

Key Points:

- Thrust faults and associated large-scale folds are the main active structures
- Seismicity defines a crustal-scale southward-dipping ramp structure related to Caribbean Large Igneous Province accretion
- Large-scale fault zones could have generated the 1751 M_w 7.5 Azua earthquake in the Ocoa Bay

Supporting Information:

Supporting Information may be found in the online version of this article.

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Present-Day Shortening Accommodated by Folding, Thrusting and Strike-Slip Faulting in the Enriquillo Basin of Southern Central Hispaniola: Implications for the Regional Seismic Hazard

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Abstract Hispaniola accommodates a significant portion of the present-day convergence between Caribbean and North American plates. Located in southern Hispaniola, the Neogene Enriquillo basin is bounded by the Neiba and Bahoruco mountain ranges. The role of active individual faults and fault systems in this basin is not well understood, particularly their geometry and kinematics, slip rates and seismic activity. Knowing this information is important to characterize the active deformation pattern in southern Hispaniola, but it is also crucial to estimate the regional seismic hazard. Here, we analyze GPS geodetic data and seismicity and present the results of fault mapping of the Enriquillo basin based on tectonic field observations, radiocarbon and luminescence dating, remote sensing and regional magnetic data. These observations indicate that WNW to NW-trending thrust faults and associated large-scale folds, as well as minor strike-slip and normal faults, have been active both in the Tertiary rocks within the mountain ranges and in the basin margins along the Quaternary. Inversion of fault-slip data establishes that a NE-directed shortening has controlled the formation of these structures. We propose a regional kinematic model in which the present-day kinematics of each main fault depend strongly on its orientation with respect to the regional stress tensor. Computed seismic hazard defines a map pattern for the peak ground acceleration elongated to the main seismotectonic fault zones. Regions around the southwest Sierra de Neiba, the western Enriquillo basin and the northwest Sierra de Bahoruco, where peak ground acceleration exceed 500 cm/s², have a high seismic hazard.

1. Introduction

The devastating 12 January 2010 M_w 7.0 Leogâne and 14 August 2021 M_w 7.2 Nippes earthquakes produced by the strike-slip system of the Enriquillo-Plantain Garden Fault Zone (EPGFZ) in the southwestern Hispaniola (Haiti and Dominican Republic) warn of the existence of a high seismic hazard in the region (Bakun et al., 2012; Calais et al., 2010, 2022; Douilly et al., 2022; Hayes et al., 2010; Maurer et al., 2022; Mercier de Lépinay et al., 2011; Okuwaki & Fan, 2022). This seismic hazard is a consequence of the location of Hispaniola at a plate boundary zone, where the present-day oblique convergence of the Caribbean plate occurs at a rate of ~20 mm/yr toward the NE relative to the North American plate (Calais et al., 2002, 2016; Mann et al., 2002). The resulting transpressional deformation is partitioned between several large-scale, active thrust and strike-slip faults (Hernández-Huerta & Pérez-Estaún, 2002; Mann, Draper, & Lewis, 1991; Mann et al., 1995), which have probably been the source of the largest earthquakes documented in the past 250 years (Bakun et al., 2012; Calais et al., 2010; Mercier de Lépinay et al., 2011; Prentice et al., 2010).

To understand the Leogâne earthquake, several geological and geophysical studies have been carried out to constrain the crustal structure and the geometry of the main active faults in the area of the main shock near the city Port-au-Prince and the entire southern Haiti region (Calais et al., 2010, 2016, 2022; Corbeau et al., 2016, 2019; Douilly et al., 2013; Mercier de Lépinay et al., 2011; Saint Fleur et al., 2019; Wang et al., 2018; Wessels et al., 2019). The adjacent southern region of the Dominican Republic has been simultaneously the subject of several studies, such as the SYSMIN project for systematic geological mapping of the country (Pérez-Estaún et al., 2007), the acquisition of magnetic and radiometric aerogeophysical data (Ayala et al., 2017), and the development of a progressively denser permanent seismic network (Rodríguez et al., 2018). However, several

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issues remain poorly understood, as the detailed geometric and kinematic characteristics, degree of strain partitioning and Quaternary slip rates of the main active fault systems, as well as their seismic activity over time constrained by geochronological data. This information is essential for understanding the present-day tectonics of southern central Hispaniola, but it is also crucial to establish the potential seismogenic sources, a seismotectonic zonation model, and the seismic hazard in this densely populated region.

The aims of the present contribution are: (a) to characterize the active deformation pattern in the Enriquillo basin and adjacent Bahoruco and Neiba mountain ranges, based on tectonic field observations, complemented with digital elevation models, regional magnetic and geodetic data, and the analysis of the seismicity; (b) to determine the Quaternary stress regime by inversion of fault-slip data, constrained by dating faulted Quaternary deposits by geochronological methods; and (c) to split the southern central Hispaniola region into a set of simplified seismogenic zones as a starting point for a subsequent probabilistic seismic hazard modeling in terms of the peak ground acceleration (PGA).

2. Geological Setting

2.1. Arc-Continent Collision and Subduction Polarity Reversal in the Northern Caribbean Plate

Located on the northern edge of the Caribbean plate, the geology of Hispaniola results from the SW-dipping Cretaceous subduction to middle Eocene oblique collision of the Caribbean intra-oceanic arc with the southern continental margin of North America (Mann, Draper, & Lewis, 1991; Draper et al., 1994; Escuder-Viruete & Castillo-Carrión, 2016; Escuder-Viruete et al., 2011a, 2011b, 2013, 2016b, 2016c; Pérez-Estaún et al., 2007). The arc-continent collision produced the blocking of the suture zone in northern Hispaniola and induced the transfer of deformation to the back-arc region in southern Hispaniola with the subduction polarity reversal (e.g., Escuder-Viruete et al., 2023; Kroehler et al., 2011). This last process led to the beginning of subduction along a new NE-dipping subduction zone, as well as deformation by back-thrusting at the resulting Peralta-Muertos accretionary prism between the middle Eocene and late Oligocene (Dolan et al., 1991; Escuder-Viruete et al., 2024a; Hernáiz-Huerta & Pérez-Estaún, 2002; Mann, McLaughlin, & Cooper, 1991; Witschard & Dolan, 1990). The new subduction zone separated the Venezuela basin from the upper island-arc crust of central Hispaniola.

2.2. Oblique Collision of the Caribbean Oceanic Plateau to the Accretionary Prism

From the early Miocene, the ENE movement of the central Caribbean plate gave rise to the oblique accretion of the northern sector of the Cretaceous Caribbean oceanic plateau of transitional crust, or Caribbean Large Igneous Province (CLIP), with the Peralta accretionary prism. The related deformation resulted in the formation of the SW-directed Haitian-Neiba fold-and-thrust belt and the San Juan-Azua basins in the foreland (Dolan et al., 1991; Escuder-Viruete et al., 2023, 2024a; Granja Bruña et al., 2009, 2014; Hernáiz-Huerta & Pérez-Estaún, 2002; Heubeck & Mann, 1991; Pubellier et al., 2000; Witschard & Dolan, 1990). During the Pliocene and until the present-day, convergence gave rise to the accretion of the central sector of the Caribbean oceanic plateau of thickened crust, causing the uplift and folding of the Massif de la Selle-Sierra de Bahoruco and the tectonic individualization of the Enriquillo-Cul-de-Sac basin (Díaz de Neira, 2004a, 2004b; Hernáiz-Huerta & Pérez-Estaún, 2002; Hernáiz-Huerta et al., 2007b; Mann, McLaughlin, & Cooper, 1991; Mann et al., 1995). Associated to arc-oceanic plateau collision, the impingement of the thickened crust of the Beata Ridge gave rise to a recess of the Muertos accretionary prism and the clockwise rotation of fold and thrust structures of the Peralta Belt (Granja Bruña et al., 2014; Hernáiz-Huerta & Pérez-Estaún, 2002; Mann, McLaughlin, & Cooper, 1991; Mercier de Lépinay, 1987). The NNE to NE-striking Ocoa-Bonao-La Guacara Fault Zone (OBFZ) accommodated part of the present-day stress-field induced by the Beata Ridge collision within the Hispaniola microplate (Figure 1; Escuder-Viruete et al., 2023). This active fault zone has recently been proposed as the onland transition between oceanic subduction and arc-oceanic plateau collision in southern Hispaniola (Escuder-Viruete et al., 2023).

2.3. Present-Day Geodynamic Configuration of Southern Hispaniola

The successive collision processes have also led to the fragmentation of the northern Caribbean plate into several microplates, bounded by large-scale fault zones that accommodate their current relative motion (Figure 1). The Septentrional microplate is a wedge-shaped forearc sliver, limited offshore to the north by the Northern Hispaniola Fault Zone (NHFZ) and onshore to the south by the Septentrional Fault Zone (SFZ; Dolan et al., 1998; Mann et al., 2002; Escuder Viruete & Pérez, 2020; Escuder Viruete et al., 2020).

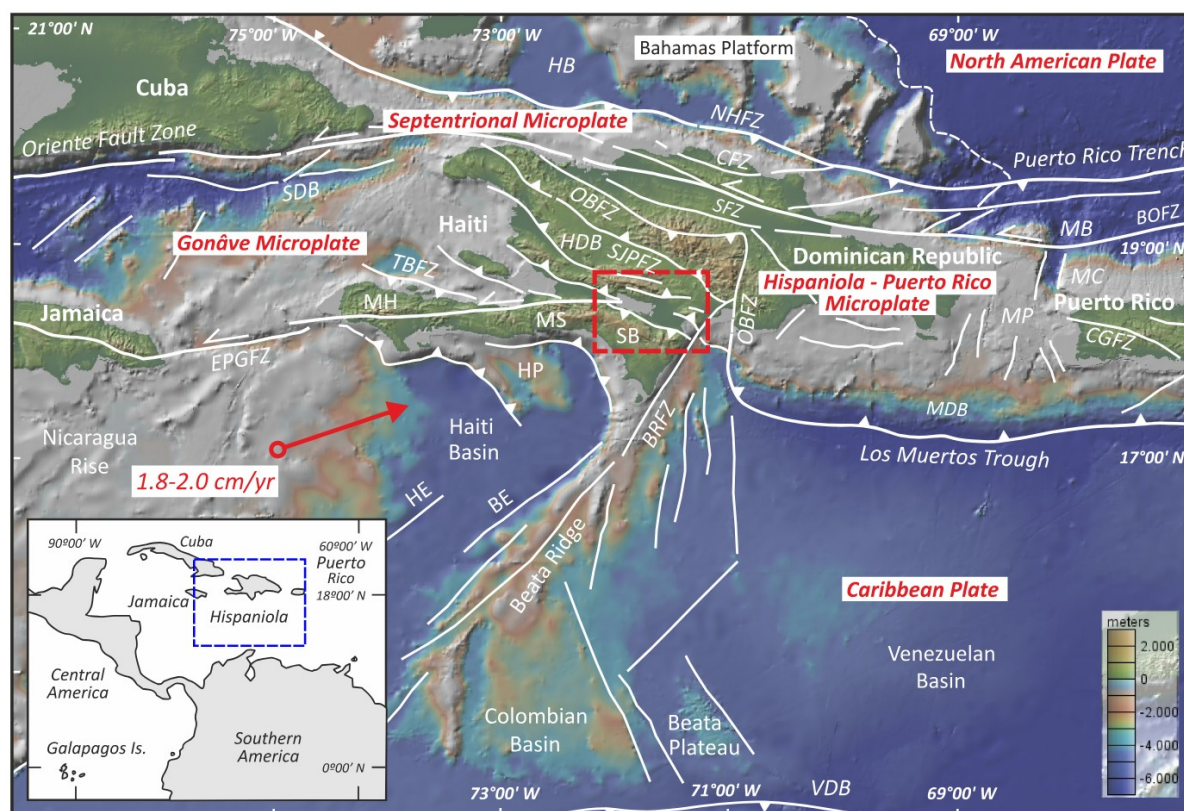


Figure 1. (a) Geodynamic context of Hispaniola in the northern margin of the Caribbean Plate showing the location of microplate boundaries and main fault zones and structures. The red arrow defines the movement vector of the Caribbean Plate respect to the North American Plate (mod. Mann et al., 2002). Topography in color scale has been made from the GMRT synthesis data set (Ryan et al., 2009) with *GeoMapApp* (www.geomapapp.org). The discontinuous red rectangle defines the location of the study area in the Dominican Republic (Figures 2 and 3). Abbreviations: BE, Beata Escarpement; BOFZ, Bowin Fault Zone; CFZ, Camú fault zone; CGFZ, Cerro Golden Fault Zone; EPGFZ, Enriquillo-Platain Garden Fault Zone; HDB, Haiti Deformed Belt; HP, Haiti Plateau; HB, Hispaniola Basin; MC, Mona Canyon; MH, Massif de la Hotte; MP, Mona Passage; MS, Massif de la Selle; MDB, Muertos Deformed Belt; NHFZ, North Hispaniola Fault Zone; OBFZ, Ocoa-Bonao-La Guacara fault zone; SB, Sierra de Bahoruco; SDB, Southern Deformed Belt; SFZ, Septentrional fault zone; SJPFZ, San Juan-Los Pozos fault zone; TBFZ: Trois Baies fault zone.

The Hispaniola-Puerto Rico microplate is an arc-crust block, limited to the north by the SFZ and to the south by the Muertos Trough (MT). To the west, the boundary between the Hispaniola block and Gonâve microplate is located in the San Juan-Los Pozos fault zone (SJPFZ). In central and southern Hispaniola, the microplate includes the Cordillera Central domain and the Peralta-Muertos deformed belt. The Cordillera Central in the Dominican Republic and its prolongation in the Massif du Nord in Haiti is an Upper Jurassic-Upper Cretaceous basement composed of Pacific Basin-derived oceanic units (Escuder-Virue et al., 2008; Mann, Draper, & Lewis, 1991). The Peralta Belt (PB) is a NW-trending and SW-verging fold-and-thrust belt, structurally located between the San José-Restauración (SJRFZ) and the San Juan-Pozos fault zones (Mann, McLaughlin, & Cooper, 1991). The belt recorded the turbiditic sedimentation in the back-arc basin of the Caribbean island-arc between the Campanian to the early Eocene, and its evolution to a transpressive fold-and-thrust belt in the middle Eocene to early Miocene (Dolan et al., 1991; Hernáiz-Huerta et al., 2007b; Mercier de Lépinay, 1987; Witschard & Dolan, 1990). The MT marks the boundary between the subducted floor of the Caribbean plate and the overlying deformed belt south of eastern Hispaniola and Puerto Rico (Figure 1). Seismic reflection profiles across the MT image an N-dipping low-angle thrust structure, with folded and faulted sedimentary rocks on top forming an accretionary prism (Dolan et al., 1998; Granja Bruña et al., 2009, 2014; Mauffret & Leroy, 1999). A geodynamic reconstruction made with *GPlates* (Müller et al., 2018) shows about 100 km of subduction of the Caribbean plate beneath southern Hispaniola (Escuder-Virue et al., 2024a; see also Pindell & Kennan, 2009; Boschman et al., 2014).

The Gonâve microplate is bounded to the north by the Oriente Fault Zone (OFZ) and to the south by the EPGFZ. The microplate includes the Haitian-Neiba fold-and-thrust belt and San Juan-Azua and Enriquillo foreland basins, which form the southeastern extension of the Plateau Central and Cul-de-Sac basins in Haiti (Hernáiz-Huerta &

Pérez-Estaún, 2002; Heubeck & Mann, 1991; Pubellier et al., 2000). The Haitian-Neiba belt consists of a NW-trending and SW-verging fold-and-thrust belt, bounded to the north by the NE-dipping SJPFZ (Hernández-Huerta et al., 2007a; Mann et al., 1995; Pubellier et al., 2000). In the Sierra de Neiba (Figure 2), the belt is made up of middle Eocene to Oligocene limestones of the Neiba Formation (Fm) and, to a lesser extent, by early to middle Miocene marly limestones of the Sombbrero Fm. The tholeiitic to alkaline geochemical signature of the mafic volcanic rocks that form the late Cretaceous substrate and the Aguacate volcano-sedimentary complex intercalated between the Neiba Fm limestones suggest that the Sierra de Neiba sector is part of the CLIP (Hernández-Huerta et al., 2007a). Activation of the thrust bounding the northeast Montagnes Noires-northern Sierra de Neiba thrust sheet during the lower-middle Miocene and the thrust bounding the southwestern Chaîne des Matheux-southern Sierra de Neiba thrust sheet during the middle-upper Miocene, indicates a southwestward progression of deformation with time (Pubellier et al., 2000). Tilting and faulting of Holocene age deposits in the northern margin of the Enriquillo basin indicate that the thrust belt is still active (García Senz, 2004; Hernández-Huerta et al., 2007b), which agrees with the seismic activity described by Corbeau et al. (2019).

The Sierra de Bahoruco is part of the Hotte-Selle-Bahoruco terrain in the southern Hispaniola (Figure 1; Mann, Draper, & Lewis, 1991). Onshore/offshore seismic refraction, wide-angle reflection and receiver function studies indicate a 26–35 km thick crustal thickness at the Sierra de Bahoruco (Kumar et al., 2020; Núñez et al., 2016, 2019). The core of the mountain range is constituted by the Cretaceous Dumisseau Fm, which forms a >2.0 km-thick sequence of submarine basaltic flows, pyroclastic deposits and intercalated pelagic sediments, intruded by doleritic dikes and sills (Joubert, 2010; Pérez Valera & Abad, 2010). The geochemical and isotopic characteristics of the mafic volcanic rocks establish a mantle-plume source similar to those of the CLIP (Escuder-Viruete et al., 2016b). This volcanic basement is unconformably overlain by a 1.5 km-thick sequence of middle Eocene-Oligocene pelagic limestones of the Neiba Fm and Miocene shallow-water marine limestones of the Barahona Fm. The frontal tectonic contact between the Sierra de Bahoruco and the Enriquillo basin is located at the Bahoruco fault zone (BAFZ), which integrates a NW-trending and NE-verging system of mid to high-angle thrusts (Figure 2).

The Beata Ridge is a NE-trending bathymetric high, more than 450 km long, built on the Caribbean plate (Figure 1; Mauffret & Leroy, 1999; Mauffret et al., 2001; Granja Bruña et al., 2014). The ridge comprises an unusually thick oceanic crust (20–22 km; Núñez et al., 2016, 2019), essentially made up of gabbros, dolerites and basalts of the CLIP (Dürkefeld et al., 2019). NNE to NE-striking faults mainly controls the crustal thickness of the Beata Ridge, as the Beata Ridge fault zone (BRFZ) that follows its axial trend (Granja Bruña et al., 2014). The BRFZ continues to the NE, abruptly limiting the Sierra de Bahoruco and Sierra Martín García to the southeast, until it intersects the SJPFZ in the western Ocoa Bay. As the OBFZ, the BRFZ also accommodated part of the present-day shortening induced by the Beata Ridge collision (Figure 1; Escuder-Viruete et al., 2023). In the Ocoa Bay, the BRFZ bends the fold and thrust structures of the Peralta Belt and the SJPFZ, as well as deforms the lower Miocene to Early Pleistocene sedimentary fill of the Azua basin.

