CCAF-DB: The Caribbean and Central American Active Fault Database

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Abstract. A database of ~250 active fault traces in the Caribbean and Central American regions has been assembled to characterize the seismic hazard and tectonics of the area, as part of the GEM Foundation's Caribbean and Central American Risk Assesment (CCARA) project. The dataset is available in many vector GIS formats, and contains fault trace locations as well as attributes describing fault geometry and kinematics, slip rates, data quality and uncertainty, and other metadata as available.

5   The data is public and open-source (available at https://github.com/GEMScienceTools/central_am_carib_faults), will be updated progressively as new data is available, and is open to community contribution. The active fault data show deformation in the region to be centered around the margins of the Caribbean plate. Northern Central America has sinistral and reverse faults north of the sinistral Motagua-Polochic Fault Zone, which accommodates sinistral Caribbean-North American relative motion. The Central American Highlands extend east-west along a broad array of normal faults, bound by the Motagua-Polochic Fault

10 Zone in the north and dextral faulting in the southwest between the Caribbean plate and the Central American forearc. Faulting in southern Central America is complicated, with trench-parallel reverse and sinistral faults. The northern Caribbean-North American plate boundary is sinistral offshore of Central America, with transpressive stepovers through Jamaica, southern Cuba and Hispaniola. Farther east, deformation becomes more contractional closer to the Lesser Antilles subduction zone, with minor extension and sinistral shear throughout the upper plate, accommodating oblique convergence of the Caribbean and North

15 American plates.

1   Introduction

The Caribbean and Central American region is characterized tectonically by deformation zones surrounding plate boundaries with rapid relative plate motion. While this is not an uncommon situation on Earth, it is troublesome from a seismic risk perspective because nearly all of the Caribbean plate's subaerial land is within these deformation zones. As a result, most of

20 the region's 100 million inhabitants is within ~50 km of at least one active fault.

Though earthquakes in the region have been described throughout history and the area has received a fair amount of scientific study, there has so far been little coordinated and internally-consistent assessment of seismic sources and hazard covering the entire Caribbean and Central American region. To this end, the GEM Foundation and its collaborators are working on the

USAID-funded Caribbean and Central American Risk Assessment (CCARA) project (https://ccara.openquake.org/) to calculate probabilistic seismic hazard and risk analysis for the region. As a component of the CCARA project, we have compiled a database of active faults (Styron et al., 2018), available at https://github.com/GEMScienceTools/central_am_carib_faults, for use as fault sources for probabilistic seismic hazard analysis (PSHA).

5   This paper describes the format of the database and the methods used to construct it (i.e., mapping the faults in GIS), as well as the data contained therein. The database description is contained in the eponymous section. The data are described in the "Overview of Regional Faulting" section, which documents the structures at the minimum level of detail required for constructing a seismic hazard source model with an understanding of the sources of the data and attributes as well as their uncertainties. This section also serves readers more interested in tectonics than quantitative hazard analysis as an introduction

10   to the patterns of active faulting and literature of any given region. This section is not meant to be read as a start-to-finish narrative, but instead as a reference for each region. Finally, the paper discusses where the most important fault research should be done from a seismic hazard and risk perspective in the "Faulting, seismic risk and uncertainty" section.

Seismic hazard and risk analysis is multidisciplinary, involving scientists and engineers working on field geology, geodesy, seismology, structural and civil engineering, economics, finance, and policy. Consequently, the analysis process consumes data

15   generated by one field, and produces data (or models) intended for another field. The CCAF-DB and this paper documenting it serve to synthesize fault geologic and geodetic information for seismic hazard workers who may not be experts in those fields. Consequently, many of the typical concerns of tectonicists are not considered in detail here. Research into geodynamical topics such as the driving forces of deformation, or geological topics such as the longer-term history of faulting and the evolution of the Caribbean plate that have motivated much of the data collection in the region.

20   A note on terminology: Consistent with usage in quantitative fields spanning science, engineering, finance and governance, *hazard* describes the likelihood and occurrence of potentially damaging events, while *risk* describes the likelihood of loss to human life and assets given the hazard. In the case of seismic hazard and risk, a seismic hazard model is a probabilistic model of earthquake occurrence and consequent ground motion over a region, while a seismic risk model convolves probabilistic ground motion maps with an exposure model incorporating population and infrastructure maps with quantitative assessment of

25   the response of assets to different levels of ground shaking.

2   Database description

The Caribbean and Central American Active Faults database is a GIS-based dataset of ~250 fault traces from the Chiapas region of México south to Panamá, and east through the Greater and Lesser Antilles. The dataset is meant to complement similar datasets with coverage of northern South America (the Active Tectonics of the Andes dataset (Veloza et al., 2012)

30   and the SARA Active Faults data [https://github.com/GEMScienceTools/SARA-Active-Faults]) and central México (Villegas et al., 2017); therefore, faults in central México and northern South America (including the Caribbean-South American plate boundary) have not been included in this database.

