Searching for the 2010 Haiti earthquake fault

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ABSTRACT

On January 12, 2010 Haiti suffered a major earthquake with subsequent tragic human and infrastructural loss. Surface expression of the earthquake fault has not yet been unambiguously identified. Thus, key geologic components of the devastating event are not well resolved. The Haiti Subsurface Imaging (HASI) Project, supported by the SEG Foundation, aspires to find expression of this "blind" fault. We have made two geophysical reconnaissance surveys to Haiti: Undertaking GPS and gravity surveys near Port-au-Prince, and ten days of seismic, GPS, and gravity surveys in the Léogâne Delta region (close to the earthquake's epicenter). These surveys have provided near-surface rock properties as well as some evidence of faulting. Further east along the main Enriquillo-Plantain Garden Fault zone, lies Lake Enriquillo. We have conducted sonar surveys on the Lake which have produced some exciting details of the main faults. We anticipate that the top of the proposed 2010 blind fault could be some several kilometers deep. While our shallow, short seismic lines show some evidence of disruption, the image is not clear and the discontinuities are not necessarily part of a larger fault system required to create the 2010 earthquake. Thus, we must return and image deeper in the section with a larger source (in March, 2014).

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 paper documents progress made on the HASI Project over Year 1 (2012-2013) with the generous support of the Geoscientists Without Borders (GWB) program and SEG Foundation. 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 next 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

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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 reconnaisance 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.

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.

These three 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 proposed, we must return and image deeper in the section (Phase 3). This requires a larger seismic source (vibrating truck or heavier weight drop). We plan to return to Haiti in the winter of 2014 and ship a larger seismic source to Haiti. In addition, we will have acquired significantly more lake surveying capability with new side-scan sonar, boomer, and chirp systems. We will deploy and use these instruments in Haiti.

Geophysics is providing 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. For the 2014 (third) stage of this Haiti Project, we anticipate significant development advances and geologic insight.

INTRODUCTION

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

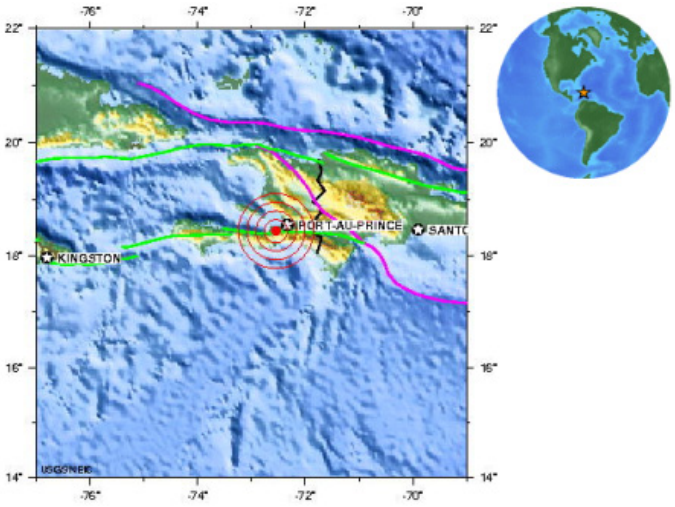

FIG. 1. Map of the Haiti region with annotated epicenter of the January 12th, 2010 magnitude 7 Haiti earthquake (from the USGS Earthquakes website).

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

FIG. 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.

FIG. 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 logisitics 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 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. 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 in 2013 (currently delayed).

FIG. 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 3) – 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.

FIG. 5. Setting up the total station surveying instrument (left) on with on-looking local villagers. Undertaking a reconnaissance seismic survey on the Delta (right).