2.4. The Enriquillo Basin

The Enriquillo basin is a WNW-trending flexural basin limited by two thrust systems of opposite vergence: to the northeast by the SW-verging Matheux-Neiba fault zone and to the southwest by the NE-verging Bahoruco fault zone (Figure 2; Mann et al., 1995; Hernández-Huerta & Pérez-Estaún, 2002; Deschamps & Fondeur, 2004; Díaz de Neira, 2004a, 2004b; García Senz, 2004; Hernández-Huerta, 2004; Hernández-Huerta et al., 2007b; Nicol, 2004). The basin is filled by a ~4 km-thick upward shallowing and coarsening mega-sequence composed of Miocene to Early-Middle Pleistocene marine sediments (Deschamps & Fondeur, 2004; Díaz de Neira, 2004a, 2004b; García Senz, 2004; Hernández-Huerta, 2004; Mann et al., 1999; McLaughlin et al., 1991; Nicol, 2004). The mega-sequence includes initial deposition of turbiditic-type clastic sediments in a deep marine environment in the middle to upper Miocene (Trinchera Fm) and in a shallow-water platform in the lower Pliocene (Quita Coraza Fm). The regressive character of sedimentation gave rise in the Pliocene to shallow-marine clastic and coral reef deposits (Arroyo Blanco Fm), halite and gypsum evaporites in the center of the basin (Angostura Fm), and fine-grained saline bay sediments (Las Salinas Fm). The change to continental deposition took place in the late Pliocene-Early Pleistocene in the northern Enriquillo basin, with the sedimentation of coarse-grained clastic sediments (Arroyo Seco Fm), and in the Early-Middle Pleistocene in the southern Enriquillo basin, with an upward change from reef limestones and supralittoral marls (Jimaní Fm) to alluvial-fan breccias and conglomerates. The relationships

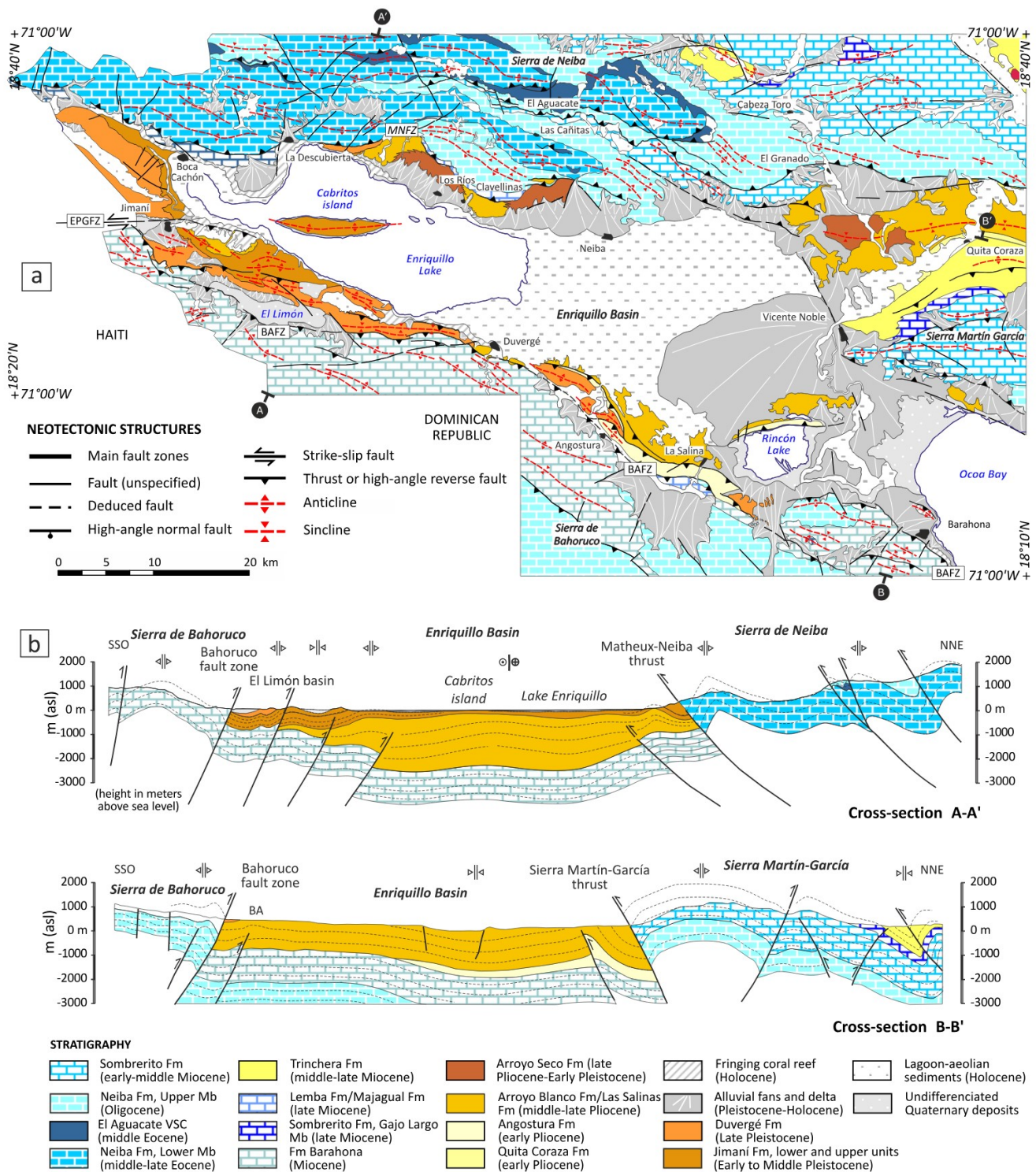


Figure 2. (a) Schematic geologic map of the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges in southern Hispaniola (mod. from the SYSMIN Project; Pérez-Estaún et al., 2007). (b) Geological cross-sections through the Enriquillo basin (location is shown in a; mod. from Hernáiz-Huerta et al., 2007b). Abbreviations as in Figure 1, in addition: BAFZ, Bahoruco fault zone.

between Middle to Late Pleistocene to Holocene sedimentation and regional tectonics in the Enriquillo basin are described below.

3. Methodology

3.1. Topographic, Bathymetric, and Magnetic Data Sets

In the present study we used the following topographic and bathymetric data sets: (a) digital elevation models (DEM) from the Shuttle Radar Topography Mission with a resolution of 30 m (SRTM15+; Tozer et al., 2019); (b) DEM obtained from ALOS Global Digital Surface Model with a resolution of 25 m (Takaku et al., 2020); (c) satellite images from Google Earth Pro® (<http://earth.google.com>) with a resolution from 1 km to 10 m; and (d) topographic profiles obtained from the GMRT data -set (available with GeoMapApp; www.geomapapp.org; Ryan et al., 2009). These combined resolutions are appropriate for the analysis of tectonic structures at different scales.

We jointly analyze the regional lithological, structural and magnetic data to constrain the crustal structure underlying southern central Hispaniola, to establish the distribution of different crustal blocks with specific geophysical properties at the surface, and to identify their tectonic boundaries. The magnetic data set proceeds from the aerogeophysical flight carried out between 1995 and 1997 by the Compagnie Générale de Géophysique (CGG) in the onland territory of the Dominican Republic, in the context of the SYSMIN Program of the EU of *Cartografía geotemática de la República Dominicana* (García Lobón & Rey Moral, 2004). The data were obtained with a 500 m line separation and a nominal height of 120 m. Additional information on the magnetic data and their preliminary interpretation can be found in García Lobón and Rey Moral (2004), García-Lobón and Ayala (2007), and Ayala et al. (2017). A new analysis of the magnetic data was carried out with the Geosoft Oasis Montaj® software, building a grid of 250×250 m cell size using a minimum curvature algorithm. Several procedures were followed to ensure data quality, such as micro-leveling and filtering frequencies greater than Nyquist. The resulting total magnetic field data were modified using a reduction technique to the pole, which assumes a local inclination of 48°N and a declination of 10°W . This technique removes the inclination effect of the total magnetic field by transforming the anomaly into the vertical component of the field produced as if the source were at -90° inclination in the North magnetic pole. The inclination and declination used in the reduction to the pole were calculated from the International Geomagnetic Reference Field subroutine in Oasis Montaj® based on the latitude and longitude. The first vertical derivative grid was also calculated to highlight and better enhance the fault zones and the edges of magnetic anomalies identified from the total magnetic field. We interpret the magnetic grids on variations in amplitude, wavelength character, lineament distribution, texture, and structural discontinuities.

3.2. Geodetic Data

The geodetic data used in this study come from measurements at periodic (Benford et al., 2012; Calais et al., 2016, 2022) and permanent GPS stations (UNAVCO GPS/GNSS data center; <https://www.unavco.org/data/gps-gnss/gps-gnss.html>) carried out in the Dominican Republic and Haiti. The velocities used here are a subset of a station data set covering the entire Caribbean region openly available online (Calais et al., 2022), routinely processed following the procedure described in Symithe et al. (2015). The velocity field was analyzed in a reference frame attached to the Caribbean plate, which involves rotating the velocities originally expressed in the International Terrestrial Reference Frame (ITRF2014) into a Caribbean-fixed frame. The coordinates and relative velocities of the GPS stations used in this study are included in the Supporting Information S1.

3.3. Seismicity

We compile an earthquake catalog to determine their spatial and temporal distribution, to establish the seismic activity of the main fault zones, and to characterize the seismic parameters of the seismogenic sources. For southern Hispaniola, the compiled catalog includes historical (SISFRANCE-Antilles, 2009; Bertil et al., 2015; Flores et al., 2011; McCann et al., 2011; ten Brink et al., 2011; Bakun et al., 2012; and references herein) and instrumental data (Álvarez et al., 1999; Tanner & Shepherd, 1997; Terrier-Sedan & Bertil, 2021; ISC and USGC-NEIC catalogs). We obtained the information about earthquakes in ghost areas of the global seismic network from the local network, which is made up by the *Instituto Sismológico Universidad Autónoma de Santo Domingo* (ISU; www.uasd.edu.do), the *Observatorio Sismológico Politécnico Loyola* (OSPL; www.ospl.ipl.edu.do) and the

Projet Ayiti-Seismes CARIBACT (www.ayiti.unice.fr/ayiti-seismes). The catalog was revised for data quality, duplication of events, and foreshocks/aftershocks (e.g., Bertil et al., 2015), as well as homogenized to the moment magnitude scale (M_w). Details of the compiled catalog are included in Escuder Viruete et al. (2020, 2023). Following Terrier-Sedan and Bertil (2021), we classified the earthquakes of the catalog into three groups: historical data before 1750 of a high uncertainty related to the location and magnitude; historical data between 1750 and 1960 of intermediate uncertainty; and instrumental data after 1960 generally of low uncertainty. The catalog includes at least 10 earthquakes of $M_w \geq 6.0$ that have affected the southern Hispaniola region, including the 1615 (destroyed Santo Domingo), 1673 (affected Santo Domingo), 1684 (affected Azua and Santo Domingo), 1691 (destroyed Azua, affected Santo Domingo), 1701 (affected Leogâne), 18/10/1751 (destroyed Azua), 21/11/1751 (affected Port-au-Prince), 1770 (destroyed Port-au-Prince), 1911 (affected San Juan) and 12/01/2010 (destroyed Port-au-Prince) earthquakes.

3.4. Optically Stimulated Luminescence Dating

We sampled fine-grained sandstone, siltstone and laminated mudstone of relatively distal alluvial fan deposits of Quaternary age for optically stimulated luminescence (OSL) dating. They are good candidates for OSL dating because sediments deposited in such continental conditions have a high chance of complete bleaching before burial (Durcan, 2021; Murray & Olley, 2002). The samples are rock cylinders 5 cm in diameter and 10–15 cm in length, from which we extracted the core under dim red light. We treated the samples with the usual preparation methods to isolate 90–250 μm quartz grains through sequential treatment with HCl and H_2O_2 , sodium polytungstate density separation, Frantz magnetic separation and HF treatment. We measured the luminescence signals on multi-grain aliquots (each containing 50 to 80 grains) per sample using the automated Risø TL/OSL-DA-20 reader light at the facilities of the Luminescence Dating Laboratory of CENIEH in Burgos. The instrument is equipped with $^{90}\text{Sr}/^{90}\text{Y}$ beta sources providing doses rates of ~ 0.10 Gy/s at the sample position. Between 12 and 24 quartz multi-grain aliquots of 2 mm were measured following the Single-Aliquot Regenerative-Dose (SAR) protocol at a preheat/cutheat temperature of $220^\circ/200^\circ$, to obtain representative dose distributions. The equivalent dose was estimated using a weighted average of the dose values excluding outliers (dose values outside of 1.5 in the interquartile range). Total dose rates were based on radionuclide activity concentration. Contribution of cosmic radiation were calculated according to the burial depth of the sample. The environmental dose was calculated using the DRAC software (Durcan et al., 2015) after measuring the radioactive elements (U, Th, K, and Rb) using inductively coupled plasma mass spectrometry at the CENIEH. Sample measurements, environmental dose, dose distribution and normalized OSL signal for each measure dose and age calculations are summarized in the Supporting Information S2. Obtained OSL ages and dose-rate information are provided in Table 1.

3.5. Radiocarbon Dating

We collected shell and coral samples from a Holocene fringing coral reef for radiocarbon dating. First, we look the fossils with the scanning electron microscope (SEM) and analyze them by X-ray diffraction (XRD) to estimate their state of recrystallization. These works were done at the IGME-CSIC laboratories in Tres Cantos, Madrid. XRD is a useful tool for this task since aragonitic corals and shells should not contain calcite unless they are recrystallized. Afterward, we send the samples to Beta Analytic Testing Laboratory (www.betalabservices.com), where they were prepared, bleached and analyzed with four in-house NEC accelerator mass spectrometers (AMS) and 4 Thermo IRMS instruments. The calculated age was rounded to the nearest 10 years and reported as radiocarbon years before present (BP), where “present” = 1950 CE. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the ^{14}C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1σ counting statistics. The conventional radiocarbon ages were calibrated to calendar year equivalents by means of the high-probability density range method with BetaCal4.20 (Bronk Ramsey, 2009) using the MARINE20 database (Heaton et al., 2020). A reservoir correction (delta R-value and delta R-error) of -153 ± 17 was used, as calculated from the Beta website (<http://calib.org/marine/>; last access: 01 July 2023) based on the local values of DiNapoli et al. (2021). Quasi-simultaneous analysis of reference materials with the samples was used to validate the radiocarbon analyses. Quality assurance results are reported as expected values versus measured values, which were calculated relative to NIST SRM-4990C and corrected for isotopic fractionation. Results are reported using the direct analytical measure percent modern carbon (pMC) with one relative standard deviation. Agreement between expected and measured values is taken as

Table 1
Results of Optically Stimulated Luminescence Dating

Sample	Longitude (X)	Latitude (Y)	Depth (m)	Quadrangle (E. 1:50k)	Main lithology	U (ppm) ^a	Th (ppm) ^a	K (%) ^a	Rb (ppm) ^a	Dose rate (Gy/ka)	n/N ^b	OD (%) ^c	Burial dose (Gy)	Age (ka) ^d
21JE27	-71.8238	18.4686	5.5	Jimaní	Gravels, sands and muds	1.28 ± 0.04	0.64 ± 0.03	0.23 ± 0.01	6.90 ± 0.24	0.64 ± 0.03	19/24	17	45.1 ± 2.2	71.0 ± 4.5
21JE34	-71.8241	18.4679	2.5	Jimaní	Gravels, sands and muds	1.04 ± 0.03	0.28 ± 0.02	0.05 ± 0.01	1.87 ± 0.09	0.44 ± 0.02	09/12	34	13.9 ± 1.8	31.5 ± 4.2
21JE38	-71.6448	18.4123	7.5	Duvergé	Conglomerates	1.66 ± 0.05	0.67 ± 0.03	0.16 ± 0.01	5.13 ± 0.18	0.64 ± 0.03	22/24	26	24.2 ± 1.4	38.2 ± 2.8
21JE59	-71.1558	18.2320	6.0	Barahona	Gravels, sands and muds	0.35 ± 0.02	1.03 ± 0.04	0.14 ± 0.01	7.56 ± 0.26	0.37 ± 0.02	19/24	24	27.2 ± 1.5	73.4 ± 5.4

Note. Stratigraphic Unit: Duvergé Fm. ^aAnalyses obtained using inductively coupled plasma-mass spectrometry. A 10% relatively uncertainty was applied to U and Th concentrations and a 5% uncertainty to K. ^bN, Number of measured aliquots; n, number of aliquots that provided a dose value and were used for the burial dose estimation. ^cOD, over-dispersion values of the derived dose distribution. ^dOptically stimulated luminescence ages are reported with 1 s and expressed in kiloyears (ka).

being within 2σ agreement to account for total laboratory error. Analytical information, OSL dating results and quality assurance measurements are summarized in Table S2.

3.6. Fault-Slip Data Analysis

Following Angelier (1994), we evaluate stress and/or strain in the studied area using fault-slip data inversion methods. The inversion of fault-slip data to determine stress fields and to demonstrate temporal and spatial changes in the late Cenozoic stress regime has been successfully used in many active tectonic areas around the world (Twiss & Unruh, 1998; C  lerier et al., 2012; and references therein). This involves first collecting fault data such as plane orientation, fault striae direction and sense of slip from kinematic indicators at the outcrop scale in several regionally distributed sites. The next step involves calculate the principal stress axes that best fit the reduced stress tensor from a population of fault-slip data at each measurement site. Inversion results include the orientation (azimuth and plunge) of the principal stress axes ($\sigma_1 > \sigma_2 > \sigma_3$) of a reduced stress tensor as well as the stress ratio R [$R = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$]. This parameter accounts for the shape of the stress ellipsoid. The stress tensor provides information on the stress regime, which can be compressional (with σ_3 vertical), strike-slip (with σ_2 vertical), transpressional (σ_2 or σ_3 vertical and σ_2 close to σ_3 in magnitude), or extensional (with σ_1 vertical). Several inversion methods have been proposed in the literature (see review by C  lerier et al., 2012; Riller et al., 2017; Sperner & Zweigel, 2010) and the combined use of several of them (therefore different algorithms) increases the accuracy of the result by reducing the effect of systematic errors.

The main goal of the fault-slip data analysis was to characterize the Quaternary to present-day stress regime in southern central Hispaniola. Fault-slip data were measured on one side in late Eocene-Oligocene limestones and on the other side in alluvial fan deposits and coral reef terraces of Quaternary age. Following Riller et al. (2017), local strain perturbations induced by the main fault zones and the spacing between stations of fault slip data acquisition were taken into account. In natural conditions, fault-slip data sets measured at one location can be polyphasic, that is, include several fault subpopulations consistent with different stress tensors. The separation of the fault subpopulations referring to each tensor was performed prior to the inversion method for stress, calculating the pressure (P or compression axis) and tension (T or tensional axis) axes for each fault-slip data. Appearance of several clusters of P or T axes in stereographic projection were interpreted as indicative of the existence of fault-slip data related to different stress tensors, allowing their separation in fault subpopulations. Fault cross-cutting relationships, the overprinting of several striations in the same fault plane and the absolute age of the faulted rocks have also been used as criteria to date faults and thus paleostress tensors and tectonic phases.

We first carry out the fault-slip data analysis and principal stress axes calculations with the kinematic right-dihedra method (RDM; Angelier, 1994), which shows the distribution of the percentage of compression or extension dihedral for a fault population in stereographic projection. Then we invert the fault-slip data with two independent methods: direct inversion (DIM) and numeric dynamic analysis (NDA). All inversion methods were performed with *TectonicsFP* v1.7.9 software of Reiter and Acs (2000) and Ortner et al. (2002). We obtained statistically stable stress tensors from 10 to 30 fault-slip data measured in each site. Inversion methods of fault-slip data calculate the β angle between the calculated directions of maximum shear stress acting along a particular fault plane and the measured striae. Fluctuation (F) is the arithmetic mean of β angles of fault planes associated to a station, which can be used as a measure of the quality of the tensor solution (Reiter & Acs, 2000). In this study, obtained F values are generally $<15^\circ$ ($\pm 5^\circ$, 1σ standard deviation) for data sets $>30\%$ of total fault-slip data, which indicate a high quality of the stress tensor solutions.

On the other hand, many Holocene faults do not contain well-developed striations, preventing the achievement of a state of stress during their formation by means of kinematic analysis. In these conditions, clustering of fault and fracture data using a mixed Bingham distribution was used for paleostress analysis (Yamaji et al., 2010; Yamaji & Sato, 2011), constrained with other related mesostructures (i.e., mineral veins or dilatational faults). Bingham distributions, or the orientation distributions with orthorhombic symmetry, have been applied to infer the state of stress during the formation of magmatic dykes, mineral veins and fractures. For Yamaji and Sato (2011), the symmetry axes of the Bingham distribution of planar anisotropies (ϵ_1 , ϵ_2 and ϵ_3 eigenvectors) are correlated to the principal axes of the stress tensor (σ_1 , σ_2 , and σ_3 , respectively). Yamaji et al. (2010) further argue that the R ratio of the stress field related to the formation of a planar anisotropy set could be approximated by the ratio of the concentration parameters κ_2/κ_1 of the Bingham distribution. A further explanation of the fault-slip data acquisition and analysis methodology is included in the Supporting Information S3.

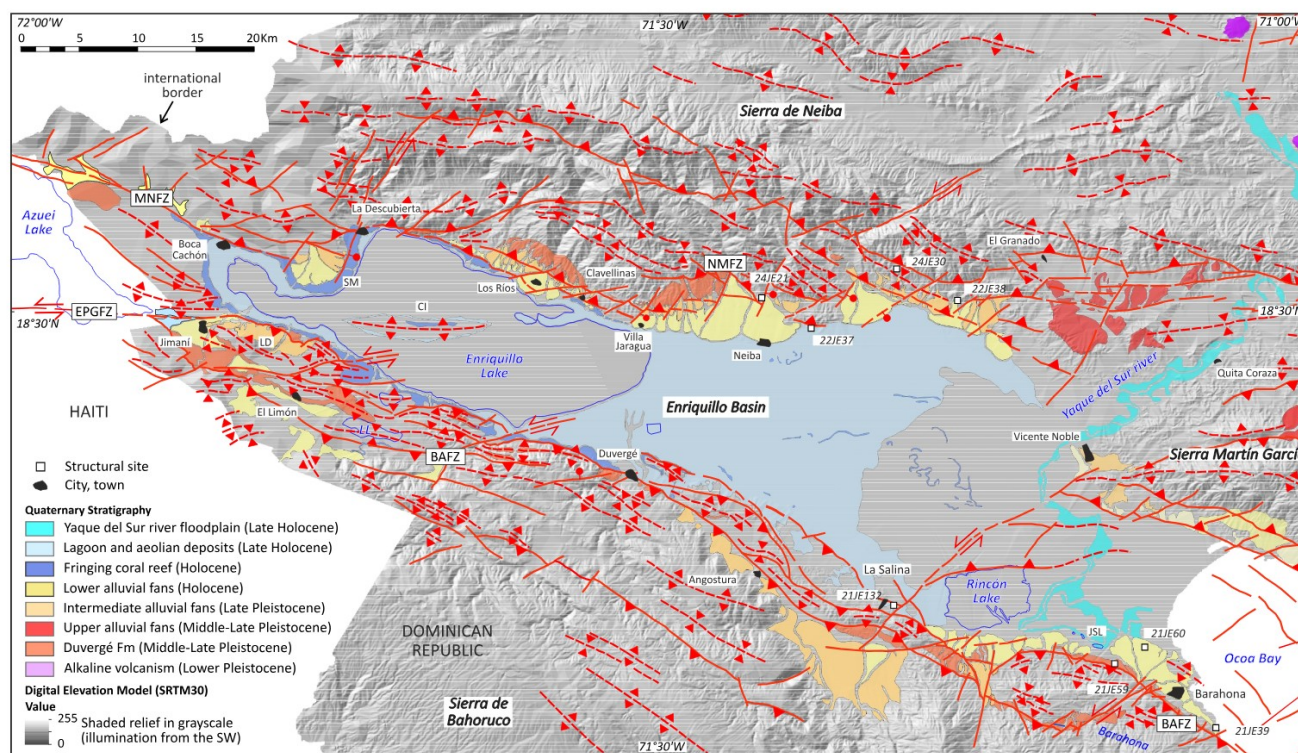


Figure 3. Neotectonic map of the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges. Shaded relief in grayscale has been made from the GMRT synthesis data set (Ryan et al., 2009) with *GeoMapApp* (www.geomapapp.org). The neotectonic structures and Quaternary lithostratigraphic units compiled in the map result from integrating new field data with the geologic map obtained by the SYSMIN Project in the Dominican Republic. For simplicity, some Quaternary fluvial cartographic units have been omitted. White squares indicate locations of OSL sampling and fault-slip data measurements. The main neotectonic structures are: EPGFZ, Enriquillo-Plataine Garden Fault Zone; MNFZ, Matheux-Neiba fault zone; BAFZ, Bahoruco Fault Zone. Sites: CI, Cabritos Island; LD, Loma Derrico; LL, El Limón Lake; PP, Potro Paso; SM, Sabana del Medio. Symbolism as in Figure 2.

