Haïti - Integrated Evaluation of Earthquake Dynamics from the Past to the Future*

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Summary

A better understanding of the tectonic context of transpressive boundaries is a critical issue for earthquake prediction. Therefore, we need to study the 3D geometry and geodynamic evolution of some of the few active restraining bends identified as potentially seismogenic. One of the areas for those studies is the Haïti region, both in the Southern part (Port-au-Prince area), where the M=7.2 January 12, 2010 earthquake occurred and the Northern part (Cap-Haïtien area), where even more intense earthquakes can be predicted. Several approaches are presently in process for evaluating the dynamics of the deformation from the past to the future along the Southern fault system, such as field studies along the active and satellite faults, as well as bathymetric and offshore seismic acquisition. The final objective is to identify the active or locked segments along the main faults.

Introduction

Surprisingly, the analysis of geophysical data from the 12 January 2010 Haïti earthquake (M=7.2) shows that the last seismic event was not initiated by the rupture of a segment of the Enriquillo-Plantain Garden Fault Zone (EPGFZ), as previously published and widely accepted in the scientific community. Rather it was the large vertical movement observed north of the surface trace of the EPGFZ and the intense ground shaking initiated by the rupture of the unknown deep-rooted Léogâne Fault, developed in the tectonic context of a restraining bend linked to the very oblique collision between the thickened Caribbean oceanic crust (Figure 1), outcropping along the Southern Peninsula of Haïti and the composite continental/island-arc block of Hispaniola.

In the regional context of Haïti, the restraining-bend pattern is distributed both onshore and offshore. This is important and allows for combining on-land and marine observation techniques, thus integrating different scales and resolutions, in order finally to describe the 3D geometry of the transpressive zone and its recent evolution as a pre-requisite for sound geophysical modelling.

Regional Context

Two mega-strike-slip fault systems accommodated the Caribbean plate ”escape“to the East, with the development of a transpressive fold and thrust belt in between. Three large structural units can be defined at regional scale:

I. The Septentrional fault system is considered as the northern active boundary where the eastward motion of the composite Caribbean plate is accommodated (see Hispaniola on Figure 1). Nevertheless, three points have to be outlined: (1) The actual location of the plate boundary is still unclear, probably migrating since the initiation of the oblique subduction and transfer processes; (2) the connection at depth between the plunging North American lithosphere and the strike-slip fault needs to be characterized; (3) the position of the transfer faults has been migrating since its primary initiation stages in Eocene (Leroy et al., 1996, 2000). Can this migration be considered as being progressive, hence implying a large lithospheric deformation band increasingly extending or as occurring sporadically because of the backstop resistant interaction with the Bahamas platform?

II. The EPG fault zone system along the Southern Haïtian Peninsula itself is seen as a mega-transpressive ridge, developed around the pure left-lateral EPGF. The compressive motion is developed laterally along the two borders of the peninsula and located essentially offshore (already mapped by Bien-Aimé-Momplaisir 1986, Mercier et al., 2011). Most of the aftershocks of the last seismic event occurred north of the EPGF, and no clear propagation of the aftershocks has been registered toward the east and south, meaning that there are places where stress accumulates intensively. The thrusts as shown in Figure 2 have to be related either to an en echelon system developing around the Southern Peninsula or to a southward-migrating offshore re-location of the junction with the third structural unit, the TransHaïtian Range. Historically, both southern and northern strike-slip mega-faults registered sporadic seismic activity only.

III. The TransHaïtian front thrust to EPGF junction onshore is located a few kilometers east of Port-au-Prince and is poorly documented. It accommodates the transpression between the two large transform systems. Deformation is propagating southwestward, with a dominance of Eocene to Quaternary thrusting (thin-skin tectonics), but implying also the rejuvenation of tilted blocks inherited from Cayman rifting (thick-skin tectonics). The southwest thrust propagation is well expressed up to the Matheux Range, and farther to the south offshore, in Gonave Bay (Figure 2).

