Tectonics Lab. – Institut de Physique du Globe de Paris (IPGP)

Preliminary evaluation of the Haiti January 12, 2010, earthquake (at the date of Jan 25, 2010)

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Tectonic and seismotectonic context :

The Haiti earthquake of 2010 January 12 (21h53 UTC) occurred on the boundary between the Caribbean and North American plates (Figure 1). Its magnitude (Mw) has been estimated to 7.0 (USGS), 7.1 (EMSC), 7.2 (french CEA). About 20 mm/yr of relative motion occurs in an 070°E direction along this relatively complex plate-boundary [1, 2]. In Haiti, located in the western part of Hispaniola island, the oblique plate relative motion is partitioned between left-lateral strike-slip movement on roughly E-W faults and N-S to NNE-SSW shortening which produces thrusts and folds across the island and along its northern and southern coastal margins (Figure 1).

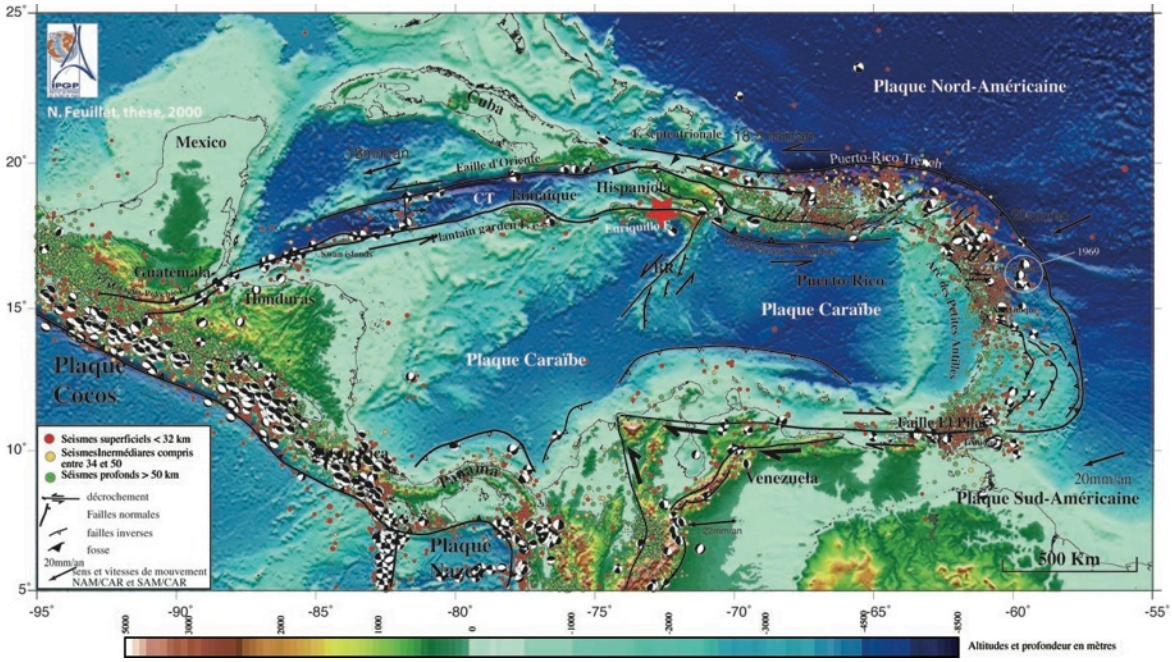

Figure 1 : Plate tectonic context of the Jan 12, 2010 earthquake in Haiti. Map after [1].

Two main active faults absorb the left-lateral component of motion : the Septentrional Fault in N Haiti and Dominican Republic, the Enriquillo Fault in SW Haiti. GPS measurements and modeling suggest that each of these faults are fully coupled, each one with slip a rate of ~7-8 mm/yr [2]. The location of the main shock hypocenter and its mechanism (sources : USGS, EMSC, Harvard), the E-W distribution of aftershocks (Figure 2)

suggest that the Jan. 12 earthquake ruptured a ~50km long segment of the Enriquillo fault SW of Port au Prince.