4. Neotectonics of the Enriquillo Basin and Adjacent Bahoruco and Neiba Mountain Ranges

4.1. Quaternary Lithostratigraphy

New lithostratigraphic data indicate that Quaternary deposits in the Enriquillo basin include the Jimaní and Duvergé Formations, three staircase alluvial fan systems, the Enriquillo Lake fringing reef complex and the present-day lagoon-aeolian sediments. In this work, the Jimaní Fm is made up of two informal cartographic units (Figure 2; Deschamps & Fondeur, 2004; García Senz, 2004; Genna, 2004): a lower unit of shallow-water marine platform limestones and marls deposited in a transitional coastal environment; and an upper unit of reef limestones and coastal bioclastic calcarenites. An upper Pliocene-Pleistocene age has been established based on the nannoflora for the Jimaní Fm, where the presence of *Gephyrocapsa oceanica* and the absence of *Reticulofenestra lacunosa* allow the age of the upper unit to be restricted to the Middle Pleistocene (NN20-21 zones; Deschamps & Fondeur, 2004). In this work, the Duvergé Fm is defined as a new lithostratigraphic unit consisting of coarse-grained continental clastic deposits, which occurs attached to the margins of the mountain ranges (Figure 3). In the Boca Cachón sector of the southern Sierra de Neiba, it is constituted by a 100 to 300 m-thick sequence of variably consolidated breccias and conglomerates. In the northern Sierra de Bahoruco, it forms a 250 to 500 m-thick succession of conglomerates and subordinated carbonate breccias, with of red sands, sandy silts and clays intercalations. In both sectors, the Duvergé Fm unconformably overlain the Jimaní Fm. The conglomerates are heterometric, exhibit a clast- to matrix-supported internal structure, and are composed of rounded to subangular clasts and blocks of limestone.

Tectonic activity continued uplifting the Neiba and Bahoruco mountains ranges during the Late Pleistocene-Holocene. Erosion of the resulting relief produced piedmont spreading deposits at the slopes of the ranges directed to the central Enriquillo basin. These deposits make up a Quaternary morphological sequence, which

records the successive development of three alluvial fans systems at different topographic levels (Díaz de Neira, 2000; Pérez Valera, 2010). The upper alluvial fan system forms small relict plateaus inclined toward the SW in the eastern Sierra de Neiba, developed from the slope rupture produced by the MNFZ (Figure 3). It is made up of a 35 m-thick sequence of poorly consolidated sandy conglomerates and coarse debris (manly cobbles and abraded boulders) of limestones, which unconformably overlap the folded and faulted rocks of the Las Salinas Fm.

The intermediate alluvial fan system has a discontinuous spatial development and exhibits a depositional slope directed to the S on the Sierra de Neiba and to the N on the Sierra de Bahoruco (Figure 3). It consists of a 20 to 50 m-thick sequence of very poorly consolidated conglomerates rich in a sandy matrix, frequently filling paleo-channel surfaces, mainly composed of angular and rounded clasts of limestone. The intermediate alluvial fan contains in the proximal part decimeter-sized blocks, sometimes exceeding 50 cm in diameter, while in the distal part, it is richer in intercalated beds of sand, silt and red clay.

The active lower alluvial fan system forms a more extensive and better-preserved deposit on the southern slope of the Sierra de Neiba, but it is spatially restricted to the Jimaní, Limón and Barahona areas in the Sierra de Bahoruco (Figure 3). These deposits have frequently developed following a radial pattern at the foot of the mountains, where the feeder channel is no longer confined between slopes. They are made up of 25–40 m-thick section of gravels, silty sands and clays. They include sporadic blocks of decimeter size, which can reach up to 2 m in diameter in the Jimaní fan. Gravels are composed of variably rounded clasts of limestone, which define a clast-supported internal structure. Between Boca Cachón and Clavellinas, the intermediate alluvial fan deposits are deeply dissected by the lower alluvial fan, which is interdigitated with the Holocene coral reef in its distal part. In turn, the lower alluvial fan deposits overlap the reef complex. Therefore, the lower alluvial fan is contemporary and slightly older than the reef complex. These relationships suggest that the lower alluvial fan controlled the location and development of the fringing coral reef, as well as its death due to the arrival of terrigenous material.

The fringing coral reef crops out on the periphery of the Enriquillo Lake, Cabritos Island and Limón basin west of Duvergé (Figure 3). Morphologically, the coral reef constitutes a terrace inclined toward the center of the Enriquillo basin between 0 and 35 m below sea level. Mann et al. (1984, 1995) describe differences in altitude of the depositional roof of the terrace at various points on the lake periphery and the of Cabritos Island anticline, indicating that gentle folds locally deform it. Mann et al. (1984) and Taylor et al. (1985) distinguish basal transgressive facies rich in ostreids, gastropods and bivalves, on which there is a 5 to 20 m-thick bioherm of massive corals deposited in the forereef. Above, follows a several meters thick massive accumulation of branch corals (*Acropora cervicornis*) of the reef-crest, fine-grained back-reef sediments and about 5 m of well-stratified lacustrine sediments. Locally, several meters-thick, hemispheric constructions of intertidal stromatolites are superimposed, grown on the reef roof at a level of 0 m. For these authors, the growth of the reef complex took place between 9760 ± 200 and 4760 ± 180 BP, as consequence of the rapid post-glacial sea level rise. Approximately 5000 BP ago, the development of the Yaque del Sur river delta, probably combined with a tectonic uplift, produced the disconnection of the Enriquillo depression with the Ocoa Bay and the death of the reef owing to restricted water flow from the Caribbean Sea (Mann et al., 1995; Genna, 2004). The definitive withdrawal of the sea and the transition to a lacustrine regime took place at 2820 ± 80 BP. Rapid evaporation in an arid climate has created the current saline Enriquillo Lake at an elevation between 42 and 36 m below sea level, allowing the exceptional observation of the coral reef on its periphery.

4.2. Large-Scale Structures

The large-scale structure of the Enriquillo basin and adjacent Bahoruco and Neiba mountain ranges is shown in the neotectonic map of Figure 3, which results from integrating new field data of the Quaternary deposits with the geologic map obtained by the SYSMIN Project in the Dominican Republic (Pérez-Estaún et al., 2007). This map covers the southeast part of the Sierra de Neiba, the northwest part of the Sierra de Bahoruco, the western half of the Sierra Martín García and the whole Enriquillo basin. This fieldwork area was selected because it contains the main active structures that control the seismic hazard of the Enriquillo basin.

The macrostructure of the Sierra de Neiba consists of a system of SW-directed thrusts, about 200 km long and 25 km wide, which forms the southeast extension of the Haitian fold-and-thrust belt (Figure 3; Díaz de Neira, 2004b; Hernáiz-Huerta, 2004; Hernáiz-Huerta, Díaz de Neira, García Senz, Deschamps, Genna, et al., 2007). Each individual thrust sheet contains a WNW to NW-trending asymmetrical fault-propagation

anticline. These anticlines have a typical profile with a long limb dipping to the NE and a short limb dipping to the SW or inverted, limited by a SW-directed medium to high-angle thrust. The frontal thrust, or Matheux-Neiba Fault Zone (MNFZ), superposes Eocene limestones of the Neiba Fm onto Middle to Late Pleistocene clastic deposits of the Duvergé or Arroyo Seco Fms (Figures 3 and 7). Thrust surfaces are cut by NE-striking normal or left-lateral strike-slip faults and NW-striking right-hand strike-slip faults.

The macrostructure of the Sierra de Bahoruco consists of a WNW-trending large anticlinorium, more than 80 km in length, which connects to the west with the Massif de la Selle anticline in Haiti (Figure 3). The anticlinorium has about 40 km wavelength and exhibits an asymmetric profile, with a southern limb gently inclined to the SW and a northern limb with a steeper slope toward the NE. Internally, it is composed of several second-order anticlines and synclines of 2–5 km wavelength and NE-vergence, which are built in the limestones of the Neiba and Barahona Fms (Díaz de Neira, 2004b; García Senz, 2004; Hernáiz-Huerta et al., 2007b). Volcanic rocks of the Cretaceous CLIP outcrop in the core of the anticlines (Escuder-Virquete et al., 2016b). The structural contact between the Sierra de Bahoruco and the Enriquillo basin is located in the WNW-trending and SW-dipping BAFZ thrust (BAFZ; Figure 3). In detail, the deformation front propagates to the NE in several mid to high-angle blind thrusts, which fold the sediments filling the Enriquillo basin. In the Duvergé-Barahona sector, the BAFZ superimposes the Miocene limestones of the Barahona Fm onto the Late Pleistocene breccias and conglomerates of the Duvergé Fm (Figure 3). The Barahona anticline is a NW-trending fault propagation fold that deforms the Lower-Middle Pleistocene deposits of the upper Jimaní Fm in the southern margin of the Enriquillo basin (Díaz de Neira, 2004a, 2004b). In the Limón and Jimaní sectors, the limestones of the Barahona Fm overthrust the conglomerates of the Duvergé Fm, producing steep slopes with triangular facets. In both sectors, the BAFZ limits to the SW the Holocene Limón and Jimaní basins, which are fed by the active lower alluvial fan system. Located in a more external structural position, the Loma Derrico and Loma Juan Ciprián thrust anticlines fold the Pliocene to Pleistocene deposits of the Salinas and Jimaní Fm (Figures 3 and 7). The thrust trace is fossilized by the gravels of the lower alluvial fan or by the Holocene reef complex. At a cartographic scale, a NE to E-striking left-lateral strike-slip fault displaces the WNW-trending folds, the BAFZ and the external blind thrusts.

The Sierra de Martín García macrostructure consists of a SW-verging asymmetric anticline, limited by reverse faults directed toward the Enriquillo basin and back-thrusts toward the Azua Basin. The trend of the anticline axis changes from NW-SE in its eastern half to E-W in its western half, where it presents a strong plunge toward the west. Both Sierra Martín García and Sierra de Bahoruco macrostructures are abruptly truncated eastward by the BRFZ.

The Enriquillo-Plantain Garden fault zone is a 1,200 km long, left-lateral fault zone that forms a major, plate boundary between the Gonâve microplate to the north and the Caribbean plate to the south (Benford et al., 2012; Calais et al., 2010, 2022; Mann et al., 1995; Wessels et al., 2019). Evidence for past strike-slip ruptures with a few meters of slip has been documented in southern Haiti, which has been empirically correlated with M_w 7.1–7.6 strike-slip earthquakes (Prentice et al., 2010). The EPGFZ cuts obliquely the NW-trending folds and thrusts of the Sierra de Bahoruco on the southern shore of Azuei Lake (Malpaso), the BAFZ southwest Jimaní, and apparently crosses the syncline zone between the WNW-trending Loma Derrico and WNW to W-trending Tierra Prieta anticlines located at the town of Jimaní (Figures 3 and 7). For Mann et al. (1995), the fault zone continues eastward across the Enriquillo Lake, being responsible for its bathymetry and for the uplift and gentle folding of the Jimaní Fm in the Cabritos Island. However, the EPGFZ does not deform the lower alluvial fan deposits in the Villa Jaragua-Neiba sector located on the northern shore of the Enriquillo Lake (Genna, 2004; Nicol, 2004).

4.3. Regional Magnetic Data

The macrostructure of the studied area is imaged by the magnetic anomalies in the reduced to the pole (RTP) and first-vertical-derivative magnetic grids (VDM) (Ayala et al., 2017). In general, areas with a long-wavelength magnetic signature correspond to regions where the magnetic source is located farther from the surface, or where the magnetic rock intensity is weak in the basement. The western Sierra de Neiba and Sierra de Bahoruco display well-structured, WNW to NW-trending, long-wavelength negative magnetic anomalies between -380 and -700 nT in the RTP grid (Figure 4a). These negative anomalies are due to the fact that both mountain ranges are made up of a thick sequence of paramagnetic limestones of the Neiba and Barahona Fms, which reduces the regional magnetic intensity. In the eastern Sierra de Neiba, however, outcrops of the El Aguacate volcano-sedimentary complex in the core of the anticlines define a pattern of long-wavelength positive magnetic

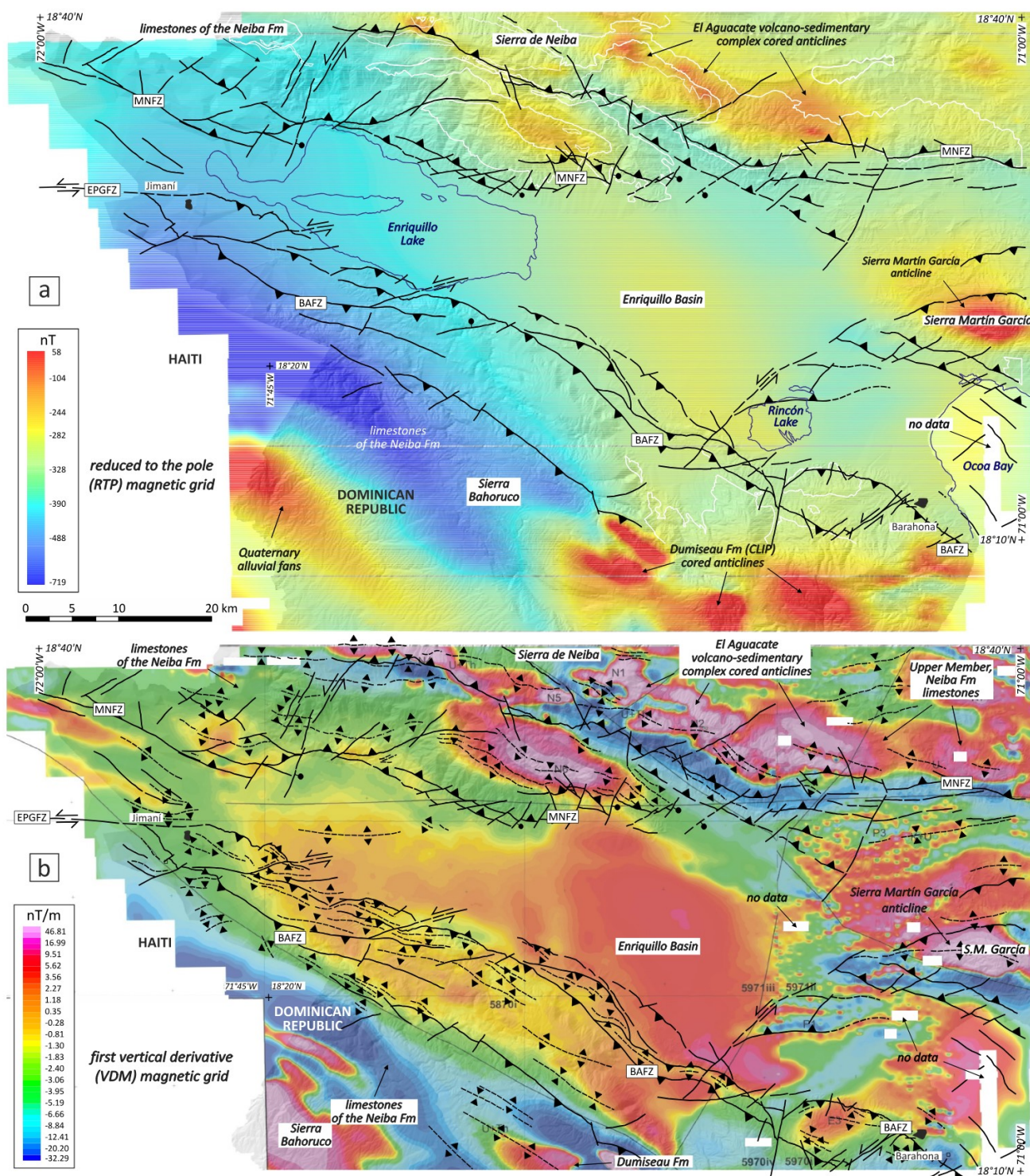


Figure 4. Magnetic maps showing major neotectonic features in the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges (mod. from García Lobón & Rey Moral, 2004; Ayala et al. (2017)). (a) Reduced to the pole (RTP) of the total magnetic field operation improves the spatial position of anomalies and helps to define areas with long and short wavelengths, regional trends and tectonic boundaries between magnetic provinces. (b) The first vertical derivative operation (VDO) from the total field allows to identify trends associated with large-scale structure, tectonic boundaries and intra-basement features. Acronyms as in Figure 3. See explanation in text.

anomalies between 50 and -200 nT in the VDM grid (Figure 4b), consistent with the WNW-ESE regional structural trend. This pattern of elongated magnetic anomalies is limited to the south by the MNFZ.

The western Enriquillo basin also displays a long-wavelength negative magnetic anomaly in both the RTP (between -300 and -400 nT) and VDM magnetic grids (Figure 4). This negative anomaly is related to the 1 to 3 km-thick overburden of paramagnetic sediments that fill the basin and reduces the basement magnetic intensity. However, the fluvial-deltaic sediments of the eastern Enriquillo basin and the limestone massifs of eastern Sierra de Bahoruco and Sierra de Martín García define long-wavelength, positive magnetic anomalies (up to 50 nT in the RTP grid). A possible explanation for this unusual magnetic signature is that the basement in these areas is composed of titanomagnetite-rich basalts typical of the Cretaceous CLIP. The outcrops of ferromagnetic basalts of the Dumisseau Fm under the Tertiary limestone sequence at the eastern limb of the Sierra de Bahoruco confirm this interpretation, since they produce a similar elongated pattern of strong positive anomalies in both the RTP and VDM grids, centered on the core of WNW to NW-trending anticlines. On the other hand, the magnetic boundary between the Sierra de Bahoruco and the Enriquillo basin is located further southwest of the surface trace of the BAFZ, at the level of the mid-angle thrust of the Neiba Fm over the Barahona Fm (Figure 4b).

Short-wavelength magnetic anomalies correspond generally to areas where the magnetic sources in the basement are located close to the surface. In the VDM magnetic grid, short-wavelength magnetic signatures characterize the northern limb of the Sierra de Martín García anticline and the southeastern sector of the Enriquillo basin (Figure 4b). These areas show sigmoidal anomalies, elongated in the ENE-WSW to E-W trend, related to the folded and faulted structure of the Pliocene sedimentary rocks (Hernández-Huerta et al., 2007b). In turn, the northwestern sector of the Enriquillo basin displays scattered short-wavelength anomalies, elongated along a WNW-ESE trend, related to the synclinal structures developed in the carbonate and clastic sedimentary rocks of the Jimaní and Duvergé Fms (Figure 4b).

4.4. GPS Velocity Data

Figure 5a shows the GPS-derived velocities with respect to a Caribbean fixed reference frame collected for the studied area (95% confidence level, see Supporting Information S1). At the ROJO site, the residual velocity of 2.11 ± 2.10 mm/yr may reflect a systematic error and/or a low movement, which would be consistent with its location on the stable Caribbean plate (Mann et al., 2002). At sites located in the Enriquillo basin and adjacent Bahoruco and Neiba mountain ranges, as well as Chaîne des Matheux and Cordillera Central, GPS velocities range between 1.87 and 10.79 mm/yr, and the vectors show an orientation between N194°E and N252°E. In a first approximation, they record a regional gradient of decreasing velocity from the NE to the SW with respect to a fixed Caribbean plate.

Through the studied area, three topographic profiles have been constructed (Figure 5b) and the components of the GPS velocity vectors parallel and perpendicular to the W-E to WNW-ESE trend of the main fault zones have been projected onto the corresponding nearby profile (Figure 5c). These fault zones probably accommodate much of the present deformation. Given the large uncertainties in the data, the calculated displacement rates are considered semiquantitative. Profile A-A' runs in the southern region of Haiti, from the Plateau Central to the Haitian sub-basin of the Caribbean Sea. The velocity component perpendicular to the faults decreases southwestward from station HINC (10.58 mm/yr) to JACM (2.17 mm/yr). The velocity differences between the sites located in the Montagnes Noires (HINC and MIRE) and those located in the Cul-de-Sac basin (BRPS, PAPH and LEOG) suggest shortening accommodated in the Montagnes Noires (MOFZ) and Matheux thrusts. The current displacement rate accumulated in these structures in the NNE-SSW direction (i.e., fault-perpendicular) is about 4 mm/yr (Figure 5c). In turn, these rates decrease about 4 mm/yr from the sites located in the Cul-de-Sac basin to those located in the Massif de la Selle (TROU, MARI) and the coast (JACM), implying shortening along the EPGFZ and/or the thrusts that limit the mountains to the N. Values of the velocity component parallel to the faults decrease from the sites located in the Chaîne des Matheux (MIRE) to sites located in the Cul-de-Sac basin (PAPH and LEOG), indicating a left-lateral displacement in the Matheux-Neiba fault zone of about 2 mm/yr. This fault-parallel component decreases again by about 2.5 mm/yr at the Massif de la Selle sites (TROU and MARI), suggesting a left-lateral displacement in the EPGFZ and/or the thrusts that limit the mountain range. The JACM station deviates from this general trend.

