Revision of the geological context of the Port-au-Prince metropolitan area, Haiti: Implications for seismic microzonation

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Abstract

Following the earthquake of January 12th, 2010 in the Port-au-Prince area, the Haitian governement in close cooperation with BRGM, the French geological Survey, decided to undertake a seismic microzonation study of the metropolitan area of the capital in order to take more fully into account the seismic risk in the urbanization and planning of the cityunder reconstruction. As the first step of the microzonation project, a geological study has been carried out. Deposits of Miocene and Pliocene formations in a marine environment have been identified. These deposits are affected by the Enriquillo-Plantain Garden N80°E fault system and N110°E faults. Tectonic observations and morphological analysis indicate quaternary activity of several faults mapped in the area of Port-au-Prince. These faults have a N110° trend and show a reverse – sinistral strike-slip motion. Moreover, on the basis of these geological results and of new topographical data, a hazard assessment of ground movements has been made. Along with the map of active faults, the hazard map of ground movements is an integral component of the seismic microzonation study.

Keywords: Geology, fault, ground movement, seismic microzonation, Port-au-Prince, Haiti

1 Context

On January 12th, 2010, Haiti was struck by one of the most violent earthquakes to have affected the country during the last two centuries. According to the DEC (Disasters Emergency committee, website http://www.dec.org.uk/haiti-earthquake-facts-and-figures), the earthquake left 220,000 dead, 300,000 injured, and over a million homeless. Port-au-Prince, the capital city of Haiti, and its metropolitan area have suffered massive losses. The study of the historical archives (Bakun and *al,* 2012) indicates that the island of Hispaniola has been hit by several major earthquakes over the past centuries. These earthquakes are concentrated in the Northern or in the Southern parts of the island. In addition to the 2010 earthquake, Port-au-Prince has already been destroyed by the earthquakes of 1751 and 1770.

In order to better integrate seismic risk parameters into the reconstruction and development planning of the capital city, a seismic microzonation study has started in 2011. It has concerned the Port-au-Prince metropolitan area. The work has been carried out by two Haitian institutions, Laboratoire National du Bâtiment et des Travaux Publics (LNBTP) and Bureau des Mines et de l’Energie (BME) and BRGM, the French Geological Survey. The selected zoning scale is 1:25,000 over the metropolitan area as a whole and 1:10,000 for strategic sectors. The zonation work takes into account the seismic ground motion in the bedrock (regional hazard) and modifications produced by this motion in relation with the local topographic and litghology conditions (location and characterization of site effects and induced effects). The techniques implemented for this mapping initiative rely on available scientific knowledge, completed and updated by on-site investigations (geological, geophysical and geotechnical) and/or modeling. Intended for decision-makers, development planners, structural engineers and architects, but also for the public at large, this seismic microzonation work is of major interest both for the rebuilding of devastated zones of the Haitian territory and for preventive actions within the framework of a well managed development planning policy.

2 The geodynamic background

The island of Hispaniola is occupied by the Republic of Haiti to the west and by the Dominican Republic to the east. With the islands of Cuba, Jamaica and Puerto-Rico it goes to make the Greater Antilles archipelago. The latter marks the boundary between the North-American and the Caribbean tectonic plates. The main motion between the two plates amounts to a relative mean rate of 2 cm/yr., with a converging direction of these two plates of N70°E that is oblique with respect to the E-W plate margins (Mann and *al.*, 2002). In the island of Hispaniola, two great fault systems mark the boundary to the running along the north of Hispaniola, and the Enriquillo-Plantain Garden fault zone (EPGFZ), to the south (see Fig. 1).

The SFZ cuts across the north of Haiti and the Dominican Republic and is extending westward beyond southern Cuba. The mean slip measured is 12 mm/yr. (Calais *et al.*, 2010; website http://web.ics.purdue.edu). The strongest known earthquake associated with this fault system, having a magnitude estimated at 8, is that of May 7, 1842. This event caused the death of half of the population and considerable damage in several towns in northern Haiti (Bakun *et al.*, 2012).

The EPGFZ runs along the southern Peninsula of Haiti. To the west, this fault system reaches the island of Jamaica (the Plantain Garden plain). To the east of the Haiti and Dominican Republic border, the EPGFZ ends against the Muertos fault system, which corresponds to the subduction of the Caribbean plate beneath the Greater Antilles archipelago. The mean slip measured on the EPGFZ is 7(±2) mm/yr. (Calais et *al.*, 2010; website http://web.ics.purdue.edu). In addition to the January 12, 2010 seismic event, other major historical earthquakes during the last centuries (1701, 1751, 1770, and 1860) are ascribed to this structure. According to Bakun *et al.* (2012), the 1751 event had a magnitude of at least 7.4, and for the one in 1770, the magnitude is estimated at 7.5.

In the center of the island of Hispaniola, a number of large active thrust faults trending NW-SE are visible in the present-day morphology (Calais *et al.*, 1992; Pubellier *et al.*, 2000). These faults are structuring the Transhaitian Belt. To the north, they are connecting to the SFZ and, to the south, to the Muertos fault system. The thrust of the Matheux range corresponds to the northern boundary of the Plaine de Cul-de-Sac (see Fig. 1). This is the main structure of the Transhaitian Belt. According to GPS data, the mean measured slip on this thrust is approximately 1 mm/yr. (Calais *et al.*, 2010; website http://web.ics.purdue.edu). Seismic profiles implemented in the Gulf of La Gonâve (Mann *et al.*, 1995) reveal the presence of folds and reverse faults dating in age from the Miocene to the Quaternary, which make the active frontal edge of the Transhaitian Belt. The reverse motion of the Transhaitian fault system partially compensates the oblique component of the convergence of the North-American and Caribbean plates with respect to their edges.

The January 12, 2010 earthquake reached a magnitude Mw of 7.1; its focal depth was 13 km. The epicenter was located between the island of La Gonâve and the eastern end of Haiti’s Southern Peninsula (see Fig. 1). The focal mechanisms computed for the main shock and the aftershocks, radar interferometry measurements, and GPS data indicate a motion along a fault striking ENE-WSW (N71°E), that is north-dipping with a reverse left-lateral component (Calais *et al.*, 2010). Thus, this fault is slightly oblique with respect to the trend of the EPGFZ (N80°E) and lies to the north of this zone. Named the “Léogâne fault” (Calais *et al.*, 2010), it is interpreted as being a blind thrust. According to the analysis of aftershocks of the January 12, 2010 event, the main rupture on the Léogâne fault appears to have triggered a reverse movement on a N120°E fault (the Trois-Baies Fault), interpreted as a secondary fault of the EPGFZ (Mercier de Lépinay *et al.*, 2011), and the reactivation at depth in a left-lateral strike of the main fault plane of the EPGFZ (Hayes *et al.*, 2011; Douilly *et al.*, 2012).