Historical [3] and instrumental data indicates that the Enriquillo fault has not produced a major earthquake since the past couple of centuries. A sequence of 3 destructive events occurred in southern Hipaniola in the 18th century; some of them are possibly associated with the Enriquillo fault [2, 4]. The sequence started with a large earthquake on October 18th 1751, which caused significant destruction and a tsunami in the gulf of Azua (in southern Dominican Republic). This earthquake is generally associated with rupture of the Muertos thrust belt offshore SE Hispaniola. On November 21th 1751, a strong earthquake destroyed Port Au Prince, a town which had been founded 2 years before (Port au Prince will become the capital of the french colony of Saint-Domingue in 1770, then of Haiti in 1804). Destructions mainly occurred along the Cul de-Sac plain to the E of the city. This earthquake may have ruptured a part of the Enriquillo Fault SE of Port au Prince, although the hypothesis of a thrust rupture on some other fault is equally tenable. On June 3th 1770, a major earthquake destroyed again Port Au Prince as well as towns west of this city (Léogâne, Petit Goâve, Miragoâne). It is likely that this event has occurred on the Enriquillo fault south and SW of Port au Prince. Finally, on April 8th 1860, a major earthquake affected the western end of the Tiburon peninsula and was associated with a tsunami. The effects of the Jan 12, 2010 earthquake appear similar to those of the June 21th 1770 event

The Enriquillo fault trace – Hypothetic location of the rupture :

From the SW of Port au Prince to Tiburon at the western end of the peninsula, the Enriquillo fault trace is segmented by several structural complexities such as changes in strike; pull-apart and push-up structures in releasing or restraining bends (Figure 3 and [4]). From west to east, the major complexities are : the Pic Macaya push-up (high relief there is due to thrusting associated with the restraining bend), the Clonard pull-apart, the

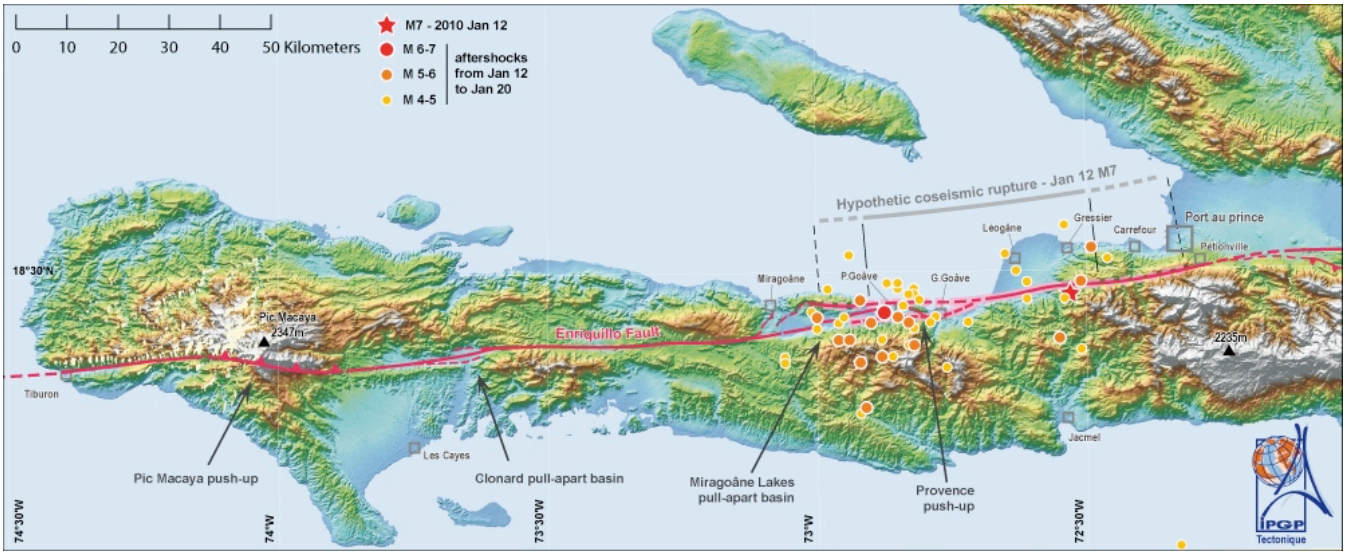

Figure 2 : Sketch map of active fault traces along the Enriquillo fault zone. Location of Jan 12 main shock and aftershocks from USGS. The coseismic rupture probably propagated from the epicenter region towards the W, ending at the Mirogoâne lakes intersegment. Map in part after [4].

Miragoâne Lakes pull-apart zone [4]. The latter zone, relatively complex, shows several pull-apart basins partly shortcut by the more recent active fault traces. It is limited to the E by the small (~8km long) Provence push-up, bounded by two main active fault traces, one, offshore, to the north, the other, onshore, south of Petit Goâve and Grand Goâve. South of Port au Prince, near Pétionville, the fault slightly changes in strike and becomes transpressive to the E, possibly defining another inter-segment. The average, first-order, segment length is 40-60 km. Preliminary interpretation of InSAR data suggest that the Jan. 12 rupture stopped in the region of the Miragoâne pull-apart zone, possibly on the Provence push-up, which probably acted as a barrier for rupture propagation (Figure 2).