Profile B-B' crosses the southwest region of the Dominican Republic from the Cordillera Central to the southern coast of the Sierra de Bahoruco (Figure 5b). Along the profile, the fault-perpendicular velocity component

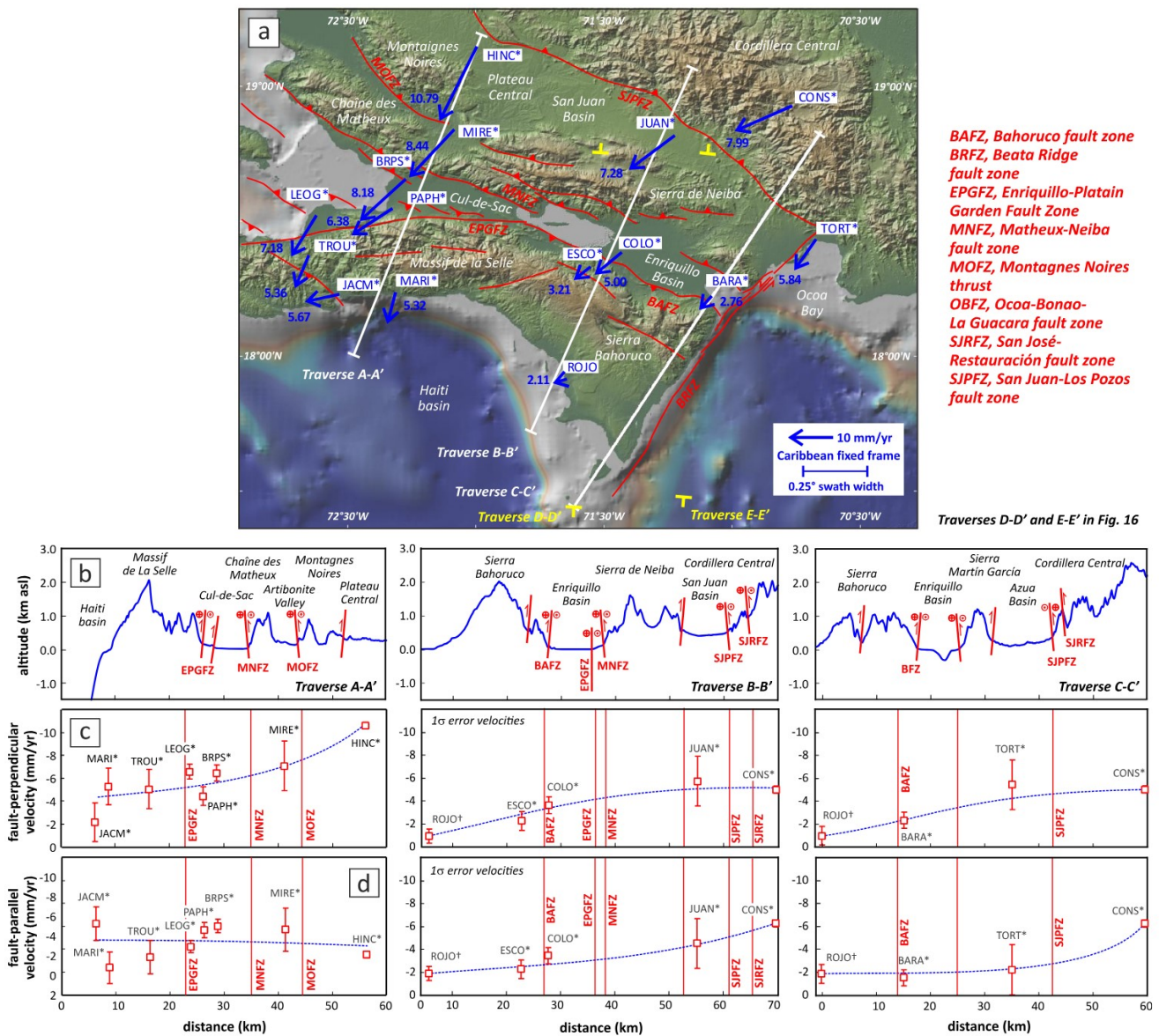


Figure 5. (a) Shaded-relief topography of southern Hispaniola showing GPS (Global Positioning System) velocity vectors relative to a Caribbean plate fixed reference frame (data from Mann et al., 2002; Calais et al., 2010 denoted by *, 2016, 2022; Benford et al., 2012; Symithe et al., 2015; and UNAVCO). Numerical values are in absolute value and are provided in Supporting Information S1. Error ellipses are not shown for clarity. Relief in color scale has been made with GeoMapApp (www.geomapp.org). (b) Topographic profiles marked in (a) drawn orthogonal to the NW-SE to WNW-ESE strike of the main active fault zones. The solid blue line indicates topography or bathymetry along the profile. (c and d) Fault-perpendicular and fault-parallel GPS velocity components relative to Caribbean plate (red squares), projected onto the topographic profiles marked in (b) using all stations within 0.25° either side of the profile line with their standard errors (red bars). All profiles show a relatively steady southwestward decrease in the fault-perpendicular component of the velocity. The blue dotted curves show the logarithmic function fit of the displacements. Abbreviations of main fault zones as in Figures 1 and 3, in addition: MOFZ, Montaignes Noires thrust. See explanation in text.

decreases toward the southwest, from CONS (4.99 mm/yr) and JUAN (5.71 mm/yr) to ROJO (0.95 mm/yr) sites. The high error of the velocity vector at the JUAN site does not allow displacement rates to be confidently inferred for the SJRFZ and SJPFZ. However, CONS and JUAN sites present higher fault-perpendicular components than the COLO site (3.63 mm/yr) on the southern margin of the Enriquillo basin, suggesting a shortening of approximately 2.0 mm/yr accommodated by folding in the Sierra de Neiba or thrusting in the MNFZ. In turn, the difference in fault-perpendicular component values between the COLO and ESCO sites indicates a shortening of 1.5–2.0 mm/yr accommodated by the thrust system of the BAFZ. Relative to the ROJO site on the stable Caribbean plate, the difference in velocity represents a shortening of about 3.5 mm/yr, accommodated by the

BAFZ together with other compressional structures existing in the Sierra de Bahoruco. The fault-parallel displacement component decreases from the CONS site of the Cordillera Central to ROJO site of the southern coast, establishing a general left-lateral movement of about 4 mm/yr. The scarcity of GPS sites does not allow discerning the structures that accommodate this displacement, but the eastern termination of the EPGFZ (Mann et al., 1995; this work), the BAFZ and the Sierra de Bahoruco folds can accommodate a movement of between 1.4 and 2.0 mm/yr.

Profile C-C' runs parallel to the western coast of the Ocoa Bay, crossing the southeastern sector of the Cordillera Central and the Sierra de Bahoruco to the Beata Island (Figure 5b). Although GPS sites are very scarce, the fault-perpendicular component of displacement decreases from the Central Cordillera to the eastern Enriquillo basin, implying an active shortening of the region. The high error in the velocity at TORT site does not allow determining the shortening rate in the SJPFZ, but the differences between TORT and BARA sites suggest a shortening of 3.5–4 mm/yr resolved in the structures that uplift the Sierra de Martín García. In addition, the difference in the fault-perpendicular component value between BARA and ROJO indicates a shortening of 1.5–2 mm/yr in the compressional structures developed in the Sierra de Bahoruco. The fault-parallel velocity component decreases from the interior of the Cordillera Central (CONS) to the southern coast (ROJO), establishing a left-lateral movement in structures such as SJPFZ and BAFZ, as well as along compressional structures in the Sierra de Martín García.

4.5. Seismicity

Historical and instrumental seismicity provides additional information on the regional tectonics of the studied area (Figure 6). Historical seismicity records for Hispaniola only cover the past ~500 years. They probably have a bias toward earthquakes that have damaged population centers and do not include earthquakes in uninhabited regions. In the Enriquillo basin and adjacent regions, there are no historical events that can be safely assigned to an individual fault since there are no known surface ruptures, and the location of epicenters is derived from earthquake damage reports and regional attenuation relationships between epicentral intensity and distance (ten Brink et al., 2011). For example, Bakun et al. (2012) propose the Muertos deformation belt or the eastern end of the EPGFZ as the possible source for the 18 October 1751 M_w 7.5 Azua earthquake. In turn, the location and magnitude of the 1684 M_w 6.0 (destroyed Azua) and 1691 M_w 7.5 (destroyed Santo Domingo) earthquakes cannot be confidently determined with the available data, since there are no known surface ruptures related to these strong earthquakes. For Terrier-Sedan and Bertil (2021), the 6 October 1911 M_w 6.7 and 3 November 1923 M_w 6.1 earthquakes were likely caused by the frontal thrust of the Peralta belt and the MNFZ, respectively. For these authors, the maximum magnitude that can produce an earthquake in the BAFZ is M_w 7.3 $\pm$ 0.3, taking into account the length of the fault.

In the study area, instrumental seismicity is mainly of low magnitude ($M_w < 3.5$) and shallow (depth <40 km), usually located at depths less than 20 km (Figure 6). Intermediate depth earthquakes (100 < depth <250 km) are very rare. Seismicity is highest throughout the Sierra de Bahoruco and along the morphological transition between the Sierra de Neiba and the Enriquillo basin. However, it is lower along the Enriquillo basin, except in the Rincón Lake and Ocoa Bay areas. Epicenters are often concentrated in, or close to, the surface trace of the MNFZ and BAFZ, as well as other related structures (Figure 6). The EPGFZ does not show a clear related seismicity in the Enriquillo Lake sector.

Relatively few earthquakes with well-constrained focal mechanism, depth and location are available for southern central Hispaniola in the Global Centroid-Moment-Tensor (Ekström et al., 2012) and the International Seismological Centre catalogs (see Table S3). Epicenters of the 1993 and 2012 earthquakes are located in the Enriquillo basin, about 5 km north of the BAFZ trace (Figure 6). Their focal mechanisms indicate nearly pure thrusting on WNW-striking nodal planes at depths of 15 and 34 km, respectively, and probably correspond to active mid to lower-crustal thrusting between the Caribbean plate and Gonâve microplate (see below). The focal mechanism solution of the 2015 earthquake shows predominant left-lateral strike-slip faulting on a NE-trending nodal plane. This earthquake and the nearby shallow earthquakes in the Rincón Lake sector likely record strike-slip faulting transverse to the Bahoruco and Martín García mountain ranges.

Rodríguez et al. (2018) describe a high seismic activity of relatively low magnitude ($M_w < 3.6$) and shallow depth under the Sierra de Bahoruco, often forming elongated clusters following the WNW-ESE trend of the mountain range. These authors calculate 24 fault-plane solutions compatible with a reverse mechanisms and NNE-trending

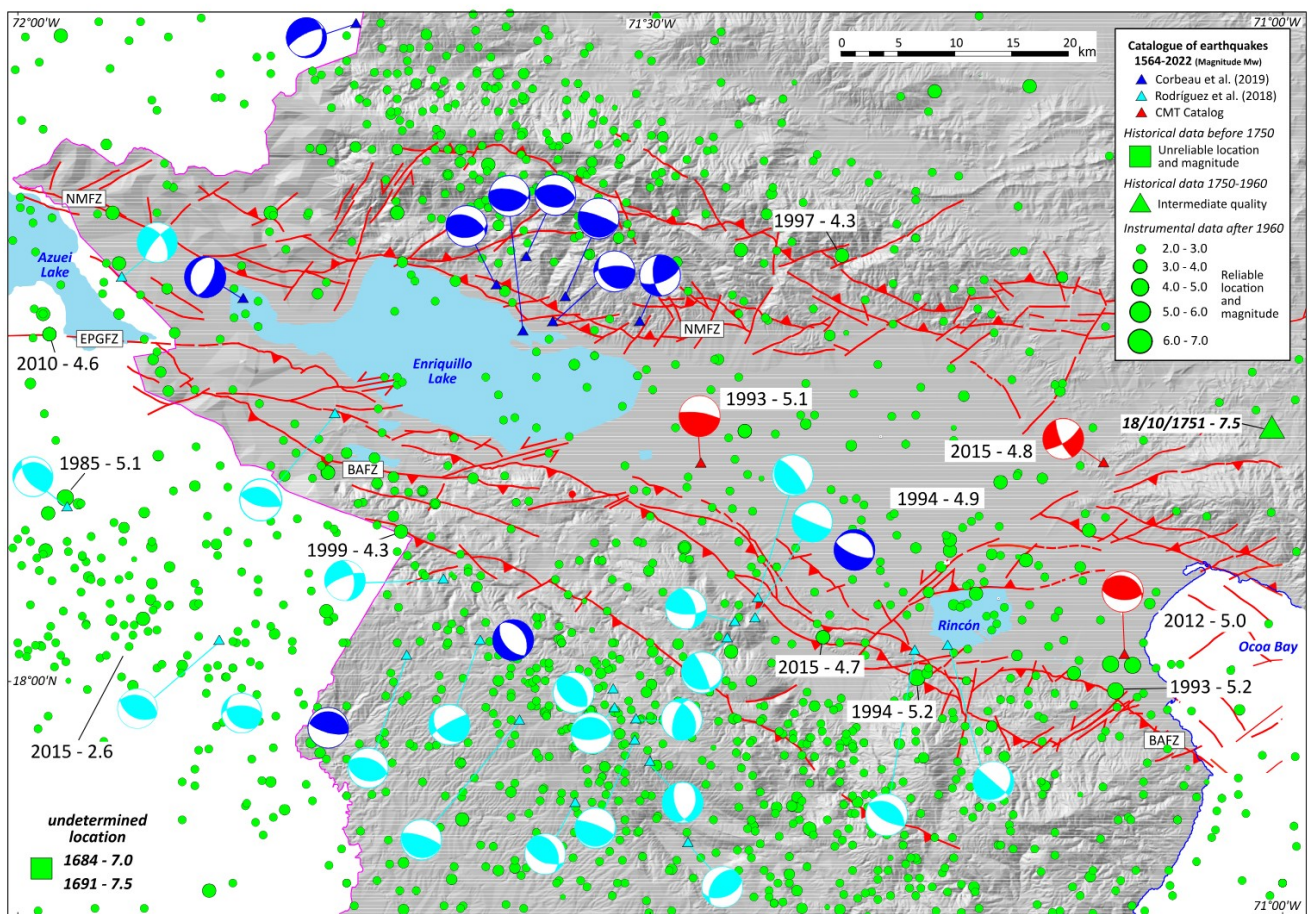


Figure 6. Catalog of earthquakes and focal mechanisms compiled for the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges. White symbols are historical and instrumental earthquakes of $M_w > 2.0$ from 1564 to 2022 A.D. Due to the high uncertainty related to the magnitude and location of historical earthquakes, they are classified into three groups following Terrier-Sedan and Bertil (2021): historical data before 1750 of unreliable magnitude and location; historical data between 1750 and 1960 of intermediate quality; and instrumental data after 1960 generally of high quality. Several earthquakes of magnitude at least M_w 6.0 are located in the study area, or the immediate surroundings. They include the earthquakes of 1684 (affected Azua and Santo Domingo), 1691 (destroyed Azua, affected Santo Domingo), 1751 (destroyed Azua) and 1911 (affected San Juan). Well-constrained fault plane solutions from 1976 to 2022 are taken from the Global Centroid-Moment-Tensor (CMT) Catalog (Dziewonski et al., 1981; Ekström et al., 2012; red triangles), Rodríguez et al. (2018; light blue triangles) and Corbeau et al. (2019; dark blue triangles). Numbers in white rectangles are well-constrained depths and dates. Details on the data sources can be found in the Supporting Informations S1 and S2. Abbreviations of main fault zones as in Figures 1 and 3.

P-axis (see Table S3), pointing to the push of the Beata Ridge against the Enriquillo basin and the Gonâve microplate as the cause of the seismicity. In detail, the focal mechanisms indicate mainly pure thrust and oblique reverse faulting on WNW to NW-trending and S-dipping nodal planes (Figure 6). As the depth of the earthquakes is generally less than 10 km, solutions indicate active deformation by NE-directed thrusts in the hanging-wall block of the BAFZ.

Corbeau et al. (2019) recorded a cluster of seismic activity composed of low magnitude events ($M_w < 3.8$) along the northern edge of the Enriquillo basin. Moment tensors determined for this cluster also have a significant thrust component, again with P-axis indicative of an NNE-trending compression (see Table S3). These authors relate seismicity to an N-dipping reverse fault, similar to those observed by Pubellier et al. (2000) in the front of the Trans-Haitian deformation belt. In detail, the focal mechanisms of the cluster indicate pure thrusting on W to WNW-trending and N-dipping nodal planes (Figure 6). The shallow depth of the earthquakes (from 0.6 to 4.2 km) and the location of their epicenters very close to the trace of the MNFZ, indicate active thrusting directed to-the-S along this fault system. Other determined focal mechanisms represent normal faulting at mid-crustal depth on sub-vertical NNE-SSW to NE-SW nodal planes, and shallow thrusting on low-dipping and WNW to NW-trending nodal planes, similar to those found by Rodríguez et al. (2018) under the Sierra de Bahoruco.

5. Fault-Slip Data Inversion and Late Cenozoic Stress Regime

In this work, we determine stress tensors from a population of 370 fault-slip data, measured in 24 sites covering an area of approximately $70 \times 60 \text{ km}^2$ in the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges. Geological characteristics of these sites are reported in Table S4. The location of the sites in the eastern and western Enriquillo basin is shown in Figures 3 and 7, respectively. Fault-slip data sets measured at each site are generally monophasic and define a single stress tensor. Inversion of the fault-slip data yields 17 stress tensors and their respective plots are shown in Figures 8–13 and the Table S5. Additionally, the orientation of fracture planes and other related structures allowed obtaining eight stress tensors in Holocene-age sediments by the Bingham distribution method, which are described in Table S6. Maximum horizontal stresses and tectonic regimes obtained by inversion methods are summarized in Table S7.

5.1. Fault-Slip Data Inversion in the Sierra de Neiba

Site 21JE19 is located at a quarry 1.2 km northwest of the Boca Chacón town, where the structural contact between the Sierra de Neiba and the Enriquillo basin can be observed (Figures 7a and 8b). In the quarry, the limestones of the Miocene Sombbrero Fm are tectonically imbricated with the conglomerates of the Late Pleistocene intermediate alluvial fan, and the ensemble overthrusts the conglomerates of the Holocene lower alluvial fan and the underlying fringing reef-complex of the Enriquillo Lake (Figures 8c and 8d). Structures in the Sombbrero Fm consist of WNW-trending and SW-verging asymmetric folds, associated with mid-dip angle reverse faults inclined to the NE. Fold asymmetry and mesoscopic S-C structures establish a top-to-the SW reverse movement. Striations measured in the reverse fault planes define a fault population compatible with a thrust faulting stress regime (σ_3 is subvertical; $R = 0.59$) and a N213°E trending compressional axis (Figure 8a). All these structures form the SW-directed frontal thrust of the MNFZ, which juxtaposes the Loma Flecha anticline of the Sierra Neiba against the poorly consolidated reef, lagoon and alluvial Quaternary deposits of the Enriquillo basin (cross-section of Figure 8b). The coral reef is made up of a 2.6 m-thick massive accumulation of *Acropora cervicornis*, which includes horizons of calcareous clasts in its uppermost part. A specimen of *Acropora cervicornis* collected at the highest stratigraphical levels of the reef has provided a calibrated radiocarbon age of 6195–5880 BP. The overlying lower alluvial fan include clasts and fallen blocks of the structurally overlying Sombbrero Fm. These relationships indicate the reactivation of the MNFZ thrust front in the Late Holocene.

The Matheux-Neiba frontal thrust also outcrops in the site 21JE20, which corresponds to the ramp associated with the WNW-trending Loma Flecha fault-bend anticline (Figure 7a). The thrust superposes the limestones of the Sombbrero Fm onto conglomerates and breccias of the Holocene lower alluvial fan (Figure 8e). These field relationships confirm the reactivation of the Matheux-Neiba frontal thrust in the Late Holocene. Clastic rocks of the footwall block define an upward coarse-grained sequence that culminate with meter-scale blocks of the Miocene limestones. This subhorizontal sequence progrades southward, overlapping the Holocene reef complex. The thrust-related structures in the Sombbrero Fm consist of SW-verging asymmetric folds, associated with mid-dip angle faults inclined to the NE, subparallel to the frontal thrust. Mesoscopic S-C structures and other kinematic indicators imprinted on the fault planes establish a top-to-the SW reverse movement. Predominant dip-slip striae in reverse fault planes define a population compatible with a thrust stress regime and a N058°E trending compressional axis (Figure 8f).

Site 21JE22 is located near the northern coast of the Enriquillo Lake, 6.5 km southeast of Boca Cachón town, on the southern limb of the Loma Flecha thrusting anticline (Figure 7a). The structures of the MNFZ frontal thrust are an imbrication of the Sombbrero Fm limestones with the Late Pleistocene intermediate alluvial fan gravels and sands. The reverse striations present in two conjugate families of WNW-trending fault planes indicate an oblique reverse movement directed both to the SW and to the NE (Figure 8a). The inversion of these fault-slip data establishes a compressional stress regime characterized by a NE-trending σ_1 .