Neither is the activity of the blind thrusts below the Cul-de Sac Plain documented, nor the connection between the active Léogâne segment of the EPGF and the TransHaïtian Range, close to Lake Azuei, which we consider as a stress-locked segment. This is confirmed by the BME (Bureau des Mines et de l'Energie) and UEH (Univ. d'Etat d'Haïti) observations, outlining that before the 2010 seismic event, the water level of Lake Azuei rose (completely disconnected in amplitude to the intensity of rainfall).

The critical point is to identify a hierarchy in the criteria responsible for the assumed strain partitioning

Generally, fault propagation is controlled by three main parameters: the tectonic regime (direction and intensity of tectonic forces), the physical/mechanical properties of the host-rocks cut by faults, and lastly by fluid and gas circulation within fault planes associated with fault permeability variation and rheology.

This IFPEN-ISTEP-GEOAZUR-UEH research project will address the two first sets of parameters.

For the understanding of the last seismic events, it is clear that no simple geophysical solution fits with the present-day geological and structural patterns. We need to identify the past configurations in order to point to the parameters impacting the partitioning of the deformation through time. In order to achieve better predictions for the present-day active system, we propose to analyse the onshore AND offshore deformation:

- the basement configuration, especially. the morphology of the NE-SW-tilted blocks inherited from the early stage of Cayman trough opening;
- the Tertiary-Neogene deformation in the TransHaïtian Ranges
- the velocity of the eastward Caribbean escape
- the shortening rate between the North and South American plates.

For the three last points, the timing could be proposed, as far as it can be determined by the field and dating studies. The most challenging topic is to identify the surface signals, such as the structural, sedimentological and diagenetic ones, which are coeval with the fault rupture at depth.

Data and Methods

Field studies and 3D analogue modelling

Based on structural field work guided by the interpretation of aerial and satellite images, the fault segmentation and re-location rules are presently tested by using X-Ray 3D analogue modelling.

Due to oblique convergence, the deformation has to be analyzed in 3D in transpressive margins as non-cylindrical deformation processes dominated, strongly induced by several parameters varying through time. To maintain a long time active strike-slip fault at the same location, it is necessary to have a dominant strong internal forcing parameter, such as crustal or lithospheric discontinuities, imposing that the deformation has to be concentrated here. Consequently, very abrupt and unstable relief is rapidly built close to the strike-slip discontinuities, while the deformation at surface is more smooth and extends far-away from the deep rupture, as it is transferred on shallow décollement levels.

Could the transfer motion permanently reuse the same fault planes or can we identify a migration of the oblique faulting during the westward progression of the Caribbean plate? In other transpressive margins such as those surrounding the Indian Plate, the partitioning of the deformation is expressed by the development of an accretionary wedge obliquely to the strike-slip motion (East India), and/or by a migration of a rupture zone at depth, as in the Chaman and Arachnal transform fault systems in Pakistan and East India (Ellouz-Zimmermann et al., 2007 2011).

Haïti-SIS oceanographic Survey

The Haïti-SIS survey is taking place on the French R/V Atalante from November 22 to December 28, 2012. The seismic survey is focusing on the characterization of the fault architecture around the Southern Hispaniola mega-transpressive ridge and in the Gonave Bay. In order to characterize the partitioning of the deformation in Haïti, it is planned to image the westward prolongation of the active main fault as well as the secondary structures associated with it.

The aim of the project is also to acquire multi-bathymetry, gravity, magnetics, seismic profiles, piston cores and heat-flow measurements across the wide plate boundary zone all around Haïti, in both southern offshore and the onshore central parts of the island. In the Haïti-SIS oceanographic survey, we propose to investigate the different structural units of the North Caribbean plate boundary around Haïti and their lateral connection with the Jamaica structures. The collection of detailed bathymetric data, HR seismic profiles, gravity and magnetic data across the entire marine area of the restraining bend system of Hispaniola (the transpressional relay), will extend from the North Gonave Margin to the north, to the oceanic basin of Haïti and Eastern Jamaica (following the western marine prolongation of EPGFZ) to the south, over to the whole marine TransHaïtian fault-and-fold system. .