3 Geological study of the Port-au-Prince metropolitan area

The map of lithological facies of the Port-au-Prince metropolitan area constitutes the essential input data controlling both the soil (and the bedrock) responses to seismic vibrations and the susceptibility to ground movements. Before the study, the geological information available for the Port-au-Prince arae was relatively poor. It mainly consisted in the geological map of Haiti at 1:250,000 scale (Momplaisir and Boisson, 1987) and the recent geomorphological sketchmap by Bachhuber *et al.* (2010), at 1/50,000 scale.

In order to make a reliable seismic microzonation mapping, it was necessary to improve the knowledge of the geological context of the area under study. Our geological study consisted in observing several dozen of outcrops, supplemented by the analysis of geotechnical boreholes drilled earlier, together with the interpretation of aerial photographs from 2002, plus the analysis of the Digital Terrain Model with 2 m pixels to a side calculated from 2012 Pleiades satellite images (KalHaiti, SERTIT/CNES), SPOT 2010 ortho-images, and 3D-view satellite images of various dates under Google Earth.

3.1 Mapping of the lithological facies

The Port-au-Prince metropolitan area lies in the Cul-de-Sac alluvial plain (see Fig. 2). Eastwards, the urban area ends near the Rivière Grise, while to the west, the city is limited by the sea. In a southerly direction, the city abuts on the Mornes of Saint-Laurent and Hôpital in the La Selle mountains range. These Mornes are bounded to the south by the Rivière Froide, of which the course is, in turn, determined by the EPGFZ.

The various lithological facies found in the field have been classified into ten types or units ranging from the oldest to the most recent: F1 (Upper Eocene) through F10 (Plio-Quaternary to Present) (Fig. 3). The estimated ages of these units are derived from the work of Butterlin (1960). The rocky substratum consists of limestones, silts, marls or conglomerates (or breccia). Sandy facies are rarely met. Marls are frequently associated with limestones to form “marly-limestone” alternations more or less rich in marine fossils depending on the site. The present-day topography is largely the result of the Mio-Pliocene orogeny and of the activation of the faults that delimit tectonic blocks, atop which Quaternary and recent erosion has occurred.

At the Mornes of Saint-Laurent and Hôpital, Eocene to Oligocene limestones outcrop to the south and Miocene conglomerates to the north. The main orographic axis is N80°E, parallel to the EPGFZ. Between the Cul-de-Sac alluvial plain to the north and the northern slope of Morne Hôpital, small shills of secondary origin and trending globally N110°E mark the topography. The marly limestones and Mio-Pliocene marls or silts form the base of this hilly topographys. Here, the stratigraphic surfaces of these formations trend WNW-ESE and dip steeply (angle greater than 45°) towards the north or the south (see Fig. 2). These reliefs are bounded, to the east and north, by the alluvial formations of the Rivière Grise, and to the west by marine alluvia. To the south, colluvial deposits or dejection cones cover these reliefs in places. The colluvia in place are mostly fairly shallow, with thicknesses generally ranging between 0.1 and 0.5 m on more rugged relief and from 0.5 to 1 m on average in less hilly areas. These remobilized surface deposits can reach thicknesses of several meters in narrow valley bottoms.

On Fig. 3, the analysis of the Miocene to Pliocene terrains in the Plaine de Cul-de-Sac shows: i) deepwater to sublittoral marine deposits (marly limestones, mudstones, fine-grained sandstones and silts) characteristic of low-energy environments and ii) sharp intercalation of detritic formations related to sequences of sandy and gravelly to silty turbiditic deposits (conglomerates). These formations correspond to marine deposits with a proportionally variable limestone component, overlain by flysch sequences that become increasingly regular and frequent at the end of the Miocene and the beginning of the Pliocene. These sharp detritic intercalations, considered to be tectonic in origin, are ascribed to the continual activation during the Mio-Pliocene of the faults bounding the Port-au-Prince plain to the south.

These Miocene and Pliocene formations are several hundreds of meters thick, with a possible high exceeding a thousand meters, on the strength of the marine seismic profiles in the Gulf of Gonâve (Mann *et al.*, 1995) as well as the borehole drilled in the Plaine de Cul-du-Sac by ATLANTIC REFINING in 1947 (Momplaisir, 1986).

3.2 Fault mapping

As to fault mapping, this work was performed by observing outcropping fault planes (Fig. 2), supplemented by the interpretation of morphological data. A majority of the fault planes measured are trending E-W to NW-SE. Most of them show reverse left-lateral activation (Fig. 4). In several locations, the contact via the fault between quaternary alluvia and Miocene to Plioene formations is visible (Fig. 5).

In the central part of the metropolitan area of Port-au-Prince, a conglomerate formation made of uncemented, graded, polymetric limestone elements embedded in a marly sandy matrix, overlies the Mio-Pliocene marly limestone and silt formations. This formation corresponds to a piedmont alluvial cone which was probably deposited between the end of the Pliocene and the early Quaternary. The hydrographic system responsible for this deposit is to be sought in the limestone relief to the south, quite probably in the upstream portion of the Bristout River catchment area (Fig. 6). The debris cone is characterized by three distinct assemblages, interpreted as successive deposits from the drainage basin. The oldest part is locatedat at the north ; at the south, the most recent part is still fed by the present-day Bristout river. Based on the central axis of the north and center portions of the cone, the hypothesis of a 1000-meter offset cannot be excluded (Fig. 6). This would indicate a horizontal displacement rate of 0.6 (±0.2) mm/yr. for the WNW-ESE fault systems mapped at this location. This estimate is compatible with the values from GPS measurements on the compressive deformations of the Transhaitian Belt (Fig.1).

Furthermore, between the Musseau and Chavannes districts, the hydrographic network presents a number of inflections in hydrographic drains following a WNW-ESE trend. These inflections may locally have sizes up to 300 m. This mean value is coherent with the hypothesized horizontal displacement rate indicated above, bearing in mind, in this instance, that these are markers of more recent date (Middle to Upper Quaternary).