Site 22JE33 is located along a N-trending gully, situated 1.2 km east of Clavellinas town, on the southeastern limb of the Arroyo Salado anticline (Figure 7a). Stream incision allows us to observe the depositional and structural relationships between the Holocene reef complex and their substrate, made up of marls, sandstones and limestones of the Arroyo Blanco Fm. Following Taylor et al. (1985), the accumulation of *Acropora Cervicornis* (6200 ± 60 to 4760 ± 100 BP) is overlain by regressive back-reef and lacustrine deposits (2820 ± 40 BP) intercalated with clastic wedges of alluvial fans, until they constitute the predominant sediment. Both the poorly consolidated gravels of the alluvial fan and the marls of the Arroyo Blanco Fm are faulted and tilted by a system of

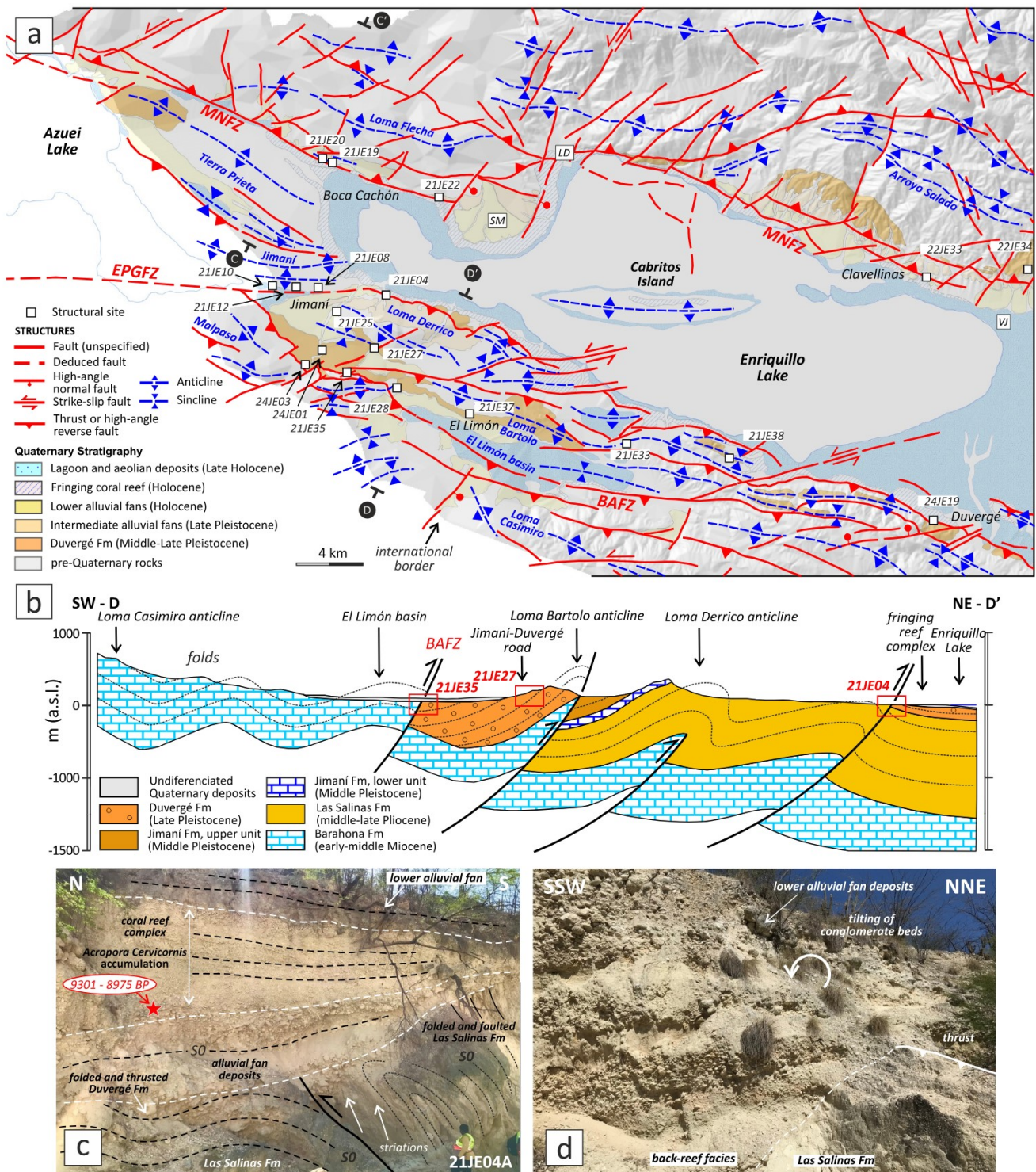


Figure 7.

NNE to NE-striking normal faults, sub-perpendicular to the WNW-trending axis of the Arroyo Salado anticline (Figures 9c and 9d). Fault planes are generally steep (dip $>60^\circ$) and striations show a normal dip-slip motion. Fault-slip data inversion reveals an extensional stress-field with a $N307^\circ E$ trending σ_3 stress axis (Figure 9a). These faults have probably given rise to the anomalous elevations of the coral reef crest measured by Mann et al. (1995) in the Clavellina area.

Site 22JE37 is located in the Balneario Marías on the Neiba-Galván highway (Figure 3). Geologically, it is located in the contact between the limestones of the upper Neiba Fm, which form part of the southwest limb of the Cerro Palomar thrust anticline, and the Holocene lagoonal and aeolian fill of the Enriquillo basin. At the outcrop scale, high-dip oblique reverse faults cut the bedding of the limestones and decametric-scale folds of WNW-ESE to NW-SE trend. Fault planes form two conjugate families: E- to ESE-striking reverse left-lateral faults; and NNW-striking reverse and oblique reverse right-lateral faults (Figure 9a). Fault-slip measurements in both families define a compressional stress regime with a $N052^\circ E$ trending σ_1 , which is perpendicular to the trend of the minor fold axes and the macrostructure.

Sites 22JE38, 24JE21 and 24JE30 are located north of the Neiba and Galván towns, on the southeastern limb of the El Granado anticline (Figure 3). The macrostructure in this sector consists of an anticline structured in the limestones of the Neiba Fm, which overthrusts a syncline made up of marls and calcarenites of the Sombbrero Fm. At these sites, mesoscale compressional structures in the footwall block are WNW-trending and SW-verging asymmetric folds of decameter-scale, associated with low to mid-dip angle reverse faults inclined to the NE. Pure reverse and oblique reverse striations measured in the fault planes define fault populations compatible with a thrust stress regime and a NE-trending σ_1 axis (Figure 9a).

5.2. Fault-Slip Data Inversion in the Northwestern Sierra de Bahoruco

Site 21JE04A is located in a gully about 3 km east of Jimaní, on the northeastern limb of the Loma Derrico anticline, which constitutes the outermost thrust structure of the Bahoruco fault system (Figure 7a). In the outcrop, the sandstones and calcarenites of the Pliocene Las Salinas Fm overthrust the conglomerates and breccias of the Duvergé Fm along the frontal thrust of the Loma Derrico (Figure 7b). These syn-tectonic clastic deposits include blocks and clasts of the overlying Las Salinas Fm. The bedding of the Las Salinas Fm is folded by WNW-trending, asymmetrical and NE-vergent folds, as well as faulted by SW-dipping mid-angle reverse faults. The asymmetry of folds and mesoscopic S-C structures establish a top-to-the-SW reverse movement. Near pure reverse striae measured in the fault planes define a population compatible with a thrust stress regime and a $N187^\circ E$ trending σ_1 axis (Figure 10a). Unfolding the stratification planes by rotating 60° clockwise along an axis $N280^\circ E$ results in a $N007^\circ E$ trending compressional axis for a reverse stress regime. Faulted rocks are unconformably overlain by an undeformed transgressive sequence made up of basal alluvial fan clastic deposits, oostreid-rich silt and clay sediments, and a massive accumulation of *Acropora Cervicornis* typical of a reef-crest (Figure 7c). A bivalve shell collected at the base of the reef complex has provided a calibrated radiocarbon age of $9301\text{--}8975$ BP. As in the 21JE19 site, the *Acropora Cervicornis* accumulation has regionally provided uncorrected radiocarbon ages between 6200 ± 160 and 4760 ± 180 BP (Taylor et al., 1985). Clastic deposits of the Late Holocene lower alluvial fan are superimposed on the reef complex, which are tilted about $10\text{--}18^\circ$ toward the SW by the elevation produced by the underlying thrust ramp (Figure 7d). These field relationships collectively indicate activity of the Bahoruco thrust system until the Late Holocene.

Sites 24JE01 and 24JE03 are located along the narrow valley of Arroyo Blanco, located 2.2 km south of Jimaní town, where the Bahoruco fault zone outcrops (Figure 7a). Following the valley, the Barahona Fm limestones are

Figure 7. (a) Neotectonic map of the western Enriquillo basin, showing the main Quaternary lithostratigraphic units, neotectonic structures, and sites of OSL sampling and fault-slip data measurements. Main neotectonic structures are: Offshore (O-OBZ) segment of the Ocoa-Bonao-La Guacara fault zone; Southern (S-JPFZ) segment of San Juan-Los Pozos fault zone; and Northern (N-BRFZ) segment of the Beata Ridge fault Zone. AZ, Azua; BN, Baní; SB, Sabana Buey pull-apart basin. Abbreviations of main fault zones as in Figure 3, in addition: SM, Sabana del Medio; LD, La Descubierta; VJ, Villa Jaragua. See explanation in text. (b) Cross section across the Loma de Bartolo and Loma Derrico thrusting anticlines in northwestern Sierra de Bahoruco. Location of the D-D' cross-section is shown in (a). (c) Sandstones and calcarenites of the Pliocene Las Salinas Fm overthrusting conglomerates and breccias of the Late Pleistocene Duvergé Fm along the frontal thrust of the Loma Derrico. Faulted rocks are unconformably overlain by alluvial fan clastic deposits, oostreid-rich silt and clay sediments, a reef-crest accumulation of *Acropora Cervicornis*, and a Late Holocene lower alluvial fan. (d) Clastic deposits of the lower alluvial fan tilted about $10\text{--}18^\circ$ toward the SW by the uplift produced by the underlying thrust ramp. See text for an interpretation.

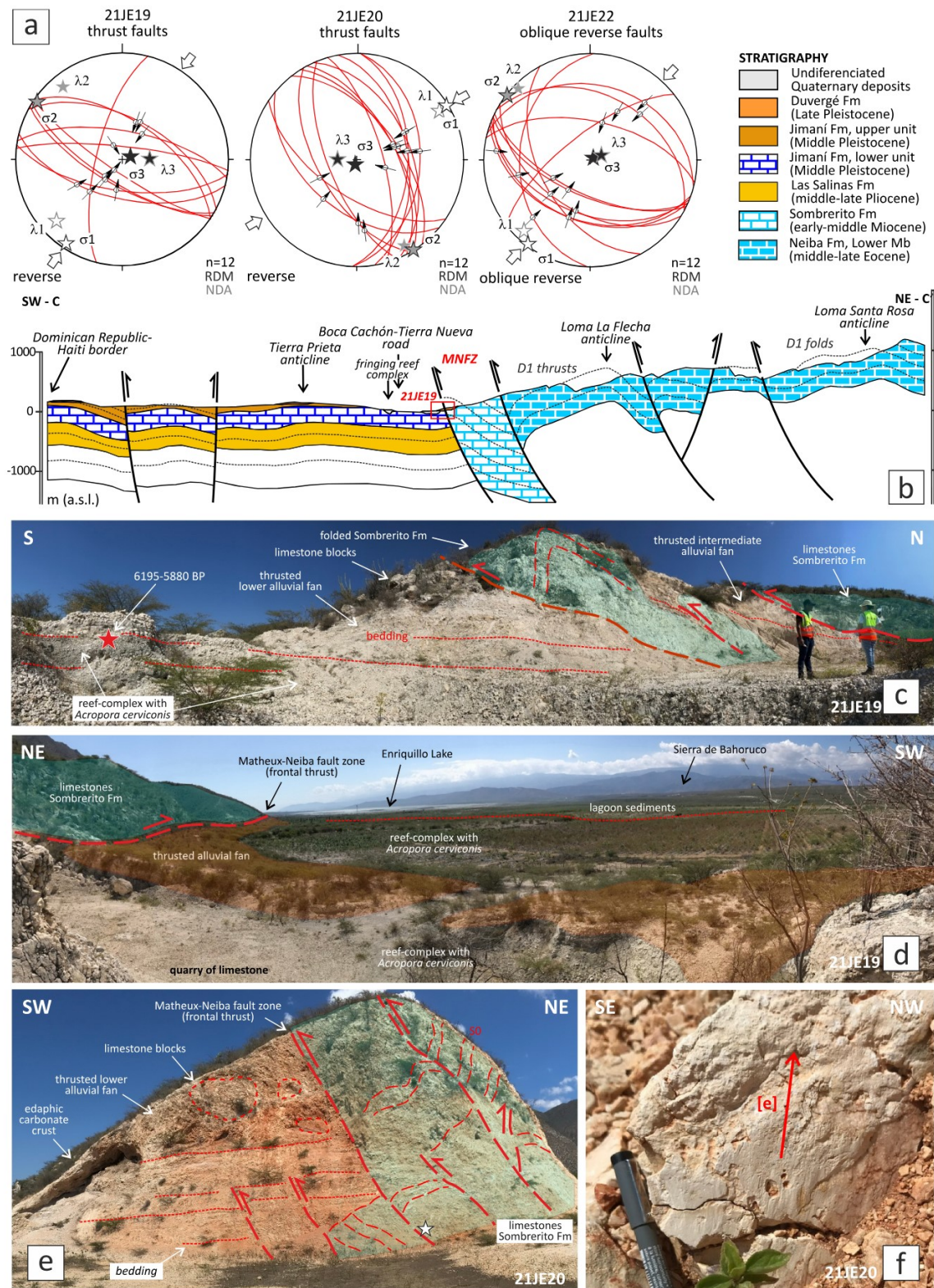


Figure 8.

deformed by the BAFZ along a band about 250 m-thick, where they are transformed into tectonic breccias, foliated cataclasites and fault-gouge (Figures 10d, 10e, and 10g). Mesoscopic porphyroclasts and S-C structures in the cataclasites establish a top-to-the N reverse movement. Slip measurements in WNW to W-striking and southward dipping reverse faults define a thrust stress regime with a N194°E trending σ_1 axis (24JE03; Figure 10a). The structurally underlying conglomerates of the Duvergé Fm are also intensely brecciated toward the BAFZ contact, as well as deformed at lower structural levels by N-verging folds and reverse faults. Near pure reverse striae measured in these faults are compatible with a thrusting regime characterized by a N184°E trending σ_1 axis (24JE01; Figure 10a). The development of a hectometric band of fault-rocks associated with the BAFZ is well observed south of Duvergé (24JE19 site; Figures 10b and 10c), where tectonic blocks of the Barahona Fm immersed in carbonate foliated cataclasites and gouge outcrop above the basal thrust.

The site 21JE27 is located on the Jimaní-El Limón Road, in the southern limb of the WNW-trending Loma Derrico anticline (Figure 7a). In the outcrop, the sandstones, calcarenites and marls of the upper Jimaní Fm are unconformably overlain by the conglomerates, sands and red clays of the Duvergé Fm (Figure 10f). Sands in this last unit have provided an OSL age of 71.0 ± 4.5 ka. These deposits are tilted southwestward as a consequence of the uplift of the Loma Derrico anticline and are deformed by ENE to E-striking strike-slip and normal faults that form a conjugate pair. The minimum dihedral angle bisector and the trend of subvertical extension fractures (T-planes) in the clasts of the conglomerate establish a strike-slip stress regime with a N252°E trending compressional axis (Figure 10a).

Site 21JE28 is also located on the Jimaní-El Limón Road, on the southwest limb of the WNW-trending and NE-verging Loma Bartolo anticline, where the limestones of the Miocene Barahona Fm overthrust the conglomerates of the Late Pleistocene Duvergé Fm (Figure 7a). Uplift of the anticline gave rise to the intramountainous endorheic El Limón basin, which is limited to the SW by the BAFZ (Figure 11c). At the site, the gravels and sands of the Duvergé Fm form a homoclinal sequence of W-E to ENE-WSW trend dipping a mid-angle to the S. Slip measurements in metric-scale WNW-striking and SW-dipping reverse faults are compatible with a purely compressional stress regime with a N224°E trending σ_1 (Figure 11a). Following the southern limb of the Loma Bartolo anticline, site 21JE37 is located 0.5 km north of the El Limón town (Figure 7a). At this site, the calcarenites and marls of the upper Jimaní Fm are deformed by thrust faults and related drag folds (Figure 11d). Striations with a reverse slip movement on the fault planes define a thrust stress regime with a N052°E trending σ_1 axis (Figure 11a). All these compressional structures are related to the fold and thrust tectonics associated with the BAFZ and its propagation to the southern margin of the Enriquillo basin during the Holocene. Uplift and erosion of the anticlines is recorded by the syn-tectonic clastic sedimentation of the Duvergé Fm.

To the west, site 21JE35 is located very close to the contact of the BAFZ, where the Barahona Fm limestones overthrust the conglomerates and sands of the Duvergé Fm (Figure 11c). A sample of sands from the inverted southwest limb truncated by the basal thrust has provided an OSL age of 31.5 ± 4.2 ka. The deposits of the Duvergé Fm are deformed by a conjugate pair of small-displacement faults of NNE-SSW to ENE-WSW trend and a high-dip angle ($>70^\circ$) to the NW and SE. This population of conjugate faults defines a compressional stress tensor characterized by a NE-trending subhorizontal σ_1 (Figure 11a). These brittle structures account for the Late Pleistocene activity of the frontal thrust of the Sierra de Bahoruco.

Site 21JE33 is located at the Duvergé-Jimaní Road, 8.0 km southeast of the El Limón, on the northern limb of a WNW-trending anticline build-up in the reefal limestones and calcarenites of the upper Jimaní Fm (Figure 7a). The anticline folds on its northern limb the conglomerates of the Duvergé Fm, where a level of red sands have provided an OSL age of 38.2 ± 2.8 ka (site 21JE38; Figure 11f). At its eastern tip, the bedding of the Holocene reef complex is tilted 10–14° toward the S (Figure 11h). The anticline is deformed by a system of high-dip angle

Figure 8. Structural analysis of the Matheux-Neiba fault zone. (a) Stereoplots of the principal stress-axes obtained from inversion of fault-slip data (see Tables S4 and S5). n , amount of data. Inversion methods: Right Dihedra Method (RDM); Direct Inversion Method (DIM); and Numerical Dynamic Analysis Method (NDA). (b) Cross section across the Loma Flecha and Tierra Prieta anticlines in southwestern Sierra de Neiba. Location of the C-C' cross-section is shown in Figure 7. (c) Limestones of the Miocene Sombrito Fm tectonically imbricated with conglomerates of the Late Pleistocene intermediate alluvial fan. The ensemble overthrusts conglomerates of the Holocene lower alluvial fan and the underlying fringing reef-complex of the Enriquillo Lake. (d) Panoramic view of the Sierra de Neiba thrust over the Enriquillo basin deposits along the Matheux-Neiba fault zone. (e) Outcrop of the Matheux-Neiba frontal thrust juxtaposing the limestones of the Sombrito Fm onto conglomerates and breccias with limestone blocks of the Holocene lower alluvial fan. (f) Detail of the high-pitch angle of the striations [e] in the fault plane (location is marked by a white star in (e)). See text for an explanation.

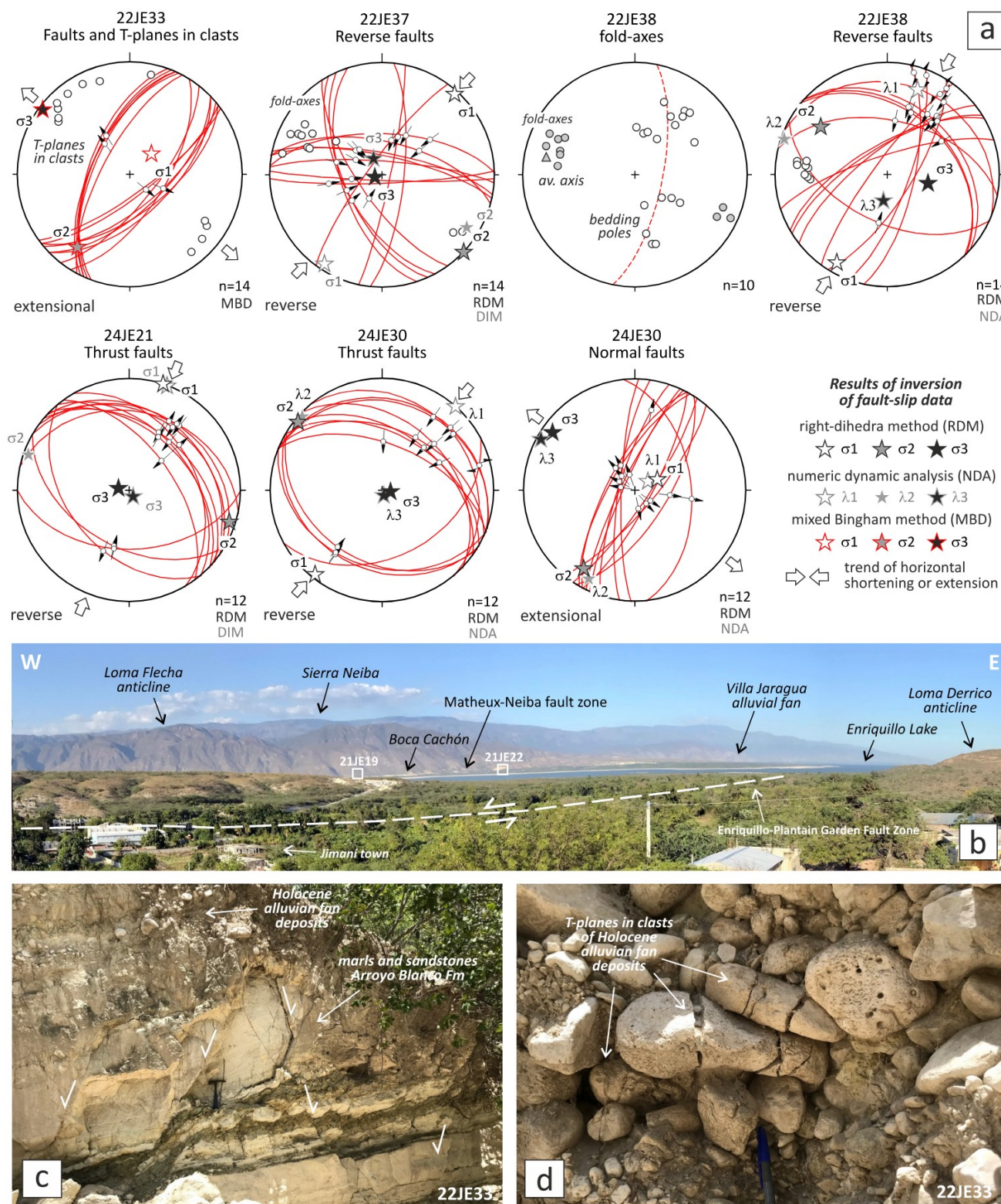


Figure 9. Structural analysis of the Sierra de Neiba. (a) Stereoplots of the principal stress-axes obtained from inversion of fault-slip data (see Tables S4 and S5). (b) Panoramic view of the Sierra de Neiba from the Jimaní town, showing the surface trace of the Enriquillo-Plantain Garden Fault Zone. (c) NNE to NE-striking normal faults deforming marls of the Arroyo Blanco Fm and poorly consolidated gravels of the Holocene alluvial fan outcropping east of Clavellinas town. (d) NE-striking T-planes developed in clast of Late Holocene alluvial fan deposits outcropping east of Clavellinas town.