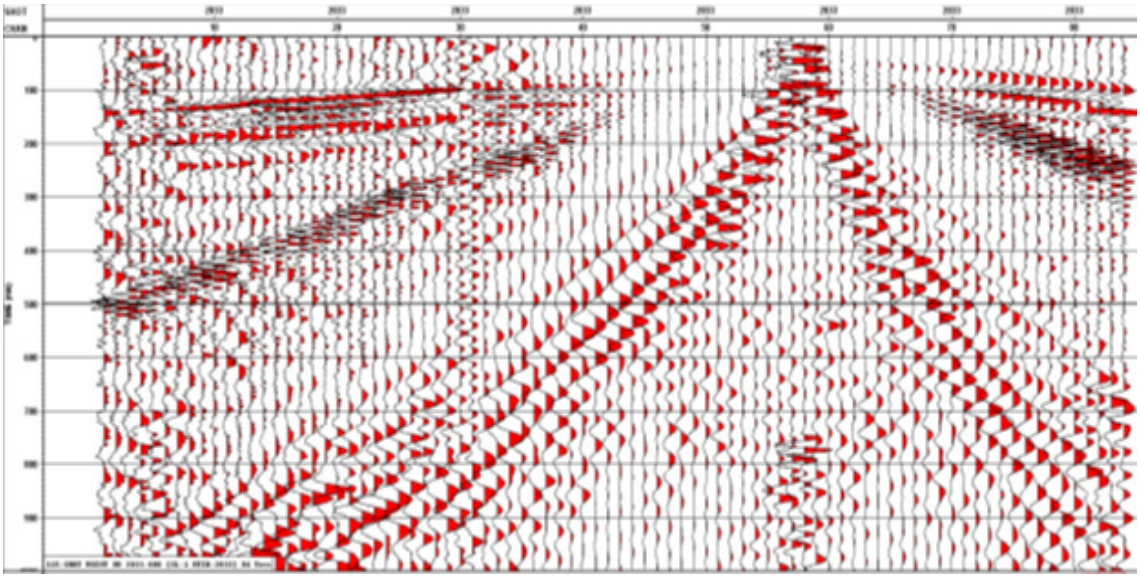

FIG. 6. Raw shot gather from hammer source recorded into 84 vertical channels.

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 are very excited that this Delta Fan looks to be a very good seismic data area. This gives hope that we may be able to image some of the earthquake fault zone.

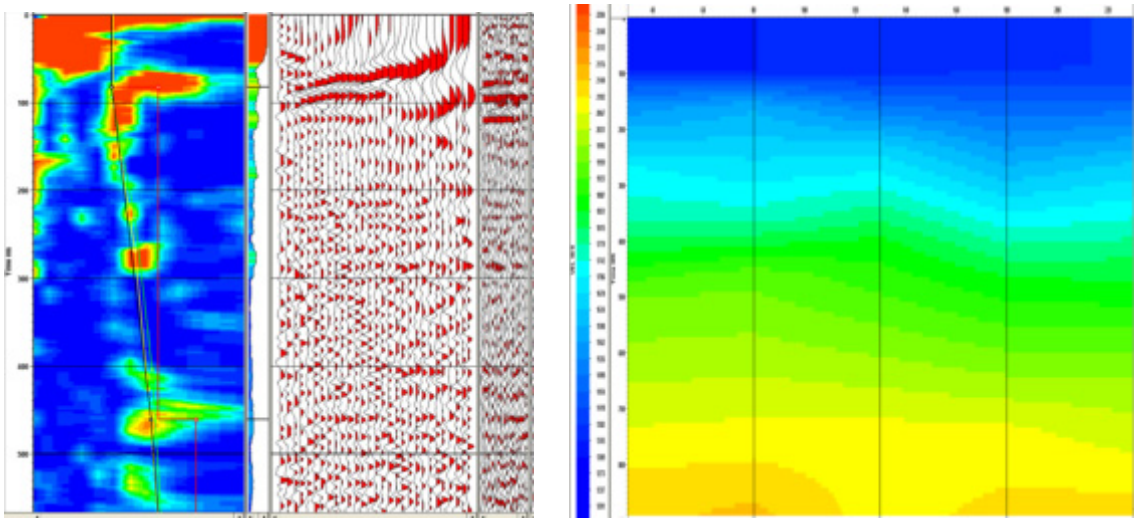

FIG. 7. Velocity analysis and NMO correction on CMP hammer seismic gather (left). Velocities range from 1200 – 2300 m/s. Stacking velocity section (right).