4 Hazard assessment of ground movements

4.1 Method used

Ground movements may be triggered by seismic vibrations. This is why they must be analyzed in the seismic microzonation process, as potential site effects. In addition to local topographic conditions, the lithologic nature of the terrains constitutes one of the main environmental factors governing ground stability.

For this part of the study, the main steps were: (i) an inventory of the ground movements of the region of Port-au-Prince (location, type of instability, geological and morphological context), (ii) depending on the type of ground movements and based on past events, an analysis of predisposing factors (involved lithology, slopes value), (iii) preliminary mapping of the susceptibility of the land for instability, (iv) study in the field and analysis of aerial photographs in 3D vision (definition of the different levels of hazard, and mapping of the boundaries of the hazard zones); (v) restitution under a GIS of the hazard map.

The geological map made within the framework of the microzonation project, the Digital Terrain Model calculated using Pléiades satellite images (KalHaiti, SERTIT/CNES), and the inventory of ground movements make up the cartographic reference data for the hazard assessment of ground movements. As attested by the past ground movements, listed in Table 1, Port-au-Prince is often concerned by slope instabilities. The inventory of ground movements results from on site observations, interpretation of aerial photographs (especially for the instability triggered by the earthquake of 2010) and local testimonies. Among the forty or so events recorded in the area, nineteen are documented by precise data as location, lithological facies and the instability's geometry. For the remainder, it generally consists of eyewitness accounts indicating events triggered by the 2010 earthquake. These events fall into two main categories: landslides and rockfalls (see Table 1). The extent of the phenomena has been estimated from observations in the field and/or by interpretation of aerial photographs. In the area under study, identified landslides can reach large to very large volumes (hundreds of thousands of m^3 to more than a million m^3), while the size of rockfall events is more limited. Rockfalls up to 10 000 m^3 are scarce.

Landslides generally involve marly limestone formations (F4, F5 and F6, cf. Fig. 3), which may be overlain by more recent layers of deposits (F7 and F8), while rockfall events concern mainly consolidated rocky layers (such as F3 and F2). In a few instances, calcretizations may be at issue (they can be up to 1 m thick) observed at the roof of the Morne Delmas geological formation (F6 to F8) or the shelly limestone banks (F6) in the marly limestone alternations.

While the lithological nature of the rocks largely conditions the type and the exent of potential ground movement, the hill slope takes also a significant part in the ground instability assessment. Other factors influence also the susceptibility of hillsides instabilities. Anyway, they are often difficult to integrate at the scale of this study. Among them, are, for example, structural data (as the dip of stratigraphic or fracture planes), lithological variations within geological formations, and hydrogeological conditions.

For each geological formation studied, slope thresholds have been defined, mostly calibrated by means of the feedback given by the inventory (Table 1). Thus, a preliminary map was produced thanks to a data digital cross-comparison, with a 5m-resolution. At each spot, a value was assigned according to the geological nature of the geological formation and the value of the slope. This digital processing yields a preliminary assessment of the landslide or rockfall susceptibilities at each point of the study area.

This preliminary map is a precious document to direct the field work and the demarcation of the various zones of hazard.

4.2 Ground movement hazard map

The finalized hazard map for ground movements is at 1:10,000 scale. It shows the distinction between the two types of ground movements, i.e. landslide and rockfall (Fig. 7). Virtually half of the studied area is concerned by landslides. The rockfall phenomenon, involving less than 10% of the studied area, is concentrated along the southern boundary of the studied zone as well as on the foothills of the La Selle mountain range. Landslides remain by far the most frequent and most damaging phenomenon identified.

Four levels of susceptibility of increasing severity have been defined. Their corresponding zonation is as follows:

1) Zones assigned to a hazard that is weak or non-existent. It applies to areas that are flat or with gently slopes (< 5°). These zones are generally not or little affected by landslide or rockfall events. The few events that may occur are minor;

2) Zones assigned to a moderate hazard level. They can be subject to landslides of limited (a few hundred m^3) or moderate (a few thousand m^3) volume. The concerned

areas present gentle slopes (between 5 and 10° on average), made of Miocene geologic formations consisting of marl, marly limestone or silt (Formations F4 to F8);

3) Zones assigned to an intermediate hazard level. They are regularly affected by landslides of intermediate intensity (several thousand m³) and, exceptionally, by larger-scale phenomena (several hundred thousand m³), as the Delmas 32 famous event that has caused the destruction of 200 houses in 1989. The concerned areas have either slopes ranging between 10 and 20°, composed of marl, marly limestone, silt or alluvia, or areas are exposed to the propagation of landslides initiated on steeper inclines upslope. Zones with intermediate hazard level can also be exposed to rockfalls. In this case, the terrains involved are rocky, with slopes exceeding 10°, or zones liable to the propagation of rockfall from above.

4) Zones assigned to a high level of hazard are proned either to frequent superficial landslides or to large-scale events (active or potential). They are characterized by intermediate to steep slopes with unfavorable geological conditions or land-use factors (typical configurations of the historical well-known landslides like Vivy Mitchell 1 and 2, Musseau), or they are concened by to massive landslide propagation from higher altitude. Thus, included under this category, we find small rivers and foot slopes, which are receptacles for materials that have slipped off slopes and can be remobilized in the rivers as mudflows.

5 Implications for preventive seismic recommandations

Within the framework of the seismic microzonation project, the next step was to complete these geological data with geotechnical and geophysical investigations, and then to map the ground responses to seismic activity. Moreover this next step has taken into account the topographical conditions of the city of Port-au-Prince. A first comparison between the distribution of damage caused by the 2010 earthquake (UNOSAT, 2010) and the lithological and topographic data shows a concentration of damage at right of topographical buttes on the one hand, and on the edge of the coastline above the alluvial marine deposits (Fig. 2, see F10-ma), on the other hand.

The map of the active faults and the hazard map of ground movements which are two full components of the seismic microzonation survey were integrated into the final products.

The geological study of Port-au-Prince reveals that the capital of Haiti is located near or directly over two active fault systems (Fig. 2), which have been taken into account in the hazard risk assessment: i) the EPGFZ, which bounds the southern limit of the Port-au-Prince urban area, and ii) the N110°E faults. The latest faults set corresponds very probably u to the south-easterly extension of the reverse faults located in the Gulf of Gonâve and which connectsto the EPGFZ to the east. The N110°E faults system mapped on land has a maximum length of 15 km but, as indicated by offshore geophysical data, this system almost certainly extends WNW into the Gulf of Léogâne. Tectonic deformations in terrains dated presumably to the middle or recent Quaternary is observed at several locations along these faults. Taken in conjunction with the morphostructural data, it indicates a reverse left-lateral displacement, associated with a mean horizontal slip on the order of 0.6 (±0.2) mm/yr.