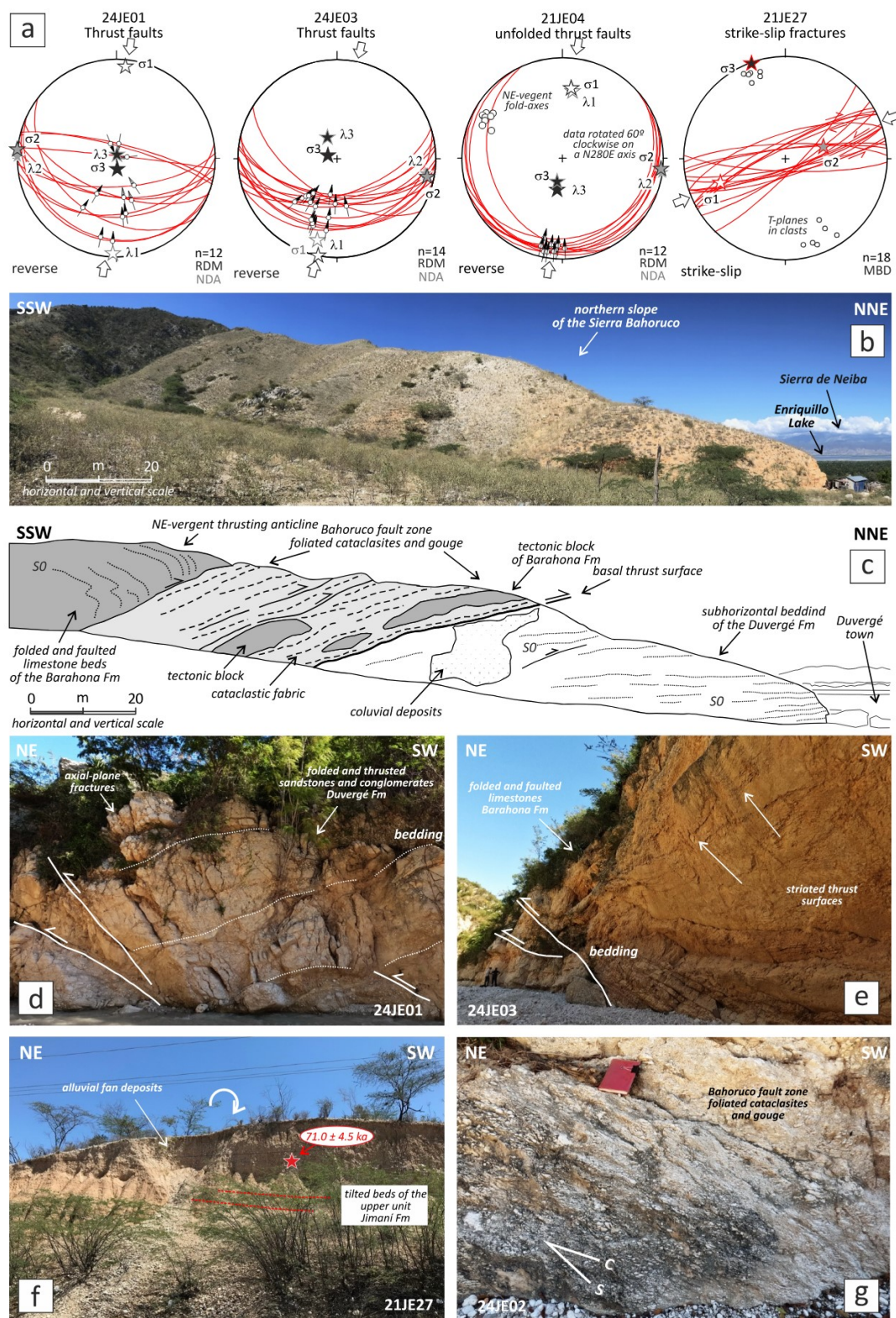


Figure 10.

(>60°) strike-slip faults, with a NE-striking family of left-lateral movement and another N-striking family of right-lateral movement (Figure 11a). Fault-slip measurements indicates faults of heterogeneous kinematics, from reverse to oblique and pure strike-slip, that is compatible with a compressional stress regime characterized by a N236°E trending σ_1 axis. These field relationships evidence the development of compressional structures related to the frontal thrusting of the Sierra de Bahoruco onto the Enriquillo basin in the Late Pleistocene and Holocene.

5.3. Fault-Slip Data Inversion in the Western Enriquillo Basin

The site 21JE12 is located 1 km northwest of Jimaní, on the southern limb of the W to ENE-trending Jimaní anticline structured in the shallow marine and deltaic deposits of the Middle Pleistocene upper Jimaní Fm, very close to the surface trace of the EPGFZ (Figure 7a). The beds in the unit dip between 50 and 70° to the S and are deformed by a conjugate pair of strike-slip faults, made up of a NNW to NW-striking dextral family and a NNE-striking sinistral family. Conjugate families establish a N210°E trending σ_1 axis indicative of a NNE-trending shortening orthogonal to the anticline axis (Figure 12a). One km to the east, site 21JE08 is located approximately 100 m north of the surface trace of the EPGFZ (Figure 7a). The deformation of the marls and marly limestones of the upper Jimaní Fm consists of a system of reverse faults with a WNW trend and medium to high-dip angle to the N and S. The pure reverse and oblique reverse movement striations that contain the fault planes define a population compatible with a thrust stress regime characterized by a N187°E trending σ_1 (Figure 12a). Therefore, cartographic folds and mesoscopic faults record a highly oblique shortening to the EPGFZ in the Late Pleistocene-Holocene.

5.4. Fault-Slip Data Inversion in the Azuei Lake

Site 21JE10 is located about 2 km west of Jimaní, on the northern shore of Azuei Lake, just on the border between Haiti and the Dominican Republic (Figure 7a). In the outcrop, the marly limestones and marls of the Jimaní Fm form the southern limb of the W-trending Jimaní anticline sub-parallel to the trace of the EPGFZ, which runs 160 m to the south submerged in the Azuei Lake. The limestones are deformed by high-dip angle (>80°) small faults and fractures organized into two conjugate families: ENE-striking left-lateral and NW-striking right-lateral faults (Figure 12a). This population of conjugate faults defines a reverse stress tensor characterized by an N-trending subhorizontal σ_1 and a subvertical σ_3 axes. An N-S shortening trend is compatible with the W-E orientation of the large-scale Jimaní anticline where station 21JE10 is located, but it is suborthogonal to the surface trace of the EPGFZ. The Jimaní Fm deposits are unconformably overlain by the clastic sediments of lower alluvial fan, that grade southward to fine-grained lacustrine deposits on the shore of Azuei Lake. These lacustrine deposits are deformed by small faults and subvertical fractures of W-E to ENE-WSW trend and reverse movement (Figure 12d), which may account for the Late Holocene activity of the EPGFZ.

5.5. Fault-Slip Data Inversion in the Northeastern Sierra de Bahoruco

The northeastern end of the Sierra de Bahoruco shows a very sharp NE-SW trending coastline, subparallel to the trace of the Beata Ridge fault zone, which runs offshore about 2.5 km to the SE (Figure 5a). Site 21JE39 is located at Playa Saladillas, about 1.5 km southeast of Barahona (Figure 3). Along the coast, the karstified limestones of the Barahona Fm define the northern limb of a WNW-trending anticline of kilometer-scale, related to the frontal thrust of the BAFZ. The footwall block is made up of conglomerates and red clays from the Duvergé Fm, which have provided at Juan Santiago lagoon an OSL age of 73.4 ± 5.4 ka (Figure 13b). Both the limestones and the conglomerates are unconformably overlain by a fossil coral reef terrace, about 10 m-thick, where a specimen of *Diploria* sp. collected in the uppermost levels has provided a U-Th age of 123.23 ± 0.70 ka (Figure 13c; Escuder-Viruet et al., 2024a), so its growth took place in the MIS 5e stage. The karstified limestones, the clastic deposits and the overlying coral terrace are faulted and tilted by a system of strike-slip faults and shear fractures. Fault

Figure 10. Structural analysis of the Bahoruco fault zone. (a) Stereoplots of the principal stress-axes obtained from inversion of fault-slip data (see Tables S4 and S5). (b) Panoramic view of the geological cross-section outcrop. (c) Geological cross-section of the Bahoruco fault zone at Duvergé site. Note the development of a decametric band of fault-rocks associated with the BAFZ. (d) N-vergent folds and reverse faults deforming the conglomerates of the Duvergé Fm in the Arroyo Blanco valley south of Jimaní town. (e) WNW to W-striking and southward dipping reverse faults deforming Barahona Fm limestones near the frontal thrust of the BAFZ, Arroyo Blanco valley. (f) Southwestward tilted conglomerates, sands and red clays of the Duvergé Fm, which have provided an OSL age of 71.0 ± 4.5 ka, Jimaní-El Limón Road. (g) Carbonate foliated cataclasites with mesoscopic S-C structures indicating a top-to-the N reverse movement associated with the BAFZ, Arroyo Blanco valley.

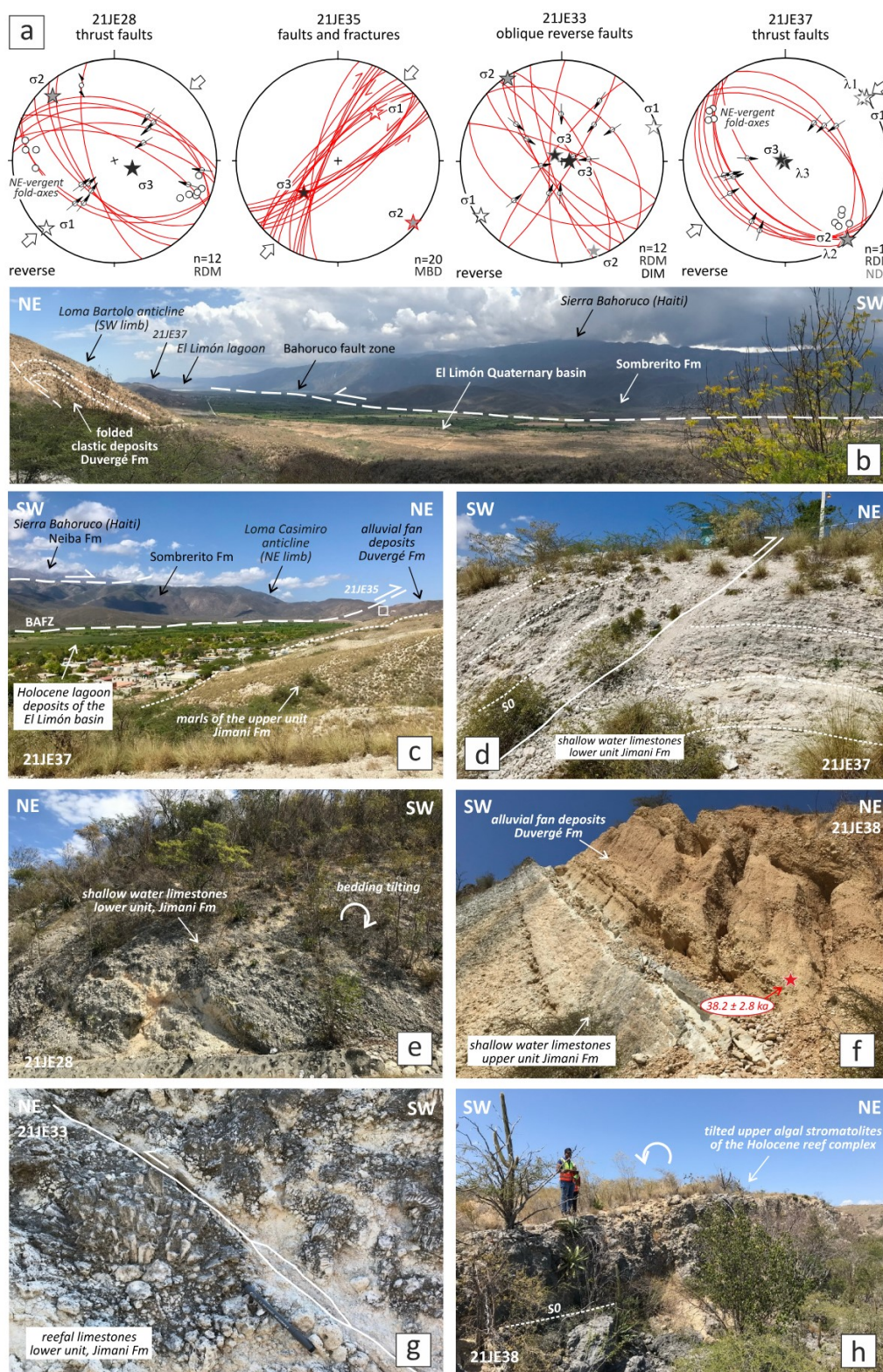


Figure 11.

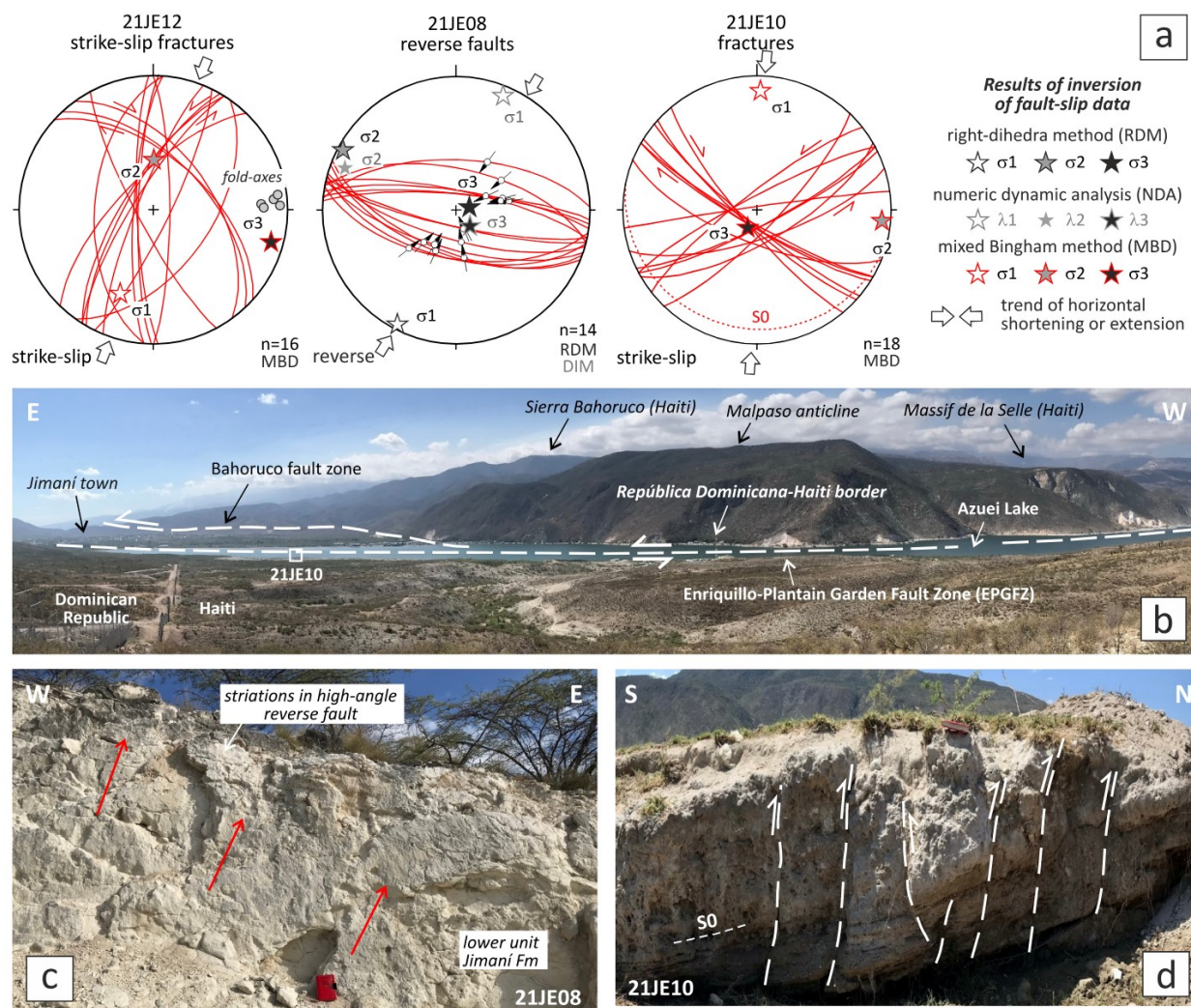


Figure 12. Structural analysis of the western Enriquillo basin and eastern Azuei Lake. (a) Stereoplots of the principal stress axes obtained from inversion of fault-slip data and fractures. (b) Panoramic view looking southward of the eastern Azuei Lake. The surface trace of the EPGFZ runs submerged under Lake Azuei. This fault truncates at a low angle the Malpaso anticline and the BAFZ. (c) Marly limestones and marls of the upper Jimaní Fm deformed by a system of WNW-trending and S-dipping reverse faults, Jimaní town. (d) Fine-grained lacustrine deposits tilted and deformed by small faults and subvertical fractures of W-E to ENE-WSW trend and reverse movement, shore of Azuei Lake.

planes are usually very steep (dip $>70^\circ$) and the kinematic indicators define two conjugate families: one dextral of N to NNE-strike and another senestral of ENE to WNW strike. Both families define a compressional stress tensor characterized by a NE trending subhorizontal σ_1 axis, orthogonal to the WNW-ESE trend of the regional anticline (Figure 13a). Toward the east, these anticlinal structures are deformed by NE-striking strike-slip faults subparallel to the Beata Ridge fault zone (Escuder-Viruet et al., 2023, 2024a).

Figure 11. Structural analysis of the frontal thrusting of the Sierra de Bahoruco. (a) Stereoplots of the principal stress axes obtained from inversion of fault-slip data and fractures. (b) Panoramic view looking southward of the El Limón Quaternary basin. This basin is limited to the SW by the BAFZ, which juxtaposes Barahona Mb limestones onto the alluvial fan deposits of the Duvergé Fm. Due to the flexural loading of the thrust, the basin tilts toward the SW active margin, giving rise to an endorheic lacustrine zone. (c) Panoramic view looking westward of the tectonic contact between the Loma Casimiro thrusting anticline and the El Limón Quaternary basin. (d) Calcarenites and marls of the upper Jimaní Fm deformed by thrust faults and related drag folds in the southern limb of the Loma Bartolo anticline. (e) Gravels and sands of the Duvergé dipping to the S in the southwest limb of the Bartolo anticline, Jimaní-El Limón Road. (f) Tilted stratigraphic contact between the upper unit of the Jimaní Fm and the basal beds of the Duvergé Fm in the northern limb of a WNW-trending anticline, Duvergé-Jimaní road. (g) Reefal limestones and calcarenites of the upper Jimaní Fm deformed by reverse faults, Duvergé-Jimaní road. (h) Bedding of the Holocene reef complex tilted toward the S on the southern limb of a WNW-trending anticline, Duvergé-Jimaní road.