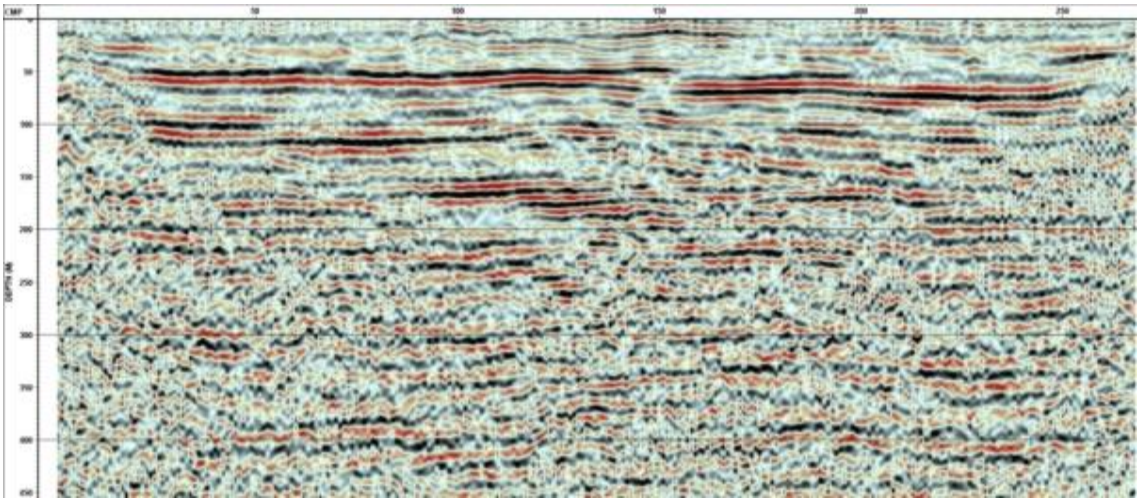

FIG. 8. Brute stack section converted to depth. Note that there is evidence of reflections from about 400 m depth using the hammer seismic source.

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.

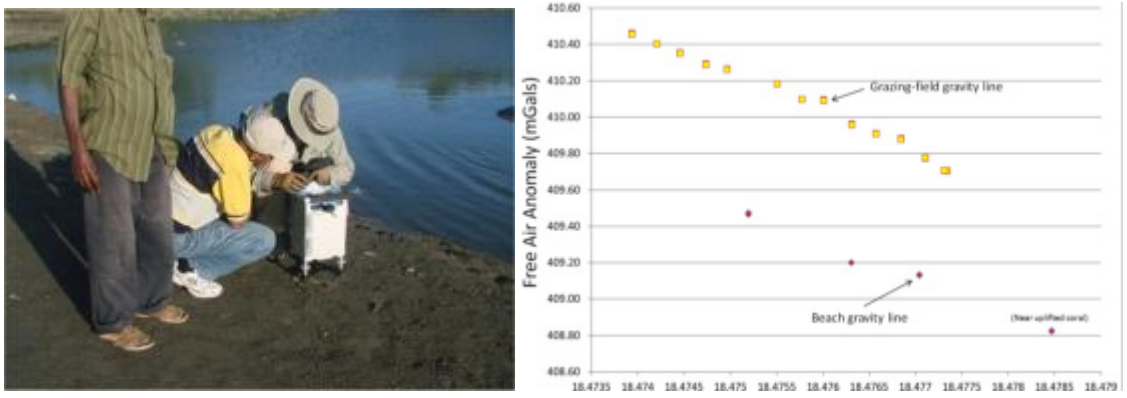

FIG. 9. Photo of the team making gravity measurements on the beach line (left). Free-air anomaly gravity results from our two traverses.

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).

FIG. 10. UH-Haiti team conducting a GPS survey above Port-au-Prince, Haiti in February, 2013.

Once again, there were reasonable concerns about health (especially cholera – see Figure 11) and safety, but we did not encounter any problems.

FIG. 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).