About 50 aftershocks with M > 4 have been recorded within the first 8 days after the main Jan. 12 shock with largest magnitudes reaching Mw~6. Aftershocks cluster in two distinct areas (USGS locations) : one around the hypocenter; the other, with more events, close to Petit Goâve and to the stepover of the Enriquillo fault in the Miragoâne plain (Figure 2). So, most of the aftershock activity appears to occur near the western rupture end, a region where the probability of failure may have been increased by static Coulomb stress change (as observed for other earthquakes elsewhere, i.e. Joshua Tree, 1992 M6.1, and Landers, 1992 M7.4, earthquakes [5]).

First results obtained on the seismic data [6] suggest a burst in moment release during the first 10s of the signal and little evidence for rupture propagation. This could suggests that the main rupture was concentrated on a relatively short segment of the fault (a few tens of km in length).

We searched for evidence of coseismic surface breaks along fault traces on Hi-Res satellite images that have been acquired after the Jan. 12 event (SPOT5, ALOS, GeoEye images). Most of the fault trace length lacks clear evidence of such breaks on the images publicly available at the date of Jan. 25 (high quality post-

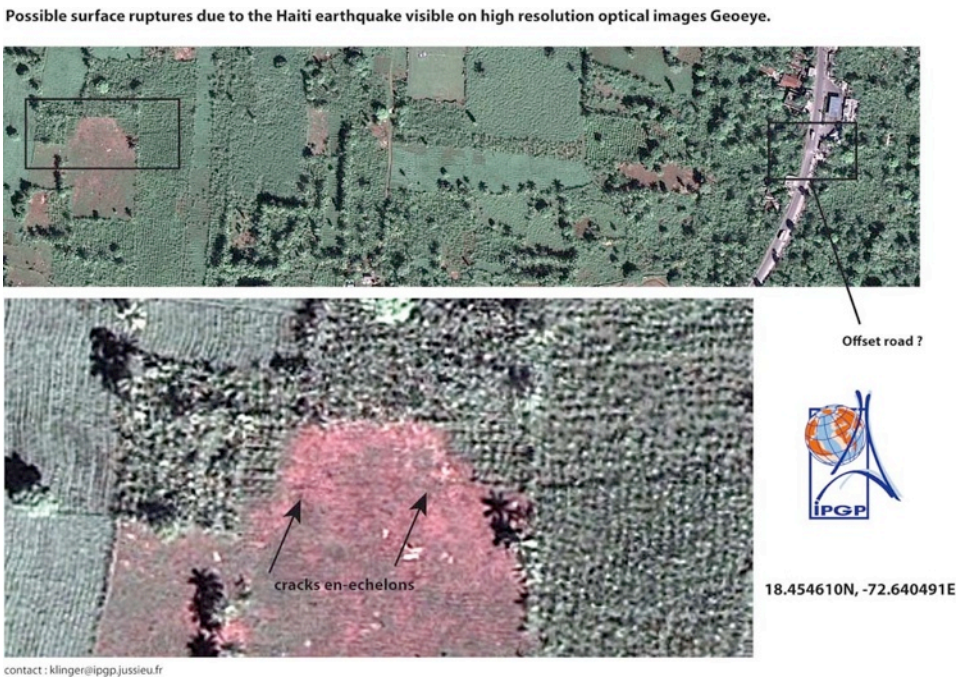

Figure 3a : Possible traces of a coseismic surface break south of Léogâne (GeoEye images, available from Google Earth).

earthquake images are still lacking W of Grand Goâve), although lateral spreading associated with shallow landslides is clearly visible on these images. This probably means that surface ruptures, if they exist, are not detectable given the resolution of the images (submetric in Geoeye images). It implies that surface offsets associated with the earthquake rupture were less than ~1m. For example, in the valleys of Rivière Momance and Rivière Froide, SSW of Carrefour, the active fault trace is clearly marked by cumulative scarps and geomorphic offsets at several places (e.g., at 72°25.64'W -18°28.68'N, or, close to the epicenter, at 72°32.25'W-18°28.68'N). Unambiguous evidence for recent fault reactivation are lacking at these sites. However, we have identified few subtle pieces of evidence indicating possible surface breaks (<0.5m) at one of the sites along the Rivière Momance, and also along the southern border of the Léogâne plain (Figure 3).