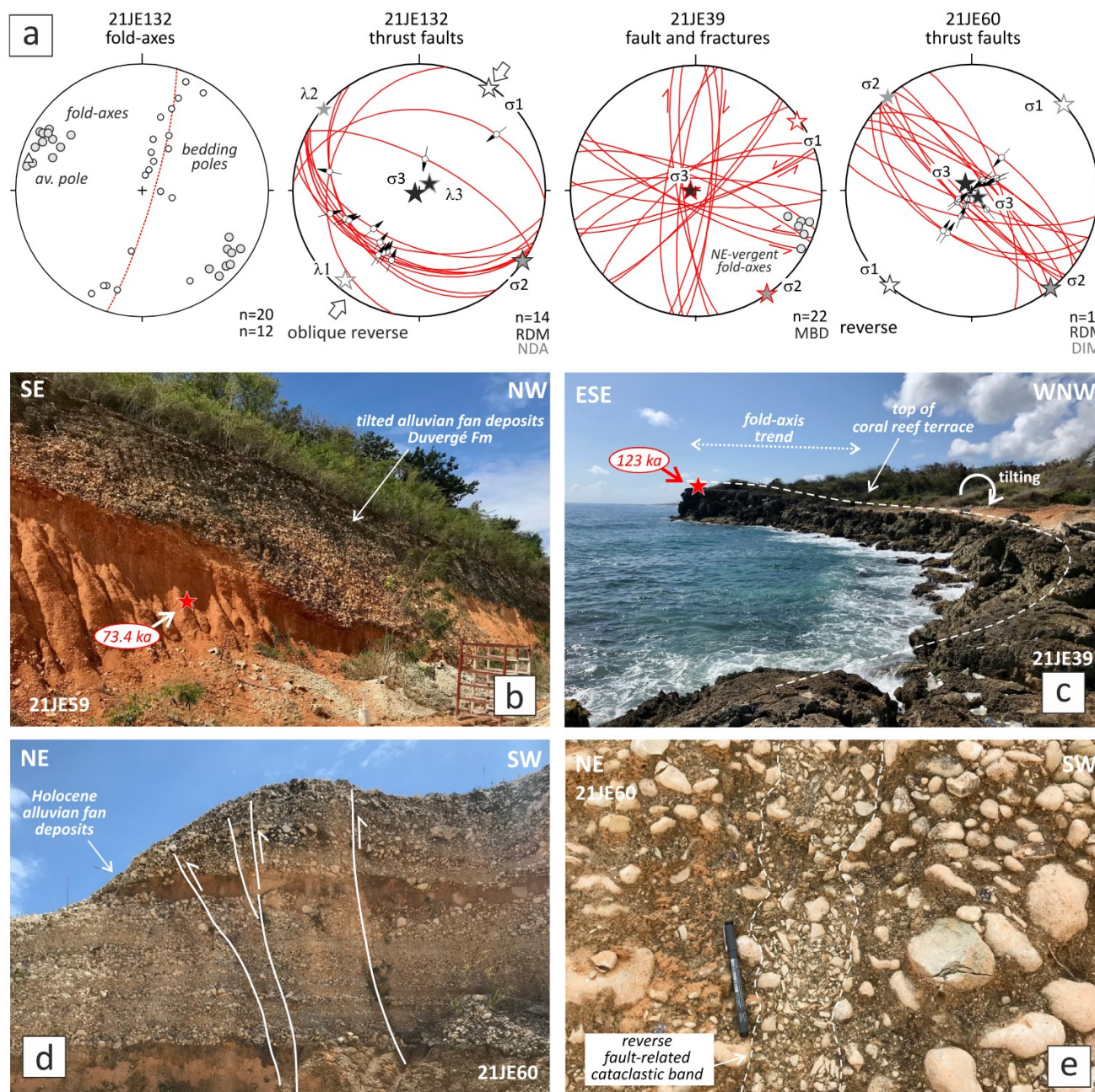


Figure 13. Structural analysis of the northeastern Sierra de Bahoruco. (a) Stereoplots of the principal stress axes obtained from inversion of fault-slip data and fractures. (b) Tilted conglomerates and red clays of the Duvergé Fm in the northern limb of the large-scale WNW-trending Barahona anticline. The height of the outcrop is about 20 m. (c) Tilted fossil coral reef terrace of the MIS 5e stage in the footwall block of the frontal thrust of the BAFZ, southeast of Barahona. (d) Red gravels and clays of an active alluvial fan deformed by NW to WNW-trending subvertical reverse faults, outcropping in a carry near the Barahona airport. The height of the outcrop is about 25 m. (e) Detail of a cataclastic bands formed parallel to the reverse faults of (d).

Site 21JE132 is located to the W, about 200 m south of the frontal thrust of the BAFZ, where the hanging-wall block gypsum and marl beds of the La Salina Fm exhibit compressional structures related to the northeastward thrusting of the Sierra de Bahoruco (Figure 3). These structures consist of WNW-trending and SW-verging asymmetric folds, associated with mid-dip angle reverse faults inclined to the NE, subparallel to the basal thrust. The asymmetry of folds and mesoscopic S-C structures establish a top-to-the NE reverse movement. Oblique reverse striae measured in the reverse fault planes define a fault population compatible with a pure thrust stress regime and a N034°E trending σ_1 axis (Figure 13a).

Site 21JE60 is located in the easternmost Enriquillo basin, where the clastic deposits of an extensive active alluvial fan developed by the Arroyo Palomino outcrop near the Barahona airport (Figure 3). The red gravels and clays of the alluvial fan are deformed by NW to WNW-trending subvertical reverse faults, whose surfaces include faint striations indicating a NE-directed reverse movement (Figures 13a and 13d). Faulting is also accommodated by the formation of 10 cm-thick cataclastic bands, parallel to the faults and characterized by a heavily fragmentation of the conglomerate clasts (Figure 13e). Regionally, these reverse faults are laterally related to a NW-trending fault-propagation anticline developed 1.5 km to the southeast in Pleistocene limestones. These structures collectively indicate the northeastward subsurface propagation of the frontal thrust of the Sierra de Bahoruco.

6. Discussion

6.1. Quaternary Sedimentation and Neotectonics Relationships

According to the tectono-sedimentary relationships, the uplift, folding and thrusting of the Cordillera Central basement, the external part of the Peralta Belt and the Haitian-Neiba fold-and-thrust belt were initiated in the lower Miocene (Escuder-Virquete et al., 2024a; Heubeck & Mann, 1991; Mann, Draper, & Lewis, 1991; Mann, McLaughlin, & Cooper, 1991; Pubellier et al., 2000). The regional style of deformation consists of a SW-directed fold-and-thrust belt that developed above a basal detachment horizon following a forward propagating sequence (Hernández-Huerta & Pérez-Estaún, 2002). This folding and thrusting event has been related to the collision between the island-arc crust of the Cordillera Central and the CLIP-related units of southwestern Hispaniola (Gonâve microplate) (Heubeck & Mann, 1991; Mann, McLaughlin, & Cooper, 1991). In this tectonic context, the San Juan-Azua and Cul-de-Sac-Enriquillo foreland basins developed sequentially in front of the fold-and-thrust belt (Díaz de Neira, 2004a, 2004b; Escuder-Virquete et al., 2024a; Hernández-Huerta & Pérez-Estaún, 2002). These basins were filled by deep-marine turbiditic and shallow-water transitional sediments giving rise to a 4 km-thick, coarsening upward regressive megasequence of lower Miocene to Early-Middle Pleistocene age (Hernández-Huerta et al., 2007a; Mann et al., 1999; McLaughlin et al., 1991; Pérez Valera & Abad, 2010). The present study documents that the deformation of the continental clastic deposits of the Duvergé Fm in the footwall of the SW-directed Matheux-Neiba fault zone, which is the current frontal thrust of the Sierra de Neiba (Figure 7), continued until the Late Pleistocene and Holocene. These conglomerates are also folded and faulted in the thrust anticlines of Loma Derrico, Loma Bartolo, La Salina and Barahona of the Sierra de Bahoruco (Figure 7), which constitute the NE-vergence frontal structures of the Barohuco fault zone. In the eastern Sierra de Bahoruco, the Duvergé Fm conglomerates unconformably overlie a fossil coral reef terrace developed during the MIS 5e (118–128 ka) and 5c (~105 ka) stages in the Last Interglacial (Escuder-Virquete et al., 2024b), and the intercalated alluvial sands have provided OSL ages between 73.4 ± 5.4 ka and 31.5 ± 4.2 ka (this work). Therefore, the Duvergé Fm is interpreted as a syn-tectonic alluvial fan system developed at the foot of the mountainous reliefs originated by the tectonic uplift and erosion of the Sierra de Bahoruco in the Late Pleistocene.

After a short sedimentary hiatus in the Late Pleistocene, the uplift and erosion of the renovated mountainous reliefs fed three staircase alluvial fan systems, developed at different topographic levels on the slopes of the Neiba and Bahoruco mountain ranges (Pérez Valera & Abad, 2010). These alluvial fans have not yet dated, but they probably also record continued uplift and erosion in the latest Pleistocene. Regionally, the intermediate alluvial fan constitutes the substrate on which the fringing coral reef was built in the periphery of Lago Enriquillo as a consequence of the rapid post-Last Glacial sea level rise (Mann et al., 1984; Taylor et al., 1985). The calibrated radiocarbon age of 9301–8975 BP (21JE04A) obtained for the basal transgressive levels of the reef complex establishes a latest Pleistocene age for the intermediate alluvial fan. The lower alluvial fan is currently active and overlies the thick accumulation of *Acropora cervicornis* branch corals and the fine-grained back-reef and lacustrine sediments. The calibrated radiocarbon age of 6195–5880 BP obtained in a specimen of *Acropora cervicornis* (21JE19) collected at the stratigraphically highest levels of the reef indicates a Middle to Late Holocene age for the overlying lower alluvial fan. The development of the lower alluvial fan therefore coincides with the disconnection of the Enriquillo depression with the Neiba bay about 5000 BP ago and the death of the reef owing to restricted water flow from the Caribbean Sea. The field data provided in this work indicate that all alluvial fan systems are deformed by structures related to the MNFZ and BAFZ. Otherwise, we have not found EPGFZ-related structures that deform the alluvial fan systems in the foothills of the Sierra de Neiba.

6.2. Regional Magnetic Field and the Large-Scale Structure Relationships

In general, the reduced to the pole (RTP) and first-vertical-derivative magnetic grids (VDM) allow us to distinguish several regional-scale magnetic domains characterized by a specific textural pattern of macrostructural significance (Figure 4). The western Sierra de Neiba, Sierra de Bahoruco and western Enriquillo basin display well structured, WNW to NW-trending, long-wavelength negative magnetic anomalies parallel to the regional structural grain, produced by a thick sequence of paramagnetic limestones or a cover of terrigenous sediments, which reduce the regional magnetic intensity. However, the eastern Sierra de Neiba, eastern Enriquillo basin and the limestone massifs of eastern Sierra de Bahoruco and Sierra de Martín García are characterized by unusual long-wavelength, positive magnetic anomalies. These positive magnetic anomalies are interpreted in this work as related to the presence of a basement of ferromagnetic basalts of the Cretaceous CLIP in these areas.

The diverse magnetic domains in both RTP and VDM grids are separated by magnetic discontinuities that correlate well with the large-scale fault zones, particularly the Matheux-Neiba and Bahoruco fault zones (Figure 4). However, the surface trace of the EPGFZ does not coincide with a clear magnetic discontinuity nor juxtaposes areas of different magnetic signatures. The VDM grid also shows the truncation and displacement of the NW to WNW-trending anticlines and synclines in the Sierra de Neiba and Sierra de Bahoruco by transverse NE to ENE-striking left-lateral strike-slip faults, sometimes marked by low magnetic values. The displacement of the macrostructure due to these NE-directed strike-slip faults is greater in the sector close to the Beata fault zone, such as the eastern Sierra de Bahoruco and Ocoa Bay.

Recently, Escuder-Virute et al. (2024a) described a structural evolution for the Ocoa Bay sector that includes a pre-Early Pleistocene event of NE-trending compression, which gave rise to the NW-trending large-scale fold and thrust structure in the Cordillera Central, Peralta Belt, Sierra Martín García and San Juan-Azua basin. This was followed by a near pure strike-slip stress regime, partitioned into the NNE-SSE to NE-SW transverse Ocoa-Bonao-La Guácara and Beata Ridge fault zones, as well as subordinate structures in related sub-parallel deformation corridors. In conjunction with previous research (Hernández Huerta & Pérez-Estaún, 2002; Heubeck & Mann, 1991; Mann, McLaughlin, & Cooper, 1991), these authors relate the shift to the strike-slip deformation with the indentation of the Beata Ridge in southern Hispaniola from the Early to Middle Pleistocene until present day. Therefore, the general WNW to NW-trending structural grain in the Enriquillo basin and the eastern Sierra de Bahoruco is only deformed by large-scale strike-slip faults in the vicinity of the Beata Ridge fault zone, which has important seismotectonic implications.

6.3. Quaternary Stress Regime

The main neotectonic structures in the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges are WNW to NW-striking thrusts and reverse faults, sub-parallel to the axes of related anticlines and synclines (Figure 3). These structures form a system of SW-directed thrusts in the Sierra de Neiba limited to the SW by the MNFZ and a composite anticlinorium in the Sierra de Bahoruco limited to the NE by the NE-directed BAFZ. These structures regionally deform the middle Eocene-lower Miocene marine platform carbonate sequence in both mountain ranges, as well as its Cretaceous volcanic substrate of the CLIP, the lower Miocene to Early-Middle Pleistocene marine turbiditic and platform sediments of the Enriquillo basin, and the Late Pleistocene continental clastic deposits of the Duvergé Fm (Hernández-Huerta & Pérez-Estaún, 2002; this work). Local deformation of the alluvial fan systems and the fringing coral reef of Enriquillo Lake by structures related to the MNFZ and BAFZ indicates that uplift and shortening continue today.

Stress tensors obtained for the Quaternary deformation in the studied area establish a general subhorizontal NE-trending σ_1 axis, ranging between N002°E and N058°E trends, with a relatively well-constrained maximum value in the density stereoplot at N215°E, plunging 06° to the SW (Figure 14). The vertical arrangement of σ_3 axis in the computed stress tensors is consistent with deformation by thrusting. The R stress ratio has values mostly of 0.50 ± 0.15 , indicating stress tensors close to pure compression (Figure 14). Therefore, the Quaternary regional stress regime consisted of a NE-trending subhorizontal shortening, which produced the main orthogonal regional structures. A general NE-directed Quaternary shortening was also obtained by Ramírez (1995) and Escuder-Virute et al. (2023, 2024a) from the inversion of fault-slip data in the nearby Cordillera Central and Ocoa Bay regions (Figure 14). This folding and thrusting deformation has been related to the collision between CLIP-related units of southern Hispaniola and the island-arc crust of the Cordillera Central (Escuder-Virute et al., 2024a; Heubeck & Mann, 1991; Mann, McLaughlin, & Cooper, 1991).

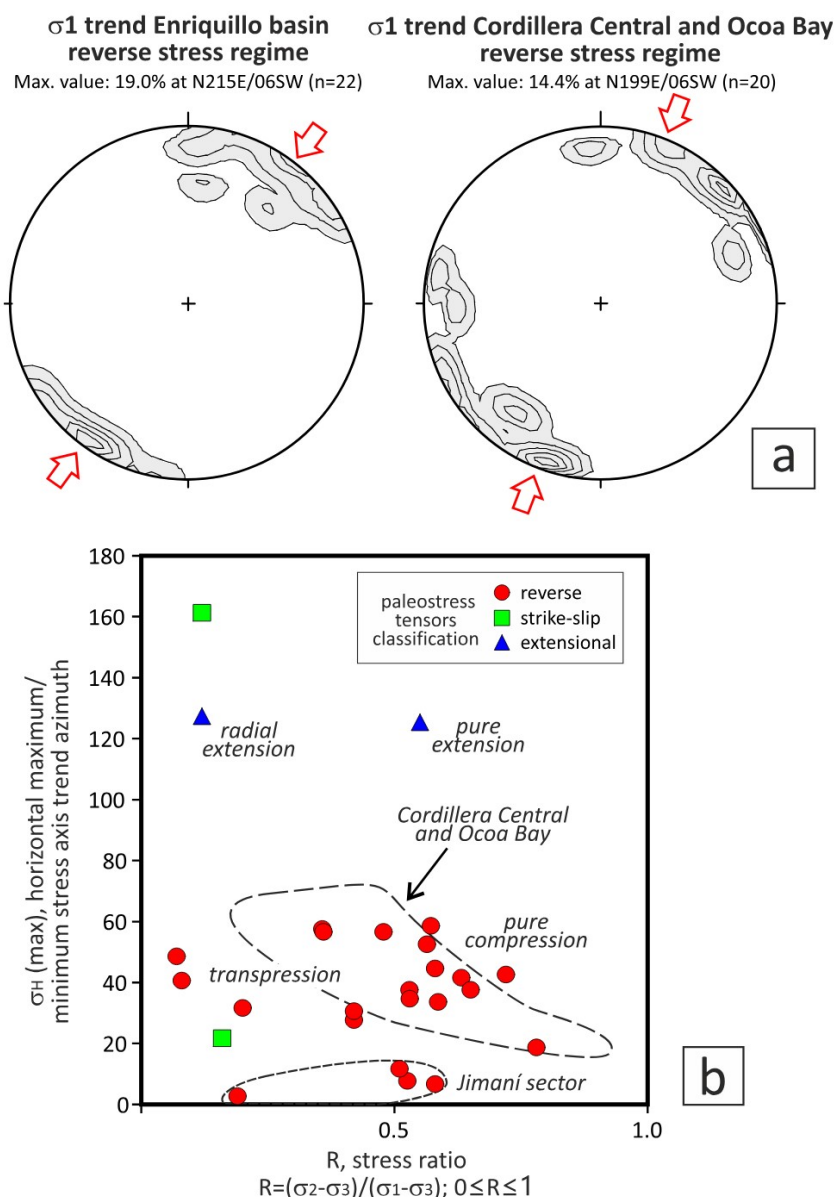


Figure 14. Stereoplots of the σ_1 stress-axes obtained from fault-slip data inversion in the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges, as well as in the Cordillera Central and Ocoa Bay (Escuder-Viruet et al., 2024a). Contours in stereoplots at 1.0%, 5.0%, 10.0%, 15.0%, 20.0%, and 25.0%. Computed mean stress axes for each deformation event are expressed in % and trend/plunge angles. (b) Classification of the obtained paleostress tensors according to its kinematic regime (see also Table S7).

However, the cartographic trace of the folds locally shows a sigmoidal pattern, characterized by a rotation of the axial planes toward the W-E direction, as in the Loma Flecha, Arroyo Salado, Tierra Prieta, Jimaní, Loma Derrico or Malpaso anticlines of the Boca Cachón and Jimaní sectors (Figure 7). This rotation of the axial planes of the folds is often accommodated by NE to ENE-striking left-lateral subvertical fault zones. Stress tensors with a σ_1 orientation close to the N-S trend have only been obtained in sites of the Jimaní sector (Figure 14). In these sites, R -ratio has values of 0.07 and 0.20, which means that the σ_2 (horizontal) and σ_3 (vertical) axes are close in magnitude ($\sigma_2 \approx \sigma_3$) and lower than σ_1 , characterizing a transpressional stress regime. These results agree with the structural field data in the Jimaní sector, which suggest that the transpressive deformation is partitioned into W to WNW-trending folds and reverse faults and NE to W-striking left-lateral strike-slip faults, like the observed at site 21JE27 displacing Loma Derrico anticline (Figure 7).

In the eastern sector of the Sierra de Bahoruco, the large-scale Barahona thrusting anticline, Rincón Lake backthrust and the BAFZ are also rotated and segmented by NE to NNE-striking left-lateral strike-slip faults (Figure 3). These transverse faults are related to the formation of the Beata Ridge and the Ocoa-Bonao-La Guácara fault zones, which produced a geographically localized strike-slip stress regime. This deformation has been related to indentation of the Beata Ridge in the Ocoa Bay region from the Early to Middle Pleistocene (Escuder-Virquete et al., 2023, 2024a).

Finally, the regional fold-and-thrust belt of the Sierra de Neiba is also locally deformed by NNE to NE-striking normal to oblique normal faults, generally with an eastern hanging-wall block. At sites located close to these transverse structures, the computed stress tensors are extensional and characterized by a narrow orientation of σ_3 axes between N125°E and N127°E. R-ratio values of 0.12 and 0.55 establish radial and pure extensional stress regimes. The age of these extensional structures could not be precisely established. However, similar normal faults deform volcanic rocks of Pleistocene age in the Cordillera Central (Escuder-Virquete et al., 2024a). In summary, a relatively constant NE-trending compressional regime controlled the Quaternary strain in the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges. This compression is only locally perturbed by near pure strike-slip and extensional events.

6.4. Constrains on Crustal Deformation From GPS Data

Calais et al. (2002), Mann et al. (2002) and Manaker et al. (2008) consider a model of active oblique collision between the Caribbean and North American plates, in which the relative motion is partitioned into the EPGFZ and SFZ onland strike-slip faults and the NHFZ and MT offshore trench faults. For these authors, the GPS velocity decrease from the NE to the SW along Hispaniola with respect to a fixed Caribbean plate is a consequence of both the accumulation of elastic deformation in individual locked faults and/or non-elastic continuous deformation throughout the entire island. Subsequently, Calais et al. (2010), Benford et al. (2012) and Symithe et al. (2015) describe the anti-clockwise rotation of the GPS velocity vectors from an oblique orientation to one orthogonal to the plate boundary, along with the progressive southward decrease in its magnitude. For these authors, this velocity field indicates a purely elastic inter-seismic deformation with some partitioning of the deformation in the strike-slip fault zones.

More recently, Symithe and Calais (2016) and Calais et al. (2022) demonstrate with an improved GPS velocity data set that the active strain accumulation in the southern Hispaniola involves an additional significant component of N-S shortening, implying a regional transpressive deformation. In southern Haiti, this transpressive deformation would be partitioned by a left-lateral strike-slip movement along the EPGFZ and an orthogonal or oblique shortening in the Jérémie-Malpassee reverse fault system, as well as the active thrusts described offshore in the Gulf of Gonâve by Corbeau et al. (2016). For these authors, deformation partitioning provides a framework to understand the 2010 M_w 7.0 and 2021 M_w 7.2 transpressional earthquakes. A N-trending component would also explain the NE-verging fault propagation folds and NE-directed thrusts that mark the structural boundary between the Massif de La Selle and the Cul-de-Sac basin, described by Saint Fleur et al. (2019, 2020), Calais et al. (2016), Wang et al. (2018), and Wessels et al. (2019).