Conclusion

Focusing on the fault architecture through time to recent periods, the combination of data coming from field studies and offshore Haïti-SIS acquisition will document and supply an integrated approach for modeling transpressive margins and will be useful for seismic and tsunamogenic risk assessment in the Great Caribbean domain.

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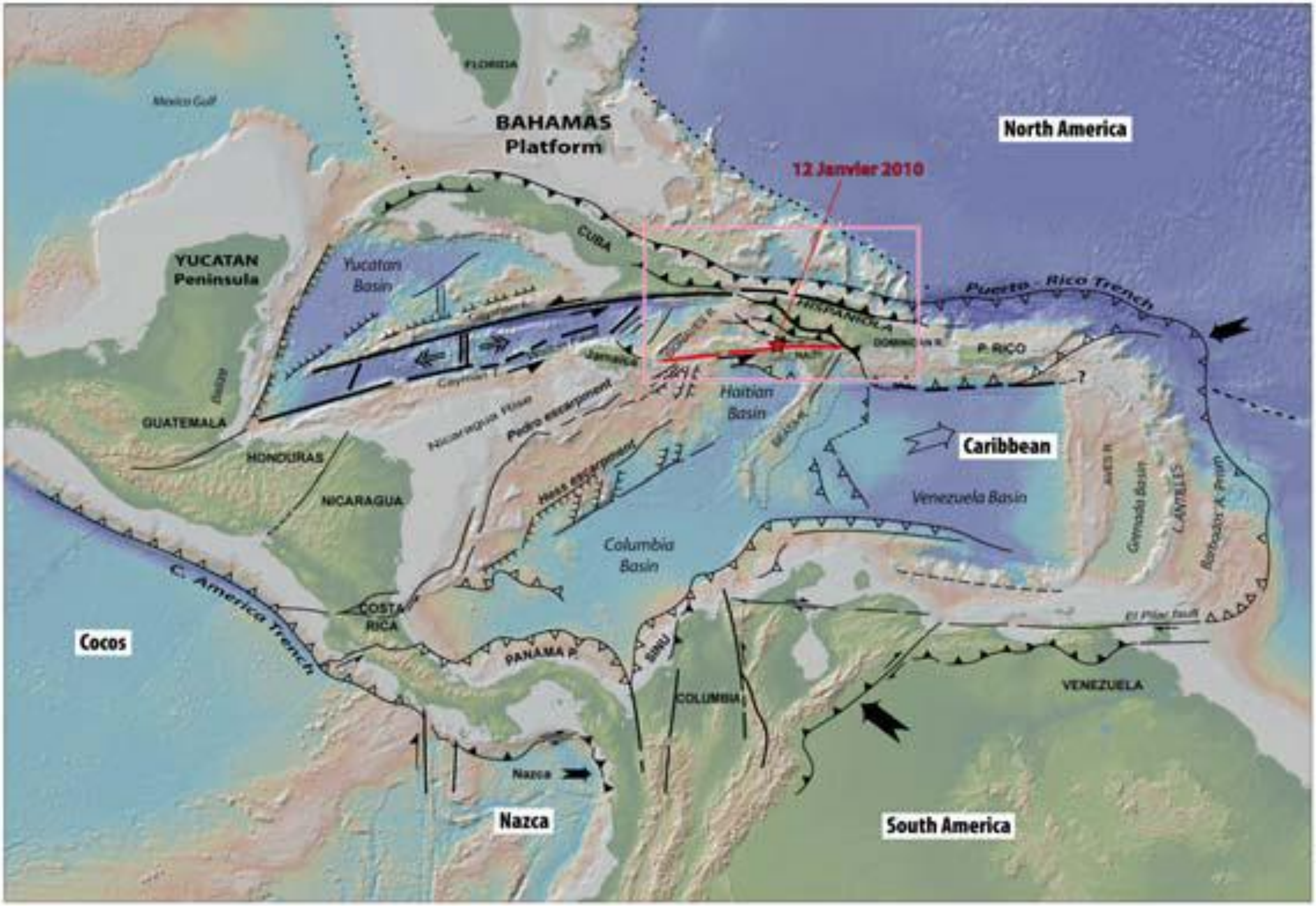

Figure 1. Superregional tectonic sketch around the Caribbean plate, with the position of the 12 January 2010 Haïti earthquake (M=7.2) and the location of the EPGFZ (in red).