FIG. 12. We were able to employ several dozen local Haitian helpers in laying out the seismic lines and equipment near Léogâne under the diligent supervison 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).

FIG. 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).

Results of the 2013 work are provided in the attached presentations and on the website: sheriff.agl.uh.edu/secure/SecureAGL/Haiti2013Report/.

Drs. Paul Mann and Matt Hoenbach returned to Hispaniola (Figure 15) in May, 2013 to undertake sonar surveys on Lake Enriquillo. This Lake has seen dramatic fluctuations in water level that are both scientifically puzzling and economically and socially hazardous.

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

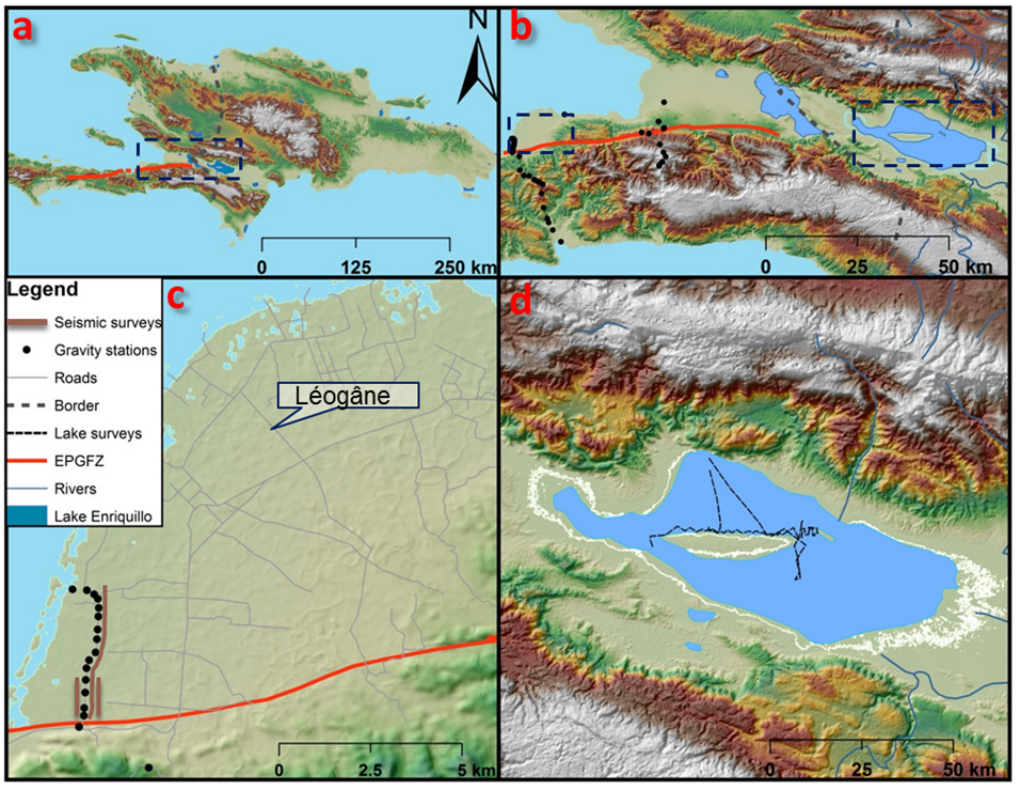

FIG. 15. Maps of Hispaniola and the sites of our 2012 and 2013 geophysical surveying work. We undertook the first geophysical lake surveys on Lake Enriquillo in May, 2013.