Thus, as a main result of the study, in the context of the Port-au-Prince metropolitan area, it is highly recommended to prohibit the construction of high-stake buildings as schools, hospitals, disaster relief centers or structures of strategic importance in the vicinity of active faults.

Concerning the ground movement hazard, each specific zone identified on the hazard zonation map (Fig. 7) is subject to specific recommendations (measures) designed to take the ground movement hazard into account in existing constructed areas or for future urban land-use development. No recommendation is made for zones of low hazard level. It just makes sense to plan and to build according to appropriate construction rules. The zones associated with a moderate, intermediate or high hazard level are governed by specific recommendations which depend of the hazard level.

6 Conclusions

The geological study performed within the framework of the seismic microzonation project of the metropolitan area of Port-au-Prince has enabled the environmental context of the deposits of the Miocene and Pliocene geological formations to be established. They are marine deposits, either deep or sublittoral, which are characteristic of low-energy environments and occasionally showing sudden inputs of detrital materials. These inputs are turbidites related to the continual activation of the southern boundary faults of the Port-au-Prince Plain during Miocene and Pliocene. Moreover, the study confirms the presence of several active faults that include not only the EPGFZ bounding the Port-au-Prince metropolitan area to the south, but also faults trending N110°E that are directly visible within it.

There are still uncertainties. Among them, the age of the lithological units should be confirmed by chronostratigraphic dating. It is also necessary to determine the relationships and contours for units F6 to F8, which are characterized by specific environments of deposition. Furthermore, the deposit of the F9 unit needs to be determined with greater precision, notably concerning its relationship with the upstream portion of the catchment area. Recommendations are made for taking into account the hazard of surface rupture along active faults, but it would be preferable to reduce uncertainties on the fault traces and to better understand the seismogenic potential of these structures. To this end, the analysis could be pursued by local geophysical studies and paleoseismic trench investigations.

The hazard map of ground movements at a scale 1:10,000 has been made mainly on the basis of the geological map and an inventory of past events. It takes into account both the initial predisposition and the propagation of instabilities, while also distinguishing between landslide and rockfall phenomena. The results will be directly integrated into the seismic microzonation map of the metropolitan area of Port-au-Prince.

The location and characterization of lithological or topographical site effects is the aim of another phase of the seismic microzonation of Port-au-Prince. To this end, the realized lithological map will be an essential input.

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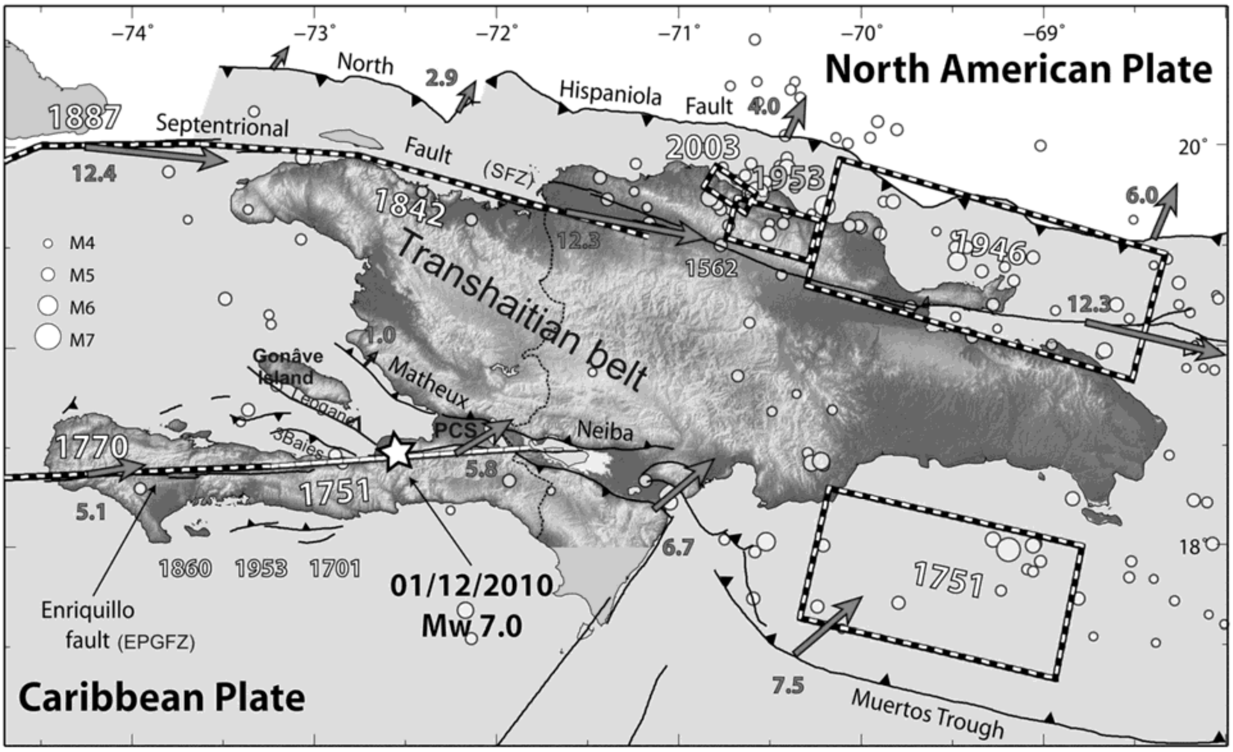

Figure 1 – Location of historical rupture zones and indications (arrows) of the active slip rates (in mm/yr) derived from geodetic measurements (modified from Calais and *al.*, 2010, http://web.ics.purdue.edu/~ecalais/haiti/context/). (PCS: Plaine de Cul-de-Sac)