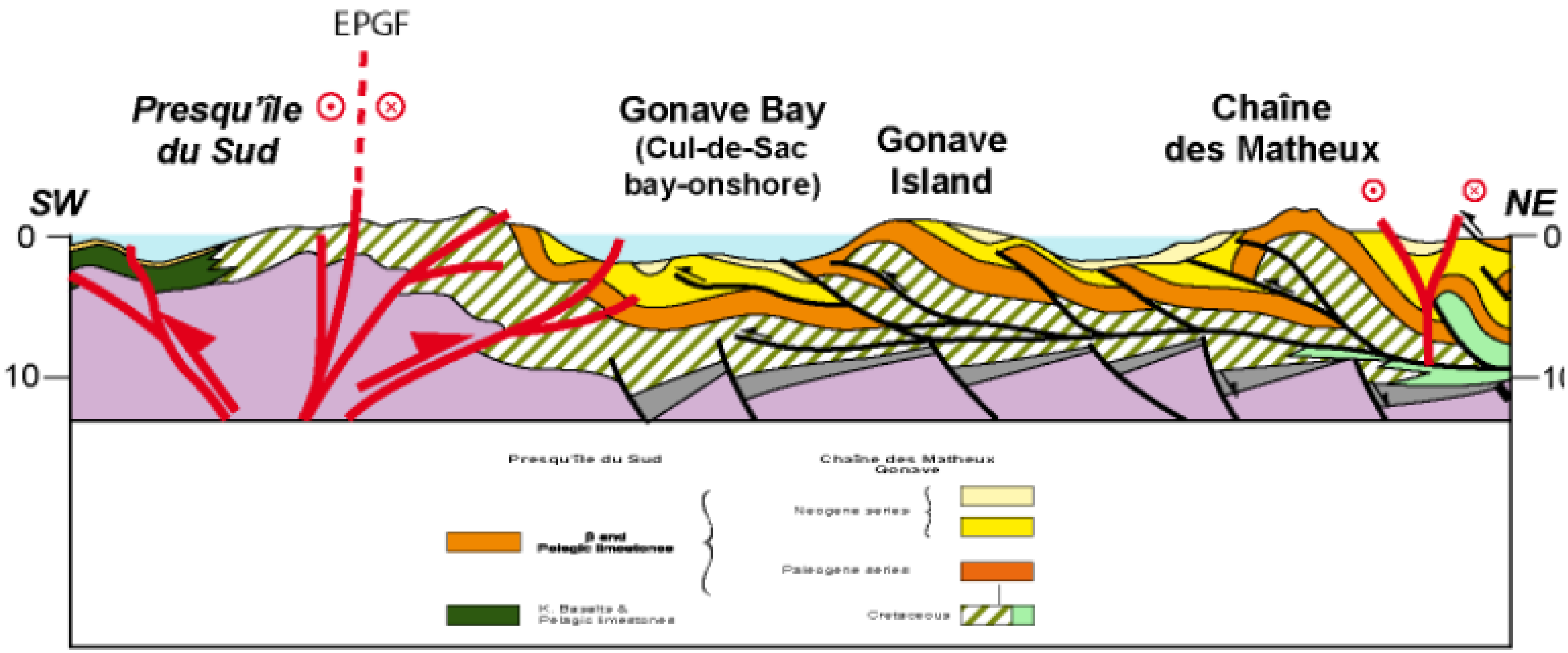

Figure 2. Cross section across the Matheux Range, the Cul de Sac Bay up to the Enriquillo Garden Fault (EPGF) Zone, see Fig. 3 for location (unpublished from Ellouz-Zimmemann et al., 2012, in preparation).