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

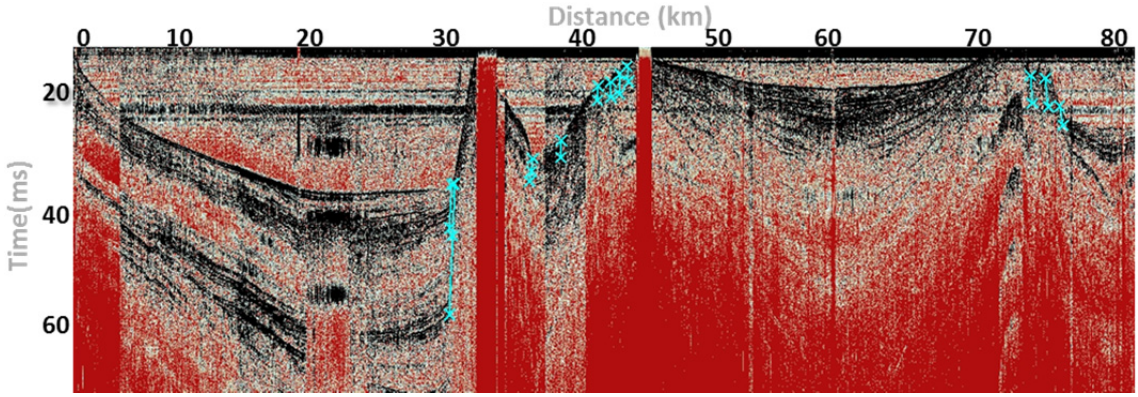

Figure 16. Sonar results from the May 2013 Lake Enriquillo surveys.

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 1. Summary of abstracts, posters, and presentations resulting from the HASI Project. All communications as well as data, references, and photos are contained at website: sheriff.agl.uh.edu/secure/SecureAGL/Haiti2013Report/.

Type	Topic	Venue	Author
Abstract	**Haiti subsurface imaging project: Seismic and gravity results**	**SEG Annual Meeting 2013**	**Kocel, E., R. Stewart, P. Mann, L. Chang, S. Roy, C. Hyslop**
Abstract	**Searching for the blind fault: Haiti subsurface imaging project**	**AGU Annual Meeting 2012**	**Kocel, E., R. R. Stewart, P. Mann, N. Dowla**
Poster	**Searching for the blind fault: Haiti subsurface imaging project**	**SEG/AAPG Expo 2013**	**Kocel, E., R. Stewart, P. Mann**
Poster	**Shallow seismic profiling of onland Leogane fan-delta, Haiti, for imaging fan stratigraphy**	**AGU Annual Meeting 2012**	**Dowla, N., P. Mann, R. Stewart, L. Chang**
Presentation	**Searching for the blind fault: Haiti subsurface imaging project**	**SEG Annual Meeting 2013**	**Kocel, E., R. Stewart, P. Mann, L. Chang, S. Roy, C. Hyslop**
Geophysical data	**Haiti 2012**	**Haiti 2012 Data**	
Geophysical data	**Haiti 2013**	**Haiti 2013 Data**	
Photos	**Photos**	**Haiti photos**	
Reference List	**Reference list**	**Reference List**	

PROJECT PLAN 2012 - 2014

The flow of our original proposed field work is outlined in Figure 17. We have finished the Phase 1 and Phase 2 efforts. After conducting test lines in the Léogâne Fan area, we thought that it might be better to use wireless instead of cabled systems. This is on account of numerous villages, streams, roads, and ditches which criss-cross the area of interest. We were thus thrilled to have Global Geophysics, Houston, provided us with 100 GSR seismic receiver nodes for the 2013 surveys.

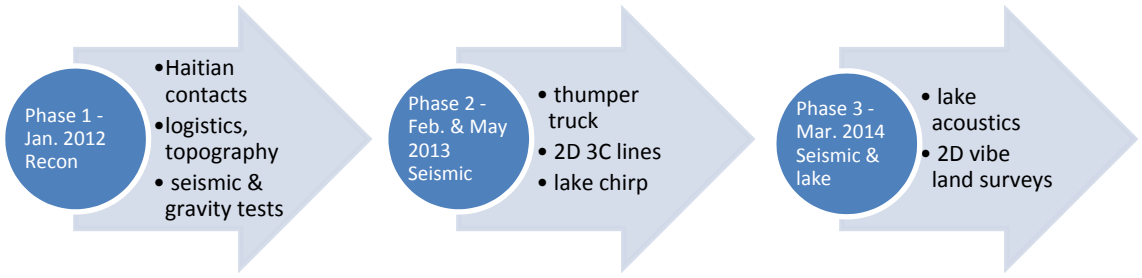

FIG. 17. Timeline of field efforts from January, 2012 through January, 2014.