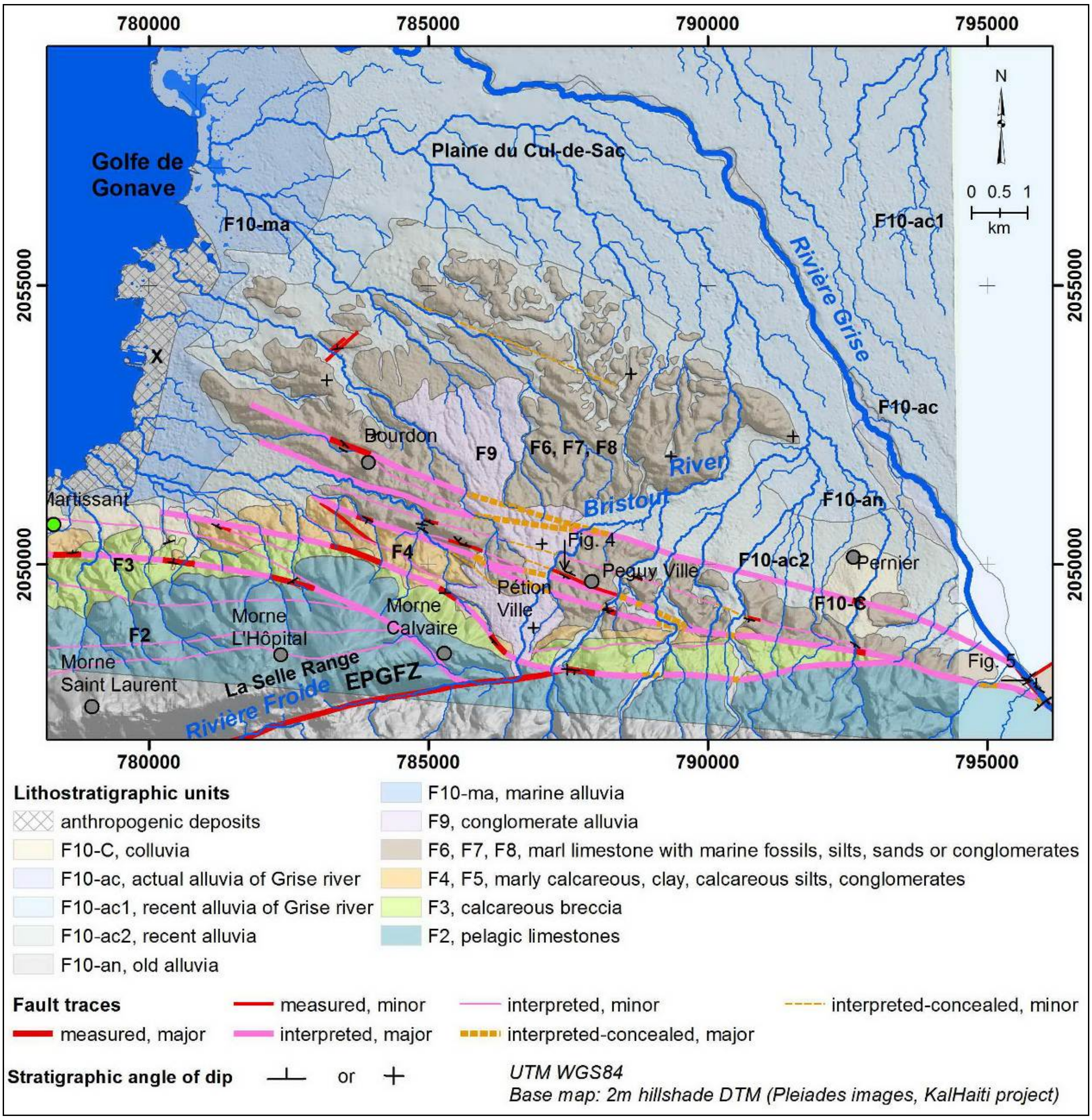

Figure 2 – Geological map of the Port-au-Prince metropolitan area.