In the studied area, the available GPS geodetic data are scarce, but they allow establishing several first-order considerations regarding the current crustal deformation. First, the GPS velocities measured at the sites of the Cordillera Central, Chaîne des Matheux-Sierra de Neiba, Massif de la Selle-Bahoruco and Cuenca de Enriquillo, show a high component directed toward the SW. This component is parallel to the main shortening direction obtained from the inversion of fault-slip data and the P-axes of focal mechanisms and is consistent with the deformation of the region by NW-trending folding and thrusting from the Late Neogene to the present. Second, GPS displacements indicate activity along the structures that control the morphostructure of mountainous alignments and intermediate basins. These structures accommodate variable components of shortening through thrusting or reverse faulting and left-lateral strike-slip displacements. Displacement rates range between 1 and 4 mm/yr for movements perpendicular and parallel to each fault zone. Therefore, models of the elastic deformation accumulation in Hispaniola must take into account, in addition to the deformation in the NHFZ and the EPGFZ, the deformation in other active macrostructures such as the Matheux-Neiba and Bahoruco fault zones (as well as diffuse shortening across the region). Third, the existence of both perpendicular and parallel displacements to the main fault zones suggests a present-day transpressive deformation. However, the movement is not generally partitioned into discrete thrusts and subparallel strike-slip faults in the sense of Dewey et al. (1998),

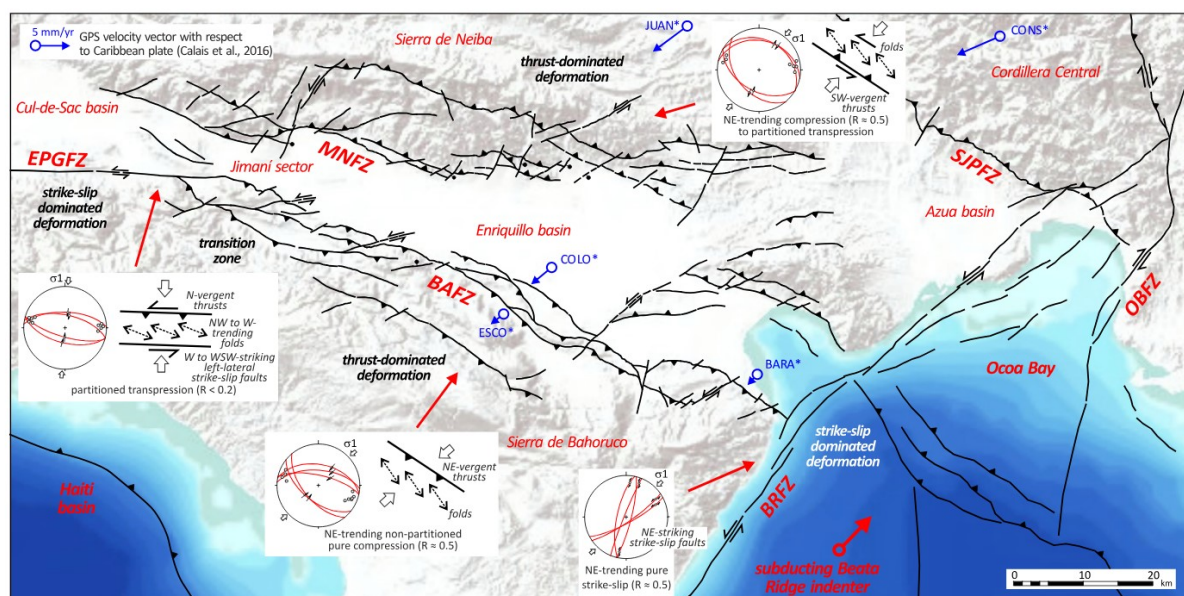


Figure 15. Schematic kinematic model for the different ways of accommodation of the Quaternary NE-trending convergence in the Enriquillo basin and adjacent Neiba and Bahoruco mountain ranges. Lower-hemisphere stereoplots indicating principal fault planes with the observed striations. Open arrows indicate regional σ_1 direction. Blue arrows are GPS velocities relative to the fixed Caribbean plate (Calais et al., 2016). Shaded relief and acronyms as in Figure 3. See text for an explanation.

because the main NNE to NE shortening component is suborthogonal to the WNW to NW direction of the main folds and thrusts in the Neiba and Bahoruco mountain ranges. Consistently, the inversion of fault-slip data in fault populations obtained throughout the region is largely compatible with a pure thrusting stress regime and a NE-trending compressional axis. Fourth, slip rates parallel to the Enriquillo-Plantain-Garden fault zone decline eastward from about 4 mm/yr in the Cul-de-Sac basin to less than 1–2 mm/yr in the Enriquillo basin, suggesting the eastern termination of this structure (Mann et al., 1995). These low slip rates, close to the instrumental error of the GPS data, agree with the proposal by Symithe and Calais (2016) and Saint Fleur et al. (2019) of a non-continuation of the EPGFZ in the eastern Cul-de-Sac Valley, Azuey Lake and Enriquillo Lake sectors. For these authors, the high rates of N-S shortening predicted from GPS block models are accommodated entirely by low-angle thrust structures in the eastern Cul-de-Sac and Enriquillo basins.

6.5. Kinematic Model

Observed major (at the regional fault zone scale) and minor (at the slickenside scale) deformations, GPS velocities and well-constrained fault plane solutions of earthquakes provide evidence of a Quaternary NE-trending shortening in the Enriquillo basin and adjacent mountain ranges. These varied data indicate that the present-day kinematics of each fault strongly depends on its orientation with respect to the stress tensor, as shown in the proposed kinematic model of Figure 15. As the angle between the direction of regional shortening and the strike of the structure decreases, kinematics ranges from pure thrust to oblique reverse fault to pure strike-slip.

In the Sierra de Bahoruco, the NW to WNW-striking BAFZ is nearly orthogonal to the main compression (σ_1) and has a reverse dip slip. The resulting non-partitioned deformation is dominated by thrust faulting. The minor oblique component of less orthogonal fault planes is accommodated by a left-lateral reverse oblique slip. In the Jimaní sector, the linking zone between the BAFZ and the W-striking eastern tip of the EPGFZ is less oblique to σ_1 , resulting in partitioned transpression (i.e., onto parallel pure reverse dip-slip and pure left-lateral strike-slip faults). In the Cul-de-Sac basin, the WSW-striking EPGFZ is very oblique to parallel to σ_1 and its kinematics is characterized by a left-lateral strike-slip movement, as described by Wang et al. (2018) and Saint Fleur et al. (2019), among others. The eastern Sierra de Bahoruco is limited by the NNE to NE-striking BRZF. This fault zone and other related faults in the eastern Enriquillo basin are subparallel to the σ_1 and present a main left-lateral strike-slip displacement (Escuder-Viruet et al., 2023). In the southern Sierra de Neiba, the WNW to NW-trending fault-propagation anticlines and the MNFZ are nearly normal to σ_1 axis, giving rise to a pure reverse faulting. However, the left-lateral *en-écheleon* arrangement of the large-scale folds that affected the Eocene to

Miocene limestones suggests some deformation partitioning with respect to the NE-trending regional compression. A more detailed study of the fault kinematics and age of folding extended to the entire Sierra de Neiba will confirm this interpretation. In summary, the current tectonic regime across the study area is transpressional, but the kinematics of each fault depends on its orientation with respect to the NE-trending shortening, which gives rise to a spatial transition in the deformation partitioning (Figure 15). This kinematic model has implications for the estimation of regional seismic hazard (see below).

6.6. Seismicity and Crustal Structure Relationships

Seismicity in the Enriquillo basin and adjacent mountain ranges is shown in Figure 6. This seismicity marks most of the active fault zones and is consistent with the location of young tectonic landforms, fault scarps and a variety of geomorphological markers indicative of active faulting and tectonic uplift along these deforming zones. Focal mechanism solutions indicate upper to mid-crustal active thrusting on both margins of the Enriquillo basin, along the SW-directed MNFZ in its northeastern sector and the NE-directed BAFZ in its southwestern sector, being consistent with field structural data and with present-day NE-trending shortening. Other events indicate local left-lateral strike-slip faulting along NE to ENE-trending faults and normal faulting on NNE to NE trending faults.

To better understand the relationships between seismicity and crustal structure, the seismic data have been projected in two transversals oriented orthogonally to the trend of the main faults (Figure 16). Projected data includes the catalog earthquakes with precise location of the focal depth (excluding earthquakes with default assigned depth of 0, 10, and 33 km) and the focal mechanisms, included in a band of 0.25° width parallel to each transversal. The crustal sections also include the interpreted location of the main fault zones, as well as the depth of Moho discontinuity following Núñez et al. (2016, 2019).

The transverse D-D' crosses the Sierra de Neiba to the Beata Island and shows abundant superficial seismicity distributed up to 30 km deep. The clustering of hypocenters defines a crustal-scale ramp structure inclined toward the southwest, which intersects the surface with the cartographic trace of the BAFZ, as well as other blind structures under the southern sector of the Enriquillo basin. This structure is similar to the thrust structure inferred from seismicity by Rodríguez et al. (2018) under the Sierra de Bahoruco and from geodetic data by Calais et al. (2022) in the Gonâve basin of Haiti. Above the ramp, seismicity delineates structures inclined to both the SW and NE that intersect at the surface with the main faults mapped in the Sierra de Bahoruco. Synthetic and antithetic structures converge at depth with the main ramp structure. These structures are interpreted as a system of active thrusts that accommodate regional shortening and uplift the Sierra de Bahoruco. Under the Sierra de Neiba and the northern margin of the Enriquillo basin, hypocenters are also abundant, down to about 20 km depth and their clustering defines crustal-scale structures inclined to the NE. One of these structures intersects on the surface with the trace of the MNFZ, so the seismicity reflects the thrusts and folds of the Sierra de Neiba. Between the Bahoruco and Neiba fault zones, there are few earthquakes under the Enriquillo basin and no seismicity is detected from W-trending strike-slip faults related to the EPGFZ.

The transverse E-E' is slightly oblique to the BRFZ (Figure 16). Along the transversal, the hypocenters also delineate the southward-dipping ramp structure up to 30 km depth, so it has a regional extension. The several branches of this structure are interpreted as large-scale fault propagation folds and reverse faults that deform the Sierra de Bahoruco and the substrate of the Enriquillo basin. This abundant seismicity contrasts with the lack of earthquakes in the crust located east of the BRFZ, so this structure separates different seismic domains. Under the Neiba and Martín García mountain ranges, earthquakes are less abundant and occur up to 20 km depth and do not image a clear structure.

At depths greater than 30 km, the seismicity defines under the Sierra de Bahoruco in both transversals an elongated domain inclined toward the N, about 30 km thick, limited at the top by the southward-dipping ramp structure (Figure 16). This intermediate-depth seismicity (30–70 km-depth) is interpreted as related to the subduction of the thick Caribbean oceanic plateau under the overlying Gonâve plate. In this geodynamic context, the subduction of the Caribbean oceanic crust of normal thickness and the arrival of the positively buoyant CLIP (Sierra de Bahoruco) to the Muertos trench has produced obstruction of the subduction channel and blocking of the subduction process. Following a mechanism analogous to that described by Mann and Taira (2004) in the Salomon-Vanuatu subduction system and modeled by Almeida et al. (2022), the closure of the subduction channel by a buoyant plateau can trigger the reversal of subduction polarity. In our case, the shutdown of the initial Muertos subduction zone, the welding of the Caribbean and Gonâve plates after plateau docking and the

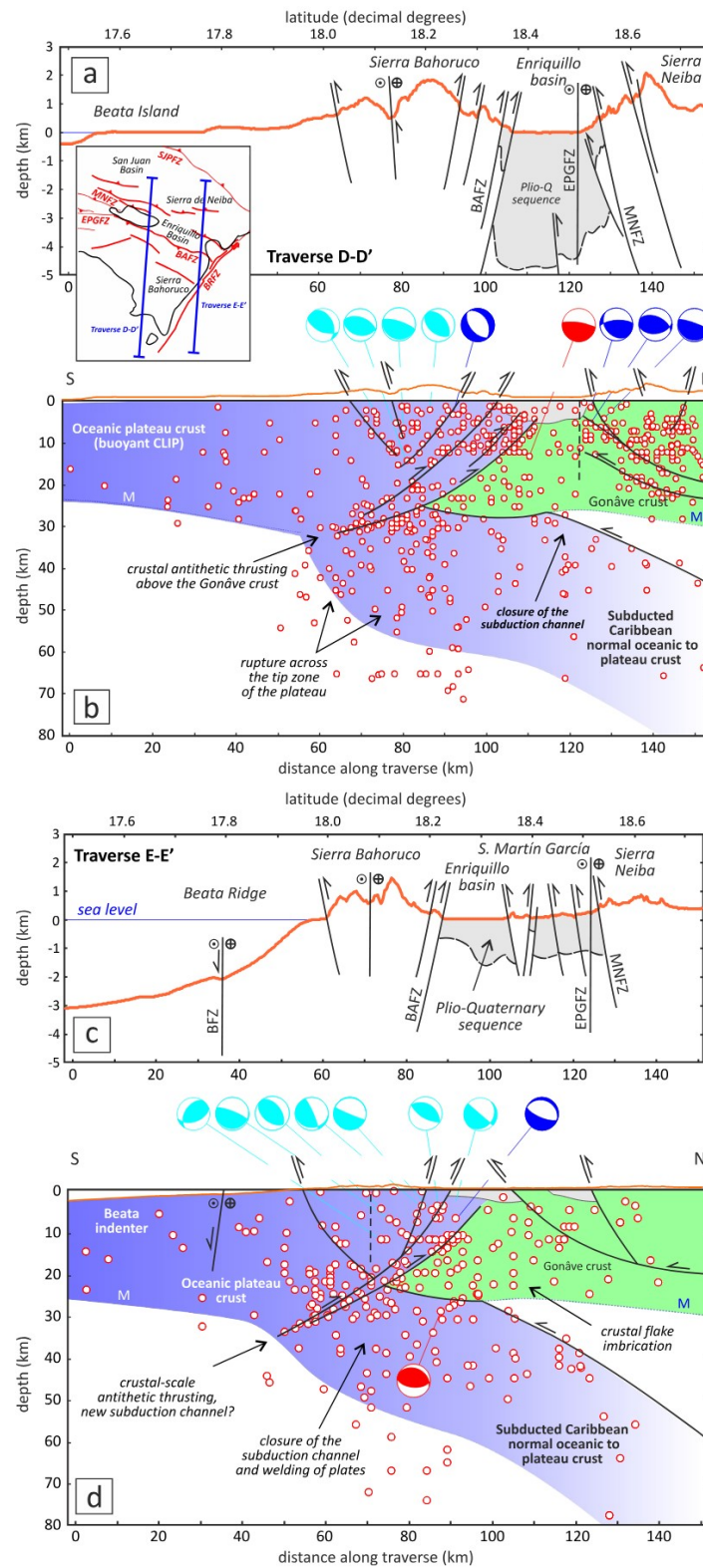


Figure 16.

continued compression between plates, have formed a crustal antithetic thrust in the upper CLIP crust and the onset of the rupture in depth of the transition between the oceanic and plateau crust. If shortening continues in the future, the downward thrust propagation across the whole CLIP lithosphere could form a new opposite dipping subduction channel, or be transferred to the thrusts of the southern Haiti sub-basin.

6.7. Seismic Hazard Assessment in the Enriquillo Basin

A probabilistic seismic hazard analysis (PSHA) quantifies the likelihood of earthquake-induced ground shaking at or above a specified intensity for a specific return period or probability, combining an earthquake occurrence model together with a ground motion model (McGuire, 2004; see also Morell et al., 2020). Hazard maps derived from this analysis show the level of ground shaking, usually expressed as a peak ground acceleration (PGA), for a particular probability or return period (Gerstenberger et al., 2020). In this work, the PSHA was calculated using the R-CRISIS code (Ordaz et al., 2014) that takes into account the spatial distribution of seismogenic sources, the occurrence and magnitude of earthquakes in time, and the attenuation characteristics of the strong motion in the ground.

Recently, Escuder-Virue et al. (2024a) carried out a PSHA in the Cordillera Central and Ocoa Bay, which is geographically extended in this work to the Enriquillo basin and adjacent Neiba and Batoruco mountain ranges. The spatial distribution of the seismotectonic structures is shown in Figure 17, which includes the SJPFZ, OBFZ, BRZF, BAFZ, MNFZ and the eastern tip of the EPGFZ. In the PSHA, they were geometrically modeled as simplified 3-D polygonal surfaces of specific widths. The Table S8 includes the characteristics of these seismotectonic structures, such as their name, deformation mechanism, estimated maximum magnitude, known biggest earthquake, estimated displacement rate, length, trend and width of the fault. The maximum magnitude of rupture for each fault or segment was estimated using the major recorded historical earthquake or scaling relations between earthquake and magnitude (Stirling et al., 2013), taking into account its degree of uncertainty (Bertil et al., 2015). Displacement rates were derived from geological data and/or geodetic GPS measurements (Mann et al., 2002; Calais et al., 2016; this work). Functions selected to describe the attenuation of the ground motion with distance from the source are the same as those used by Frankel et al. (2011; see also Escuder-Virue et al., 2023). From this information, a simplified regional seismotectonic model was built that considers four types of seismic sources: subduction, reverse and strike-slip fault zones in which the seismicity of greater magnitude is concentrated; and superficial areas located between them where the seismicity is of moderate to low magnitude and is homogeneously distributed.

Figure 17 includes the results of the seismic hazard assessment in the Enriquillo basin, expressed as PGA intervals (values in cm/s^2) and for a return period of 475 years (i.e., for a probability of exceedance of 10% in 50 years). Modeled minimum and maximum PGA values are 93 cm/s^2 and 600 cm/s^2 , respectively, with a mean (and standard deviation) of 310.4 cm/s^2 (109.2). Therefore, the regional seismic hazard ranges from low to intermediate values, being high in certain sectors. It is higher in the southwest Sierra de Neiba, western Enriquillo basin, and the northwest Sierra de Batoruco (Figure 17). Hazard decreases toward the W and SE sectors of the Enriquillo basin, but increases again in the offshore sector east of Barahona and the western Ocoa Bay. This seismic hazard zoning is different in the spatial distribution and magnitude of the PGA compared to that previously proposed by Frankel et al. (2011), Benito et al. (2012) and Bertil et al. (2015), which did not take into account all the seismic sources included in this work.

PGA zoning defines an elongated pattern generally sub-parallel to the main fault zones. Highest PGA values ($>500 \text{ cm/s}^2$) are associated with the eastern end of the Enriquillo and Matheux-Neiba fault zones. Outside of the interaction between these fault zones, the PGA decreases eastward to low values ($<300 \text{ cm/s}^2$) in the MNFZ. The BAFZ has associated low to intermediate PGA values ($280\text{--}330 \text{ cm/s}^2$), which increase to high values at its eastern and western ends in its connection to the BRZF and EPGFZ, respectively. West of the Enriquillo basin, the highest PGA values are associated with N-BRZF, S-OBGFZ and O-MT segments, whose traces frame a

Figure 16. (a, c) D-D' and E-E' topographic traverses drawn orthogonal to the WNW-ESE strike of the main active fault zones in the Enriquillo basin and Neiba and Batoruco mountain ranges. Their location is marked in Figure 5. (b, d) Interpretative crustal cross sections showing the subduction and collision of the Caribbean normal oceanic to oceanic plateau crust (CLIP). Small red circles show hypocenters from the catalog compiled for southern central Hispaniola from 1562 to Dec 2022 projected to the traverse planes. Nearby focal mechanisms are also shown which have not been rotated to the vertical plane of the traverses. Closure of the subduction channel produces the crustal-scale antithetic thrusting of the Sierra de Batoruco onto the Gonâve microplate. Abbreviations as in Figure 3. See text for an explanation.

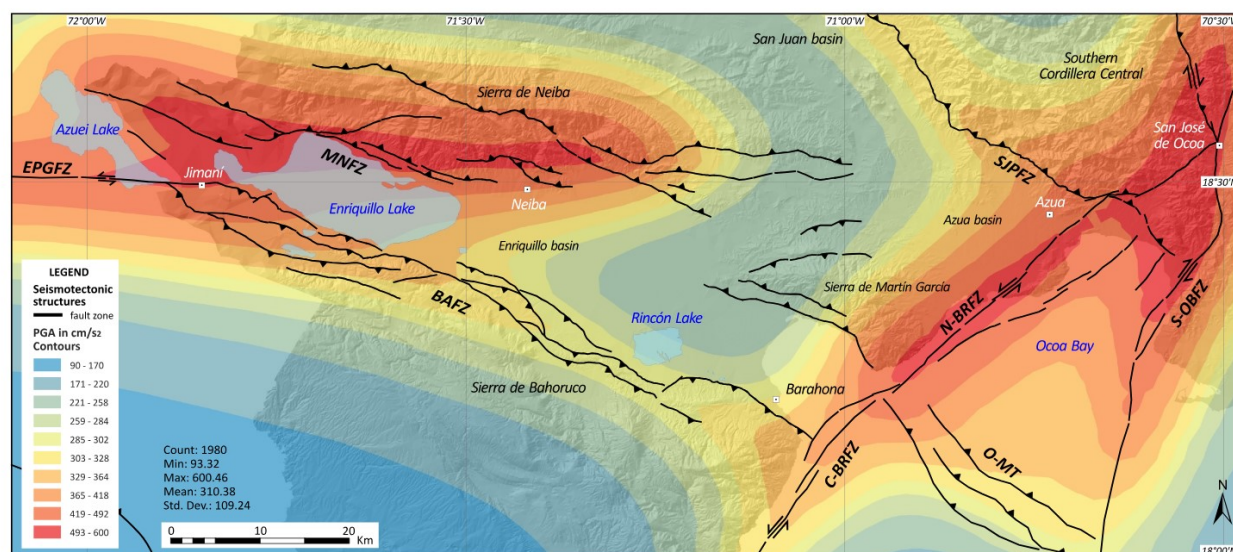


Figure 17. Result of the probabilistic seismic hazard modeling in the Enriquillo basin, Neiba, Bahoruco and Martín García mountain ranges, as well as adjacent offshore sectors of the Ocoa Bay, expressed as iso-PGA (Peak Ground Acceleration) zones (in cm/s^2) for a return period of 475 years (i.e., an exceedance probability of 10% in 50 years). Figure also includes the trace of the main seismogenic structures described in Table S8. Shaded relief and abbreviations as in Figure 3. See text for explanation.

triangular zone centered on Ocoa Bay, where the seismic hazard is high. The results of modeling indicate that the BRFZ, the O-MT and, less likely, the S-OBFZ could have generated the 1751 Azua earthquake (M_w 7.5; Bakun et al., 2012), which according to some historical accounts produced a tsunami in the Ocoa Bay.

Data Availability Statement

The data for this paper are contained in the text, figures and supporting information and can also be found in the data repository DIGITAL.CSIC which is the institutional repository of the Spanish National Research Council (Escuder-Viruet et al., 2024b).

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