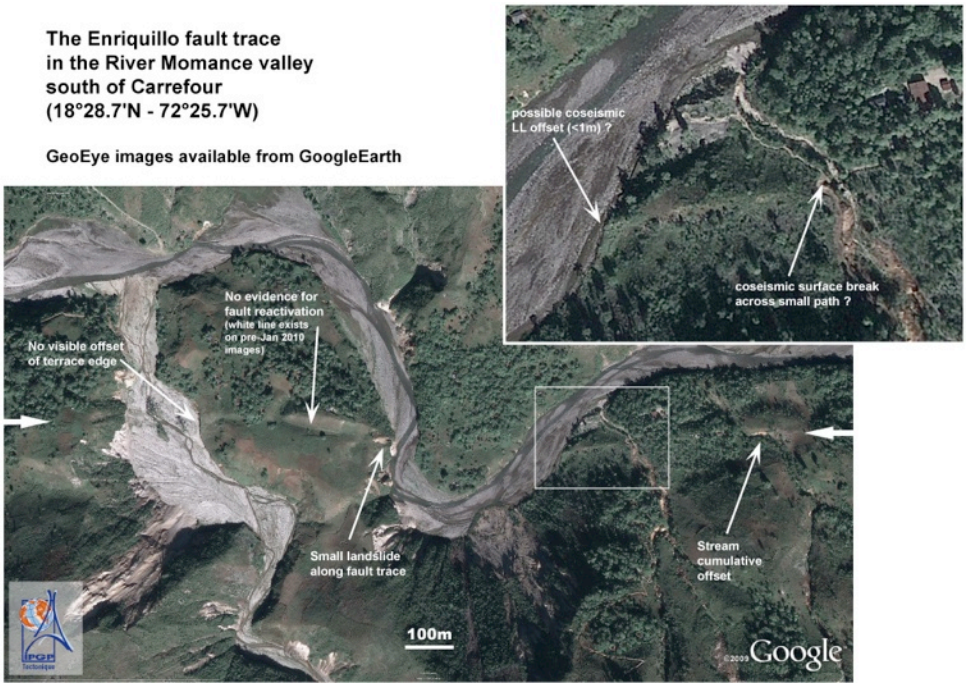

Figure 3b : The Enriquillo fault trace in the Rivière Momance valley. (GeoEye images).

First results of pixel-correlation using visible (SPOT [R. Binet, CEA/CIEST, work in progress]) or radar data [6, and M. de Michele, BRGM/CIEST, work in progress] cover the Enriquillo fault from Pétionville to the Léogâne plain. These results are very noisy and affected by still uncorrected topographic biases. Some of them show ambiguous and intriguing signals, incompatible at the first order with the seismologic, geomorphic and tectonic constraints. Evidence for localized left-lateral offsets along the trace of the Enriquillo Fault are lacking on these data, although a gradient in the far field data could be compatible with left-lateral coseismic shear.

The first interferogram calculated from ALOS data and made available by JAXA [8] suggests that the rupture terminated to the W near Petit Goâve, thus close to the Provence push-up and Miragoâne pull-apart zone. The interferogram shows the end of a lobe of fringes south of the fault where motion has been away from the

satellite (in the line of sight, or LOS, direction), which may be interpreted as the western termination of the left lateral rupture (Figure 4). From these data, the exact location of the ruptured fault west of Grand Goâve is difficult to assess. If the interpretation represented on Figure 4 is correct, it might be onshore, on the fault bounding the Provence push-up to the south. From the continuity of the lobes of fringes on both sides of the this fault, we infer that the rupture likely remained blind at its western end. At the date of Jan. 25, as comparable data are lacking towards the E, we cannot assess the eastern end of the ruptured segment.

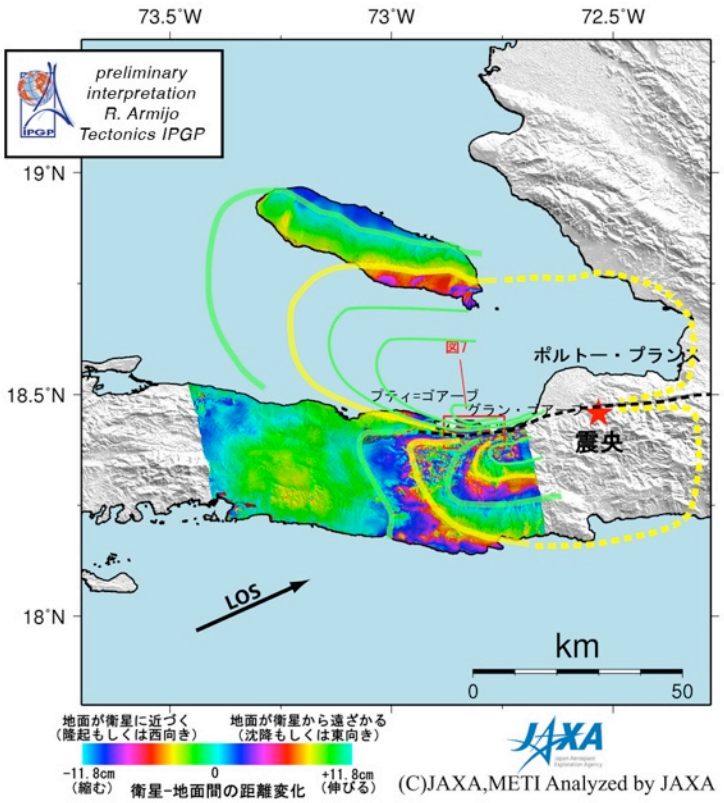

Figure 4 : Tentative interpretation of the Alos interferogram.