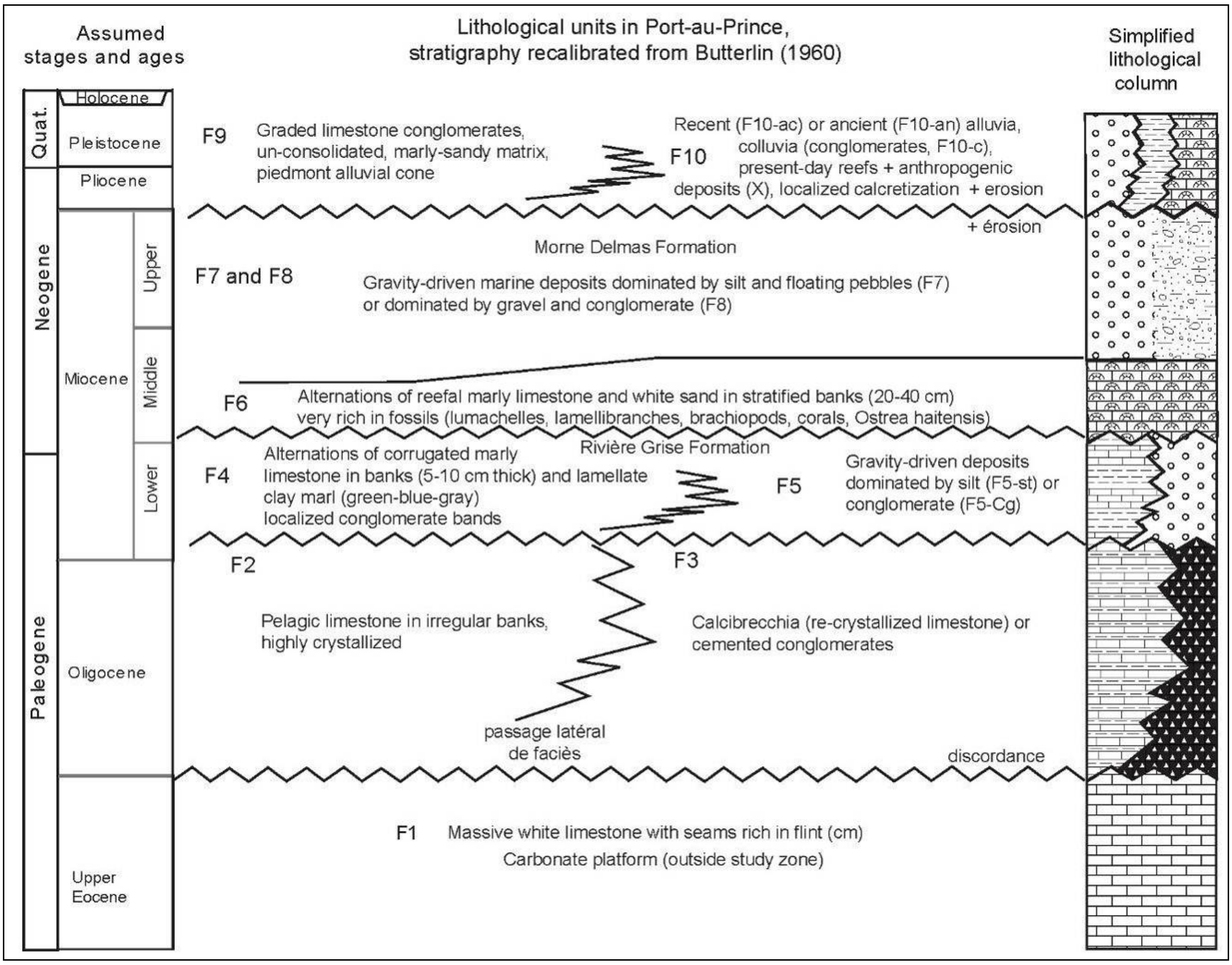

Figure 3 – Litho-stratigraphic synthesis for the Port-au-Prince study sector (stratigraphic séquence based on the work by Butterlin (1960).

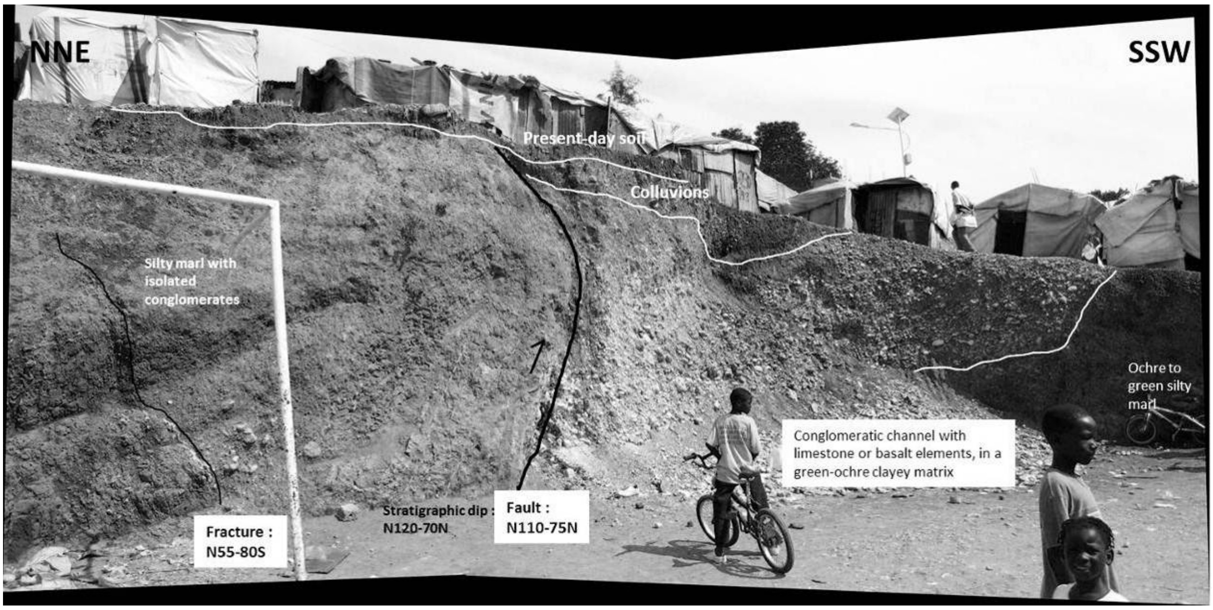

Figure 4 – Fault contact in Mio-Pliocene terrains between the deposits of sandy, ochre-colored silts and conglomerates, location fig. 2 (Photo M. Terrier).

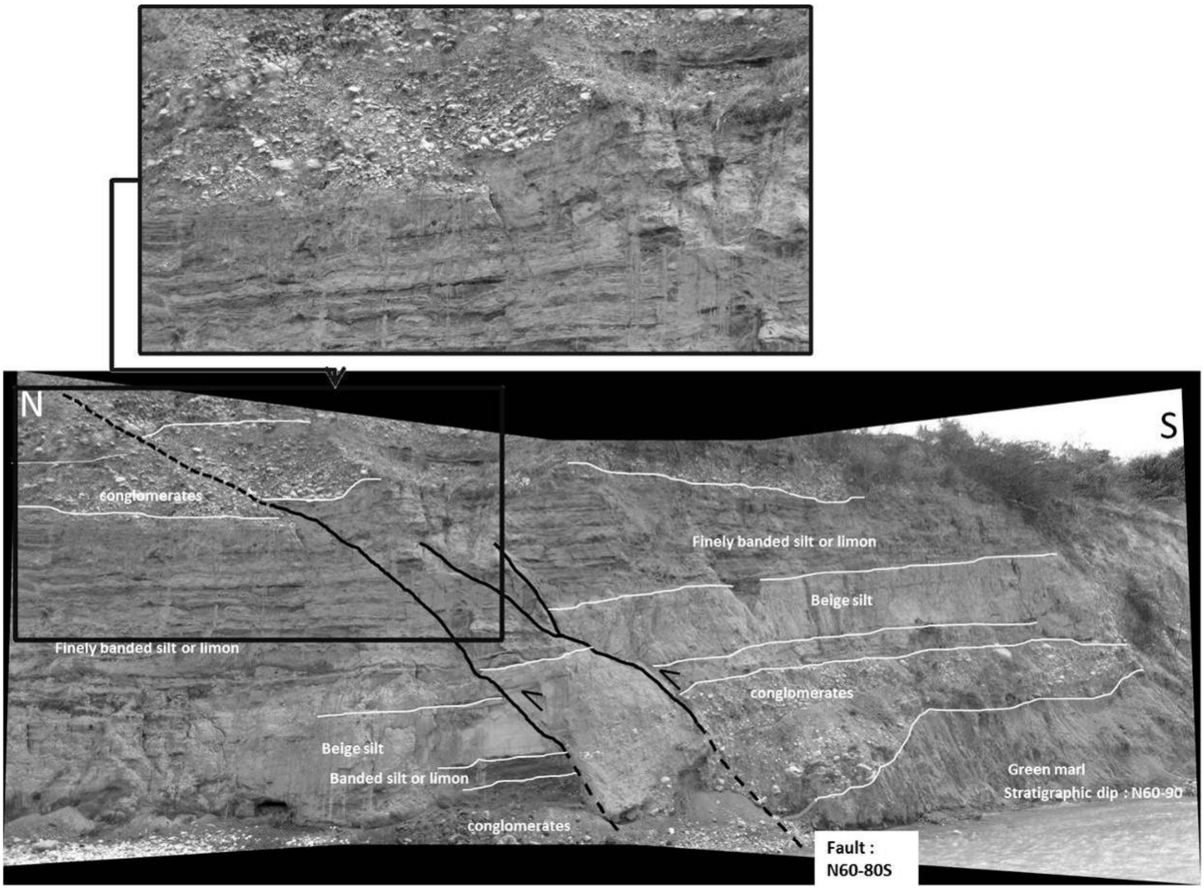

Figure 5 - Reverse faults trending NE-SW, visible along Rivière Grise in the Quaternary conglomerates and silt deposits, location fig.2 (Photo M. Terrier).