2.1 Purpose

Fault databases such as the CCAF-DB may serve a variety of purposes, ranging from seismic hazard analysis, to earthquake and tectonics research, to education and general interest. This list describes our priorities for the database in order of decreasing importance, and guides how and when we map faults and assign attribute values, particularly under ambiguity or ignorance of

5 these characteristics.

The GEM CCAF-DB and the enveloping Global Active Faults database is also made with a philosophy and technological approach more similar to open-source software than many previous fault datasets. The database itself is open-source, under a Creative Commons Attribution license (CC-BY 4.0) and is developed in an iterative way that encourages user and community contribution and feedback. As the database is hosted on GitHub (https://github.com/GEMScienceTools/central_am_carib_faults),

10 this is most readily done through the capabilities provided there (such as 'issues' and 'pull requests') but data, comments and suggestions emailed to the authors are also highly encouraged.

Regardless of the precise mechanisms of community participation, we view the database as constantly evolving, made with the intention of having the most up-to-date data readily available, rather than having infrequent major releases where most or all of the regions are remapped or otherwise updated.

15 All faults should be considered interpretation of both structures in the literature as well as topographic, seismological, geodetic and remote sensing data (i.e. 'base datasets') and not an attempt at representing any structure exactly as given by a listed reference for the structure. The reasoning behind this is grounded in our objective of providing regional fault coverage primarily for fault-based PSHA, and the consequent desire for continuity or consistency with similar expressions of faulting in the base datasets or other studies. Similarly, many structures are drawn inconsistently from publication to publication, or at a

20 scale and resolution unsuitable for our reproduction, and given the scope of our work it is not always desirable or practical to choose a single representation from a suite of competing maps. Researchers with particular suggestions, criticisms or grievances are highly encouraged to communicate this to us through their preferred channels.

Furthermore, due to the dynamic and evolving nature of the database, we encourage users to check regularly for updates, particularly users that are performing quantitative or other intensive analysis; for those with more casual purposes, this may

25 not be necessary.

The probability of major changes to the database in the foreseeable future is highest before 2020: During 2019, GEM is releasing the first version of the GEM Global Active Fault Database (https://github.com/GEMScienceTools/gem-global-active-faults), which will be a harmonized collection of existing and new active fault datasets covering all of the deforming world. The CCAF-DB is the first fault database developed in-house and serves to some degree as a testing ground for the final database

30 structure. While we do not anticipate major changes to the faults included in the database, the possibility does exist for breaking changes to the database schema, for example column names or formatting, that will aid in the assembly or application of the global database. Any such changes will be well documented within the data repository.

2.2 Mapping methods

Faults were mapped in QGIS, a free and open-sourced GIS application, based on existing mapping as well as the base datasets. All structures were mapped on Shuttle Radar Topography Mission digital elevation data (SRTM) (Rosen et al., 2000), at 30, 90 or 250 m resolution depending on the geometric complexity of the faults as well as on their relative importance in characterizing

5   the tectonics, hazard and risk of the region.

As is common with digital mapping, there is large variation in the effective map scale an individual structure is mapped at, but map scales generally range from 1:12,000 to 1:150,000 for onshore faults. This depends on the size, complexity and importance of a given structure or set of structures, as well as the resolution of imagery in Google Earth and other datasets that aid in fault characterization. However, faults illustrated in the literature are displayed at a scale of 1:100,000 to 1:5,000,000 (regardless of

10   the scale of the original mapping), with more detail reserved for small study regions (i.e. trench sites) that typically do not show the full extent of the fault and its potential linkage with nearby faults. Plates or regional maps not published in journals may show a greater expanse in smaller scale (e.g. 1:50,000) but are rarely easily available electronically, and may not distinguish active faults from older structures. The difference in map scale between our traces and the maps in the literature is a primary reason why we consider our fault traces to be interpretations of both the literature and the base datasets.

15   A major concern in this mapping is fault segmentation. Identifying the active strands in anastomosing fault zones with many subfaults can be challenging. Consistent with our first objective of hazard analysis, we map fault segments with the intention of representing the likely start and end points for a full-length, single-segment rupture. This is dominantly based on geometric criteria such as bends and stepovers (e.g., Wesnousky, 2008) but in a few cases fault slip rates or inferred dips change enough along strike that smooth and continuous fault traces are broken up into segments. The foremost example of this is the North

20   Caribbean Megathrust and its splay into Cuba, which progressively changes rake and slip rate along strike though there is doubtless a single continuous fault plane at depth.