Preliminary conclusions :

The 2010 January 12 earthquake broke a segment of the left-lateral Enriquillo fault, a fault that would account for a significant (~7mm/yr [2]) fraction of the motion between Caribbean and N-American plates. W of Haiti the Enriquillo fault prolongates offshore towards Jamaica where it becomes the Plantain garden Fault. The Enriquillo fault, which stretches for ~300km across southern Hispaniola island, was already identified as a potential source of M>7 earthquakes [2]. Before the 2010 event, this fault had not produced significant earthquakes since at least two centuries. At least one event (June 3th 1770) of the sequence that shook southern Hispaniola in the 18th century, likely occurred on the Enriquillo fault, with reported effects resembling those of the 2010 event. Only a relatively short segment of the fault (~30km, possibly 50km, Figure 2) seems to have

been activated by the January 12 event. Large earthquakes on long-quiescent, strike-slip fault zones tend to trigger one another, thus producing sequences of destructive events like those well documented on the North Anatolian Fault in Turkey. We thus infer that the rupture of segments east of the Jan. 12 source (immediately SE of Port au Prince) and west of it (across Tiburon peninsula) is likely to occur in the coming decades.

At the date we are writing (Jan. 25th), conclusive evidence to constrain the exact length of the ruptured segment, the location of surface breaks (if any) and the amount of coseismic slip at the surface, are lacking. However, first InSAR results may help to define the western end of the rupture, which apparently stopped in the region east of the Miragoâne lakes pull-apart. The lack of clear coseismic surface break and measurable offsets along the fault on available post-earthquake high-res imagery suggests that slip at the surface has been less than 0.5–1m and/or is distributed across a large zone. New constraints on the deformation field (in particular InSAR interferograms covering the eastern part of the rupture, and GPS measurements), higher resolution imagery (aerial photographs, topography acquired with Lidar, for instance), and field survey are clearly needed. Finally, the lack of geomorphic studies and of paleoseismological trenching along the Enriquillo fault implies that its average rate is not known at geological time-scales, neither is its seismic history precisely established.

Short bibliography - Useful links :

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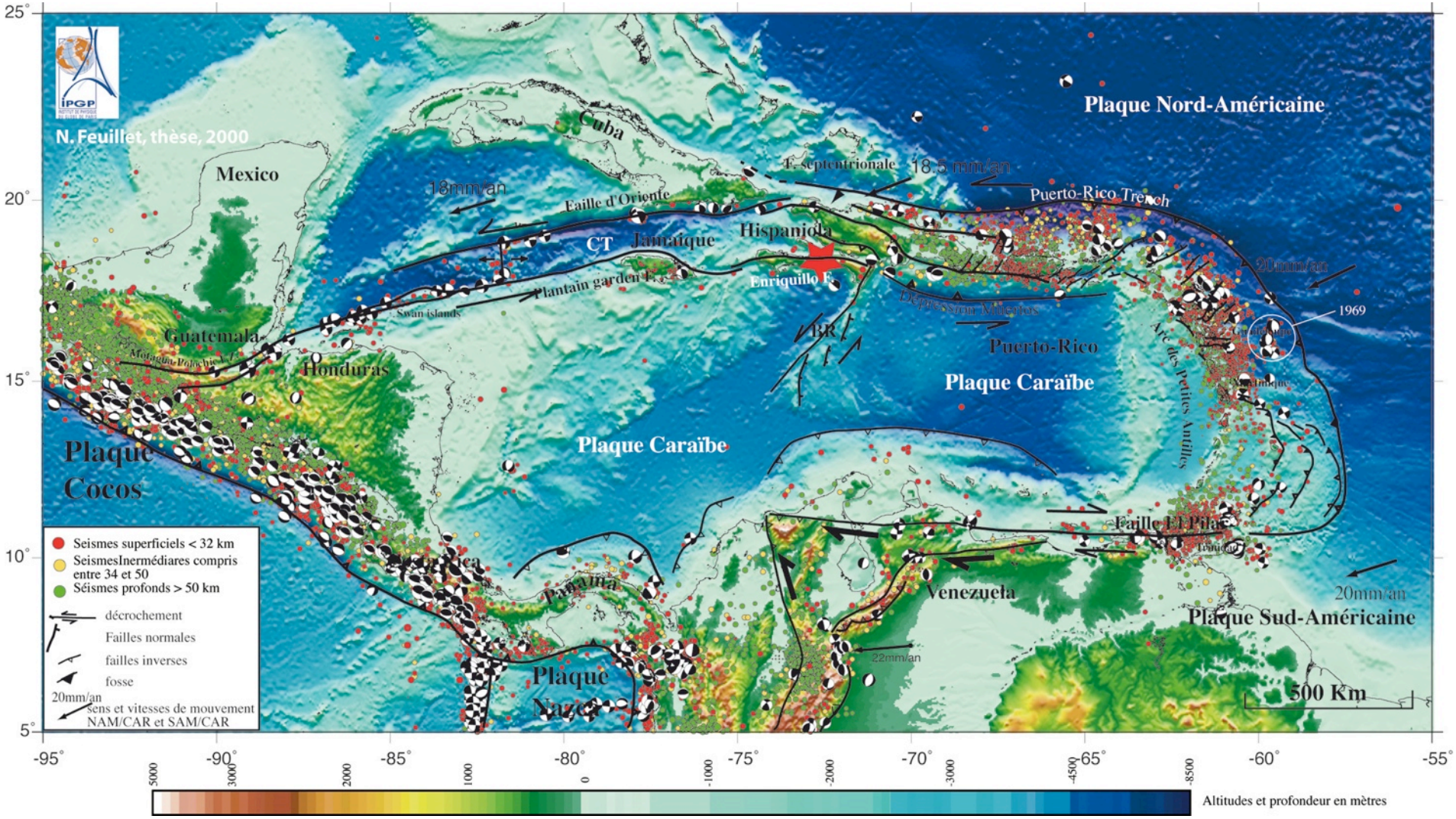
[6] Gavin Gayes (NEIC-USGS) model http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010rja6/finite_fault.php – Martin Vallée (Geoazur, Univ. Nice) model http://geoazur.oca.eu/spip.php?article614 – Anthony Sladen (Caltech) model http://tectonics.caltech.edu/slip_history/2010_haiti/