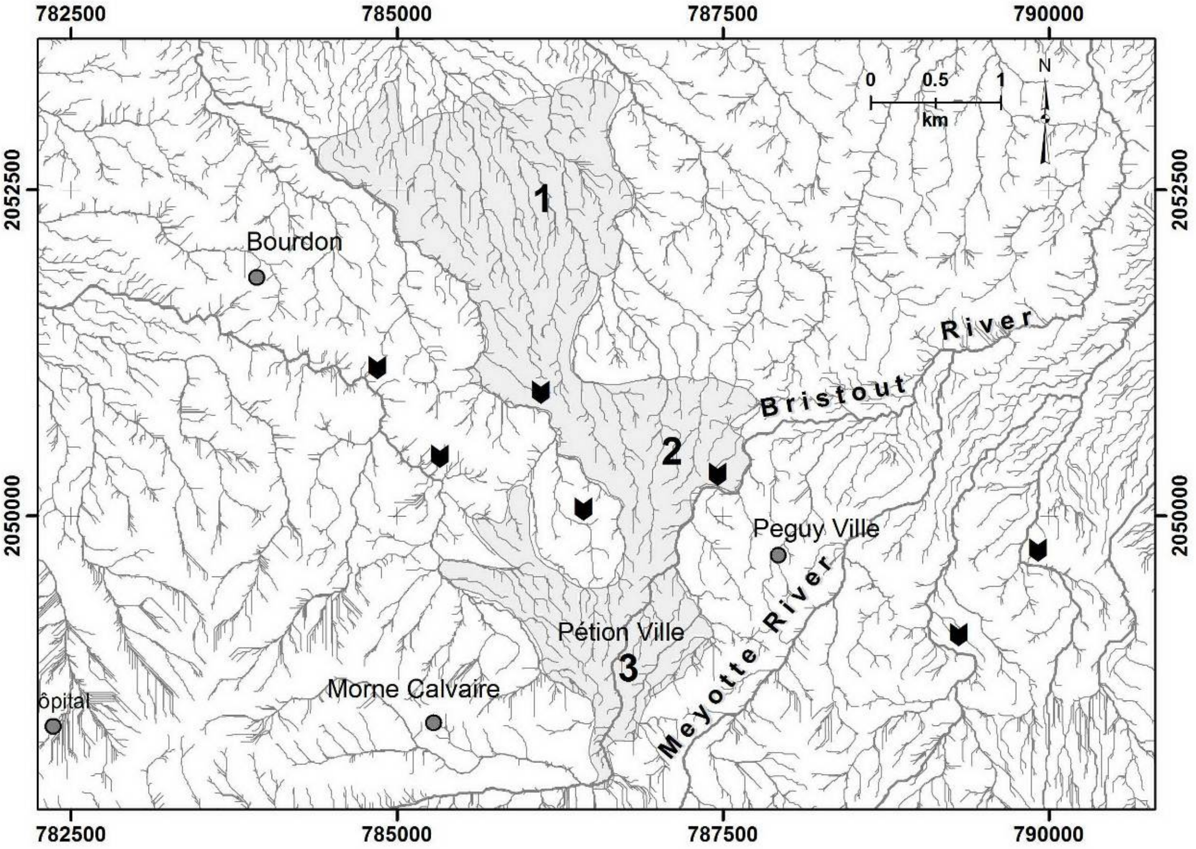

Figure 6 – Hydrographic network calculated from the Pléiades DTM: zoom on the catchment area of the Bristout and Meyotte Rivers. Numbers 1 to 3: successive segments of the alluvial cone (ranging from the oldest to the youngest; black arrows: inflexions of the water course; grey area: F9 unit.

Table 1 - Characteristics of the most important ground movements inventories over the Port-au-Prince metropolitan area (L: landslide; R: Rockfall; B: Bank Erosion)

NAME	**Type of MVT**	**DAMAGE**	**DESCRIPTION**	**LITHOLOGY**	**Triggering factor**	**DATE**	**OBSERVATION**	**SEEN**	**Size**
Musseau, imp Avalon	L	Several houses destroyed	30 m high by 50 m wide, initial slope > 37°. Bordered at the base by the Musseau ravine	Limey channel silt isolated from conglomerates (F7, F8). Marly layer at the base (F6?)	Heavy rains	2008	Accentuation in 2008 of an earlier landslide.	Yes	Large to very large
Djobel1	L	7 fatalities and 11 houses destroyed	Scarp 25 m high , by 50 m wide	Brown argilaceous silts with more indurated levels of very fine sand	Heavy rains	2003	Triggered in 2001.	Yes	Large to very large
Djobel3	L/R	None	Subvertical scarp. Rockslide over a width of 40 m and a height of 60 m.	Poorly consolidated conglomerate banks	Heavy rains, ravine	Après 2002	Bordered at the base by a ravine.	Yes	Large to very large
Djobel2	L/R	None	Scarp 40 m high. Rockslide over a width of 10 m.		Heavy rains		Slope of approximately 35°	Yes	Inter-mediate
Marcadieu	L	Road blocked	Rockslide over a height of 40 m and a width of 40 m	Poorly consolidated conglomerate banks	Heavy rains, ravine	1987?	Bordered at the base by the Bois de Chaine ravine.	Yes	Large
Vivy Mitchell 2	L	5 houses destroyed, some ten houses displaying cracking	125 m long by 30 m high, Over 100,000 m³. Moderate slope (< 20°).	Marly limestone (F6?) overlain by calcretization at the summit. Same dip as the topography	Heavy rains	>2002	Triggered in 1998. Clearly visible from DTM shading	Yes	Large to very large?
Vivy Mitchell 1	L	Several houses destroyed or with cracking	Landslide scar revealed over 60 m. Moderate slope (< 20°)	Marly limestone (F6?) overlain by calcretization at the summit. Same dip as the topography	?	Post 2002	Same configuration as Vivy Mitchell 2.	Yes	Large
Boulard / Acacia	L	Cracking in some thirty houses			Micro-earthquake	2003	Information by word-of-mouth. Nothing in the field. Intensely built-up area. Gentle slope	No	Large?
Rue Rosa	R ?		150 m long by 10 m wide.	-	?	?		No	Inter-mediate
Ravine Bristout	B	Houses		Alluvia (F10)	?	?		No	Limited to inter-mediate