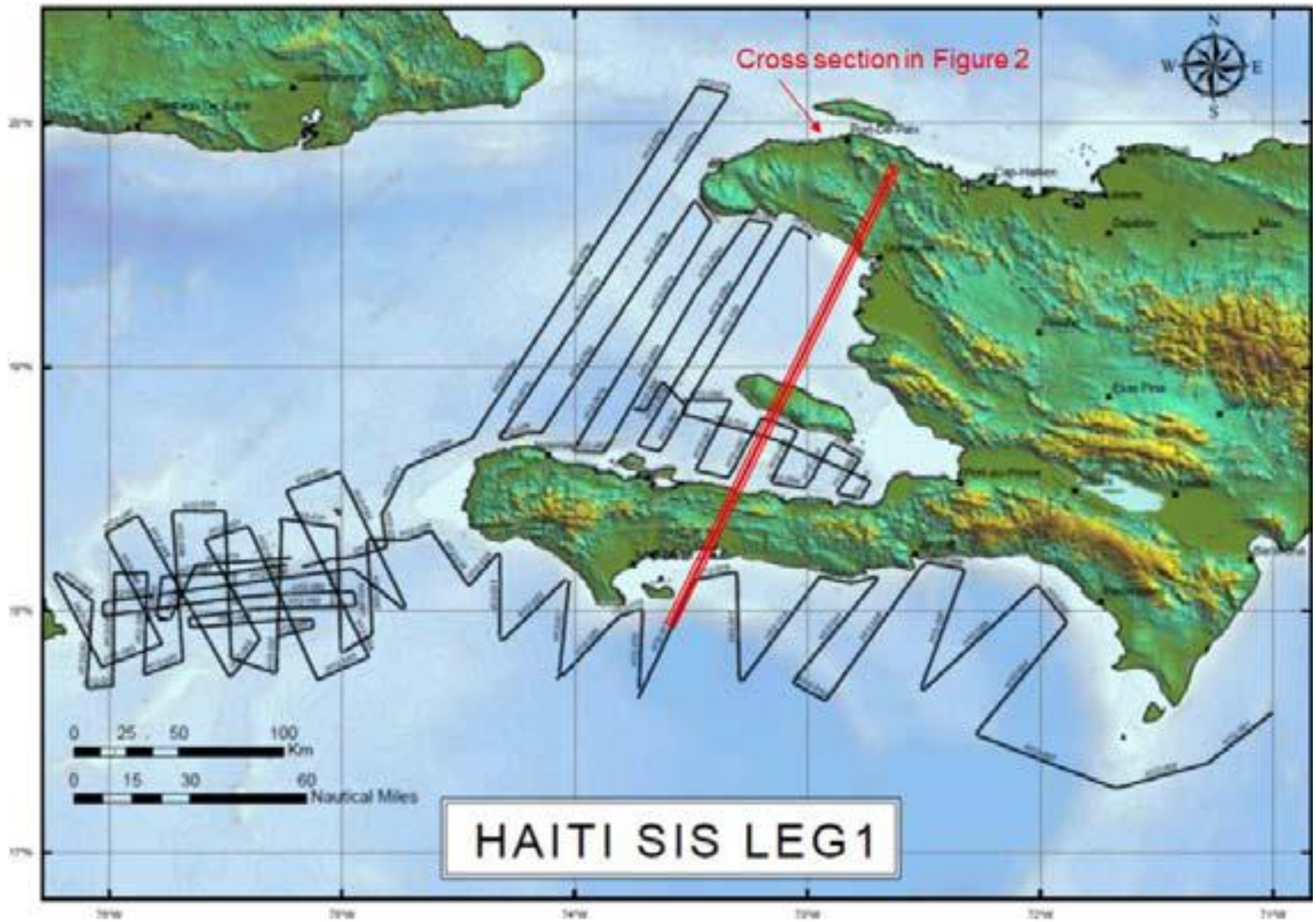

Figure 3. Location map of the Haïti-SIS survey (November-December 2012); in red, the cross section in Figure 2.