[7] Correlogram of TerraSAR-X data : http://www.zki.dlr.de/applications/2010/haiti/182_en.html and DLR's report (in PDF format)

[8] First ALOS interferogram from JAXA : http://www.eorc.jaxa.jp/ALOS/img_up/jdis_pal_haiti_100116.htm. See also http://www.eorc.jaxa.jp/ALOS/en/img_up/dis_pal_haiti_100116.htm

Some usefull web pages :

- IPGP : http://www.ipgp.fr/pages/040114.php
- Geoazur, Nice : http://geoazur.oca.eu/spip.php?article614
- EMSC : http://www.emsc-csem.org/index.php?page=current&sub=recent&evt=151256
- CEA/DASE : http://www-dase.cea.fr/actu/dossiers_scientifiques/2010-01-13/index.html
- CNRS/INSU : http://www.insu.cnrs.fr/a3348,seisme-haiti-12-janvier-2010.html
- Eric Calais - Purdue University : http://web.ics.purdue.edu/~ecalais/haiti/
- Univ. of Texas Austin (Paul Mann) : http://www.jsg.utexas.edu/news/rels/011310.html



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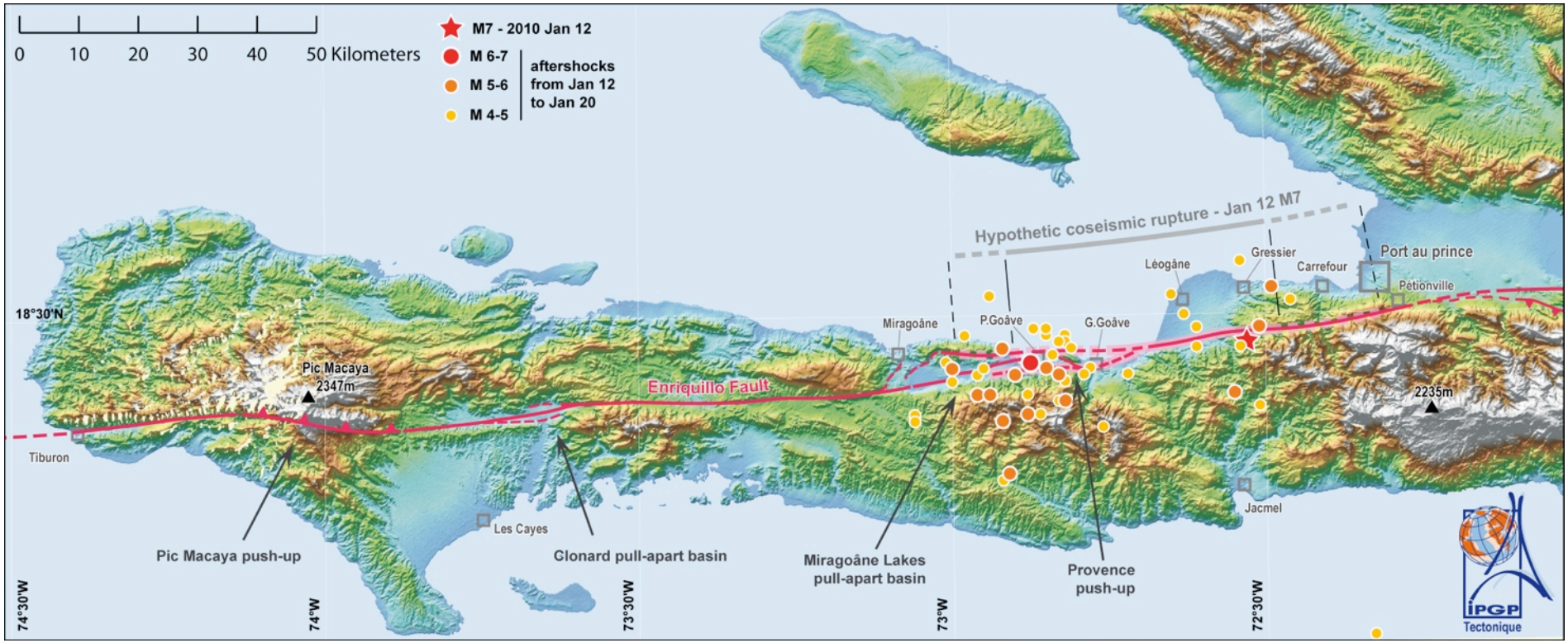

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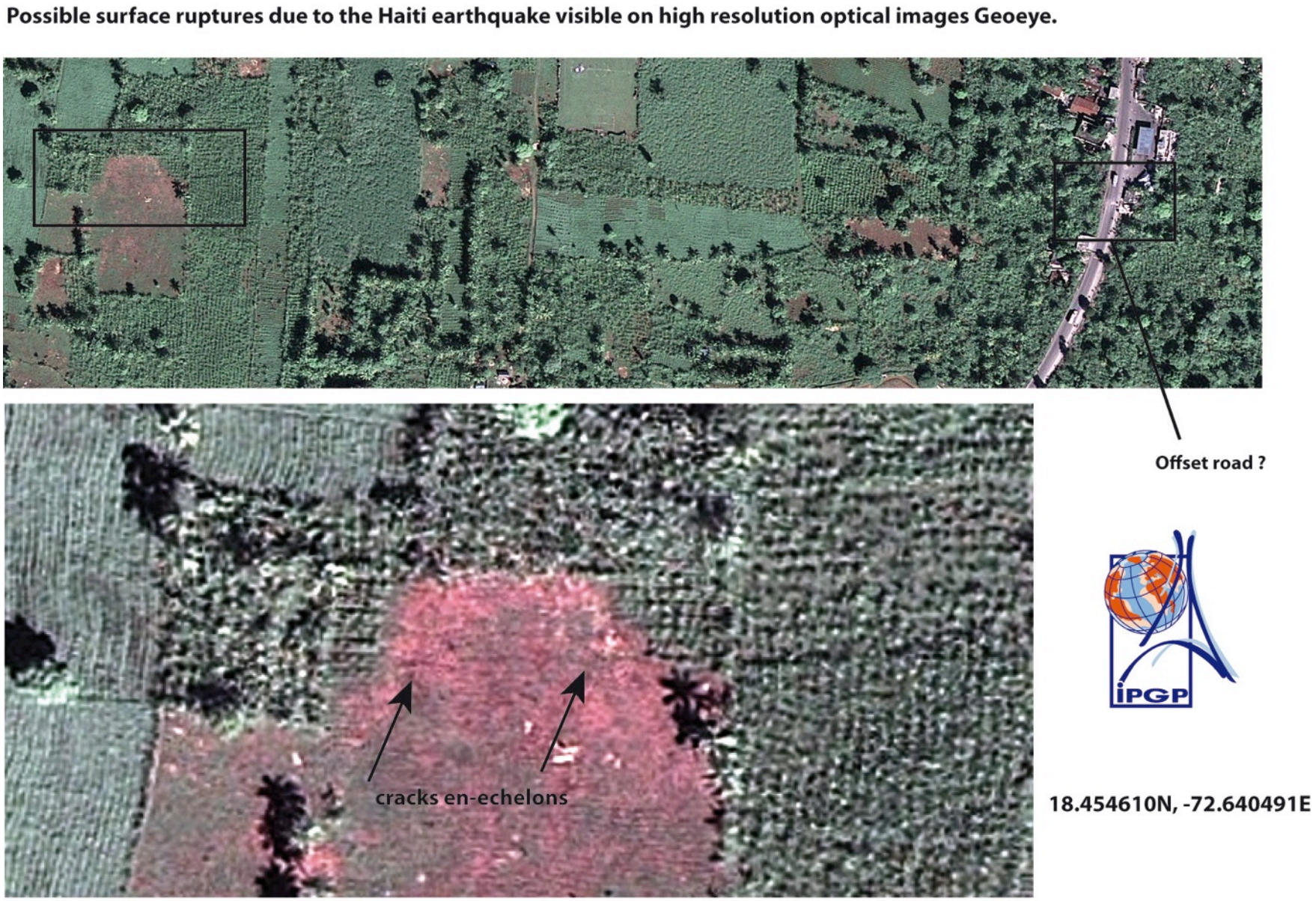