Morne Calvaire	R	None	Blocks measuring approximately 1 m³	Calcibrecchia (F3)	Earthquake	?		No	Limited
Desermite	B	Houses	Deposit of detritic material	Calcibrecchia (F3)	?	?		No	Limited
PanAméricaine_2	L		Suspected landslide	Marly limestone (F5, F6, F7, F8)	?	?	Gabion retaining wall uphill from the highway and stabilization wall below	Yes	Intermediate?
RivBoisDeChaine	L	-	Over some 100 m along the Bois de Chaine ravine and 20 m in height. Probably the same configuration as Marcadieu.	Recent formations overlying the Delmas formation?	Rain, ravine?	Prior to 2010	Niche of plucking visible from the rue Panaméricaine. Probably triggered by the action of the ravine.	Yes	Intermediate to large
Meyotte	L		Undulating terrain observed on the hillside	-	?	?		Yes	Intermediate?
PanAméricaine_1	R	-	Rockfall on the roadway, approximately 1 m³	Calcretization	?	?	Several blocks on the pavement along the rue Panaméricaine	Yes	Limited
Delmas32	L	200 houses destroyed, 60 reported injured	Hillside with a limited slope (< 15°), over ca. 30,000 m²		Rains / earthquake	1989	Moderately-sloping hillside (< 20°)	No	Very large
StGérard_2	B	One house	Sliding of the banks that probably carried off the house	Recent, poorly consolidated conglomerate	Ravine at the base?	2010?	Influence of the ravine at the base. No explicit outcrop of marl	Yes	Limited
StGérard_1	L	-	Landslide niches some 15 m long by 8 m high	Conglomerate overlying marly limestone	Ravine at the base?	?	Influence of the ravine at the base? Marly limestone outcropping at the base	Yes	Limited to intermediate

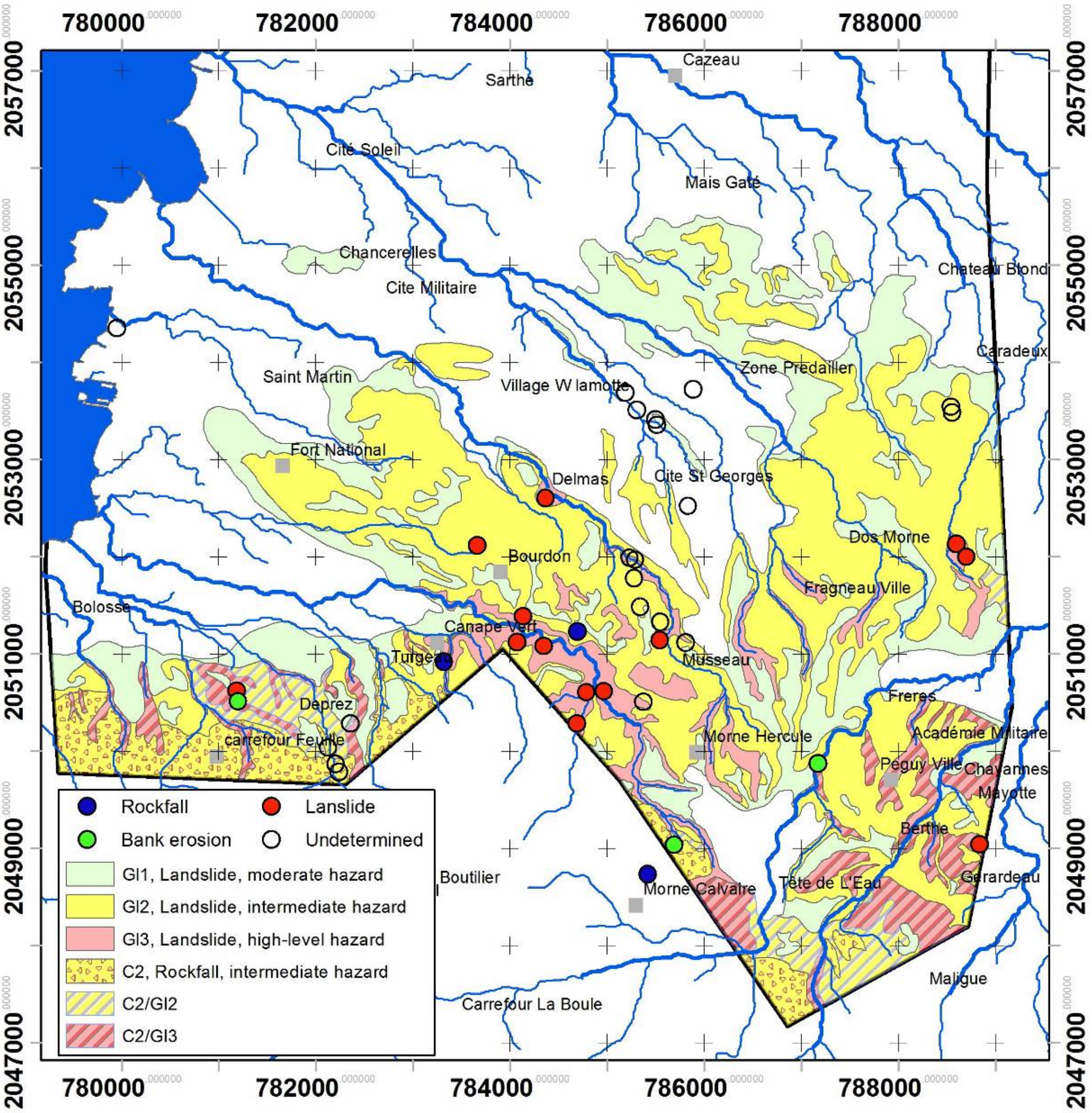

Figure 7: Hazard map of ground movements for the Port-au-Prince metropolitan area