones underlying lakes, we returned to Haiti in July, 2014. The lake data have helped illuminate and sharpen the understanding of the mechanisms of the faults.

With Haitian partners, we have been able to undertake productive surveys in key hazardous areas of Haiti. We have developed a better understanding the Haitian subsurface and assisted in advancing Haiti’s technical capabilities. We are greatly appreciative of the Geoscientists Without Borders support of this effort!
THANK YOU