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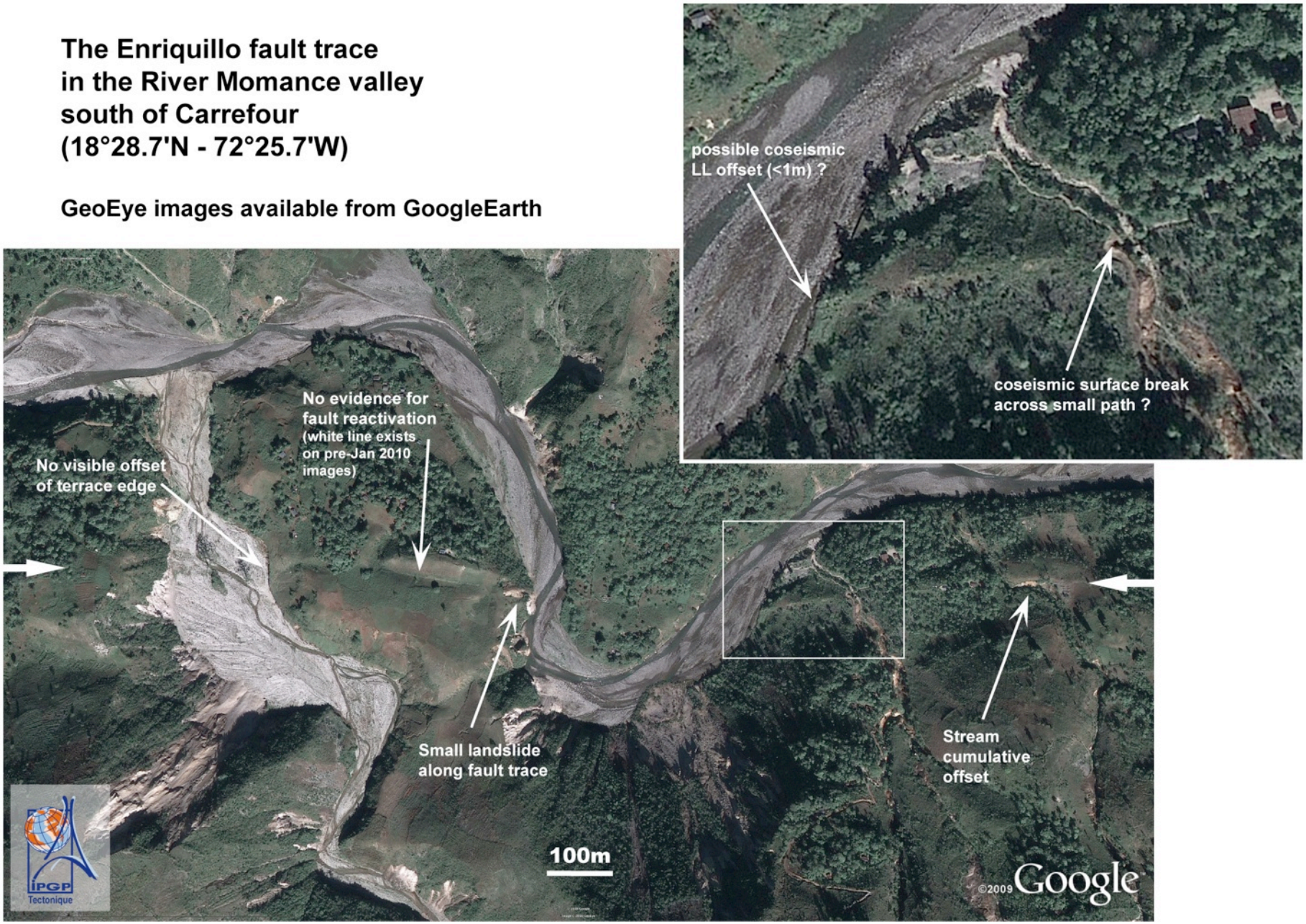

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