We originally proposed a timeline as shown in Figure 18. We are on track for the Phase 3 (2014) part of the Project.

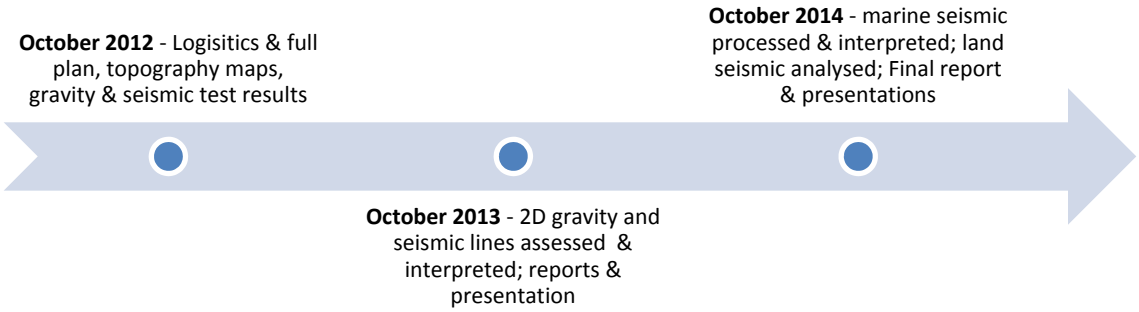

FIG. 18. Original analysis and reporting timelines of HASI project (2012-2014).

PROPOSED WORK - MARCH 2014

The prime technical goal of the HASI Project is to discover evidence of the "blind" fault that gave rise to the 2010 earthquake. To do this, we need more detailed and deeper seismic lines (thus more receivers, longer lines, and a more deeply penetrating source). Thus, we are planning to ship our vibroseis truck to Haiti to undertake the final Phase of this Project. We are organizing this Phase of the work for March 10-22, 2014. We intend to take some 200 node receivers, along with our seismic sources, to survey a grid of 2D seismic lines in the Leogane area. In addition, we propose to undertake further lake surveys with chirp, side-scan, and boomer systems. We are in discussion with the aid organization, Living Waters International, who drill water wells in developing regions. We are hoping that we can coordinate activities for the selection of several water well sites that would be useful to the local populace plus provide us with ground truth. We are also in discussion with OXFAM (Italy) to support our efforts. We hope to expand our

2014 effort with associates Drs. Matt Hornback (SMU – Dallas), Will Sager (UH), and Don Lawton (Calgary). We are in contact with two other NSF agencies that may be able to participate in the 2014 expedition: the Seismic Consortium, IRIS – to lend seismic recording instruments and the earthquake source network, NEES – to supply another vibrating truck.

Our budget includes expenditures for our Haitian colleagues ($3k), Haitian logistics coordinators ($4k), and local helpers ($3k). We will have a UH/SMU/UC team of four faculty, three students, and three UH staff ($6k). These ten team members will incur transportation ($10k) and lodging (two weeks at $14k) expenses. We will be return shipping a container of equipment, including our vibe truck, to Haiti via surface vessel ($12k). There are equipment rental (accelerated weight drop source from United Service Alliance @ $3k; Stratavisor from Geometrics @ $4k) and instrument purchase costs ($5k). We will three rent trucks in Haiti ($6k including fuel). There are numerous bonding, insurance, and other administrative costs ($3k). The Project cost is thus $73,000. for the second year of the Project. The SEG Foundation previously and generously awarded the Project a total of $49.5k for Year 2 upon receipt of acceptable Year 1 reports and final Year 2 reports.

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 majoe faults zone. To further develop Haitian geophysical capabilities and create more detailed and deeper seismic sections, we plan to return to Haiti in March, 2014. With Haitian help, we hope to illuminate the blind fault, better understand the Haitian subsurface, and assist in advancing Haiti's technical capabilities.