Offshore faults are mapped on bathymetry from the Marine Geoscience Data Clearinghouse's Global Multi-Resolution Topography Synthesis data (Ryan et al., 2009). Bathymetry resolution is variable but in general is quite poor. Therefore the accuracy, resolution and veracity of offshore faults is lower than for subaerial faults, and catalog completeness is surely worse

25   as well. Nonetheless these structures remain important sources of seismic and tsunami hazard, and are worthy of more study in the future.

2.2.1 Assessment of fault activity

The activity of faults is assessed through evaluation of published fault-specific studies, local to regional seismicity and geodetic strain consistent with the inferred fault kinematics, geomorphic evidence for late Quaternary activity, and the relationship

30   between a structure and those nearby with known activity status. While the former criteria are self-explanatory, the latter criteria merit exposition.

Geomorphic criteria suggestive of neotectonic fault activity include obvious fault scarps offsetting Quaternary deposits in the direction of fault motion, systematic deflection of streams crossing the fault trace, signs of subsidence and active sedimentation

on the downthrown block of a dip-slip fault (indicated more strongly by the presence of an internally-drained basin), a sharp and well-defined rangefront with triangular facets (particularly for normal faults), and growing folds and domes emerging from the basin near reverse-faulting rangefronts that may be fault propagation folds above young blind thrusts at the toe of a thrust wedge. Similarly, a lack of these diagnostic features suggests fault inactivity. More explicitly, clearly undeformed Quaternary

5   deposits overlying obviously faulted bedrock, and erosion and external drainage of sediments capping downthrown blocks, more strongly suggest that a pre-Quaternary fault has had little to no late Quaternary movement regardless of bedrock evidence of slip. However, given the tropical climate and intense rainfall of Central America and the Caribbean, evidence for activity based on seismic and geodetic data is weighted more heavily than geomorphic evidence for *inactivity*, as neotectonic feature preservation and identification are both more difficult here than in colder, drier, and less vegetated areas.

10   If a fault displays strong evidence of either activity or inactivity, this evidence may aid in evaluating the activity status of neighboring faults. The particulars of this are based on the geometry of faulting and the patterns of deformation. Strain in thrust belts is commonly localized at the frontal thrust (in-sequence thrusting) whereas faults farther back in the wedge may be well expressed in the bedrock but no longer active. Therefore, thrusts along strike of a known active thrust are more likely to be active, while those behind it are less likely; evidence for active slip on out-of-sequence thrusts needs to be more convincing

15   than for frontal thrusts, particularly if the frontal thrusts are active. These same considerations apply with strike-slip faults, as slip is usually localized on a major fault and transferred along strike to the next segment rather than to a parallel strand. However, the situation is different with normal faulting. Arrays of active, parallel normal faults are quite common (yielding basin and range physiography as in the highlands of Honduras and Guatemala) though slip rates and activity may change along strike.

20   The criteria for including a fault in the database is a blend of the evidence for late Quaternary faulting and the local importance of a given structure, though we are biased towards inclusiveness. Because active fault traces are more concentrated in regions of high strain and rapid strain rate, a major fault system such as the Motagua-Polochic fault system (Figure 1) will have some small strands that may have relatively low strain rates and do not contribute much to the overall seismic hazard of their vicinity, nor lend much insight into local or regional tectonics. Identifying and characterizing each of these structures is

25   time consuming and does not contribute much to our major objectives, so these faults may not be included. However, a similar fault in a very slowly deforming region far from a plate boundary may be the most important structure for many kilometers and therefore merits inclusion. Nonetheless, we recognize that for some purposes (such as statistical analysis of fault networks), the consistency of fault representation is quite important, and with further iteration we expect to increase the homogeneity of fault catalog completeness between areas.

30   ## 2.3   Assignment of attributes

The database has a fairly minimal set of attributes that are necessary for seismic hazard analysis, as well as a few ancillary fields. These provide information on the fault geometry, kinematics, slip rate, uncertainties, references, date of last earthquake, and a field for any notes worth including.

Fault attributes may be text, integers, or floating-point numbers which represent continuous random variables[1], depending on the attribute. Integers are used in a semi-quantitative or categorical sense and do not represent continuous random variables; for instance, the `activity_confidence` attribute carries a value of `1` (if activity is certain) or `2` (if activity is uncertain), and the `accuracy` attribute lists the denominator of the scale a structure is mapped at (such as `50000` for 1:50,000 scale

5   mapping). Attributes that represent random variables are given by a 3-tuple [2] of numbers in a `(most likely, minimum, maximum)` format (e.g., `(135,90,180)`). This tuple is intended to represent a triangular probability distribution, with the `most likely` value being the mode and the `minimum` and `maximum` values being the bounds of the probability distribution, rather than 1-standard deviation confidence intervals or quantiles. However, there may be instances when these values are taken from the literature and Gaussian parameters (mean, standard deviation) are listed, either due to ambiguity in the

10   source or by mistake during data entry. Users performing quantitative analysis with the numbers given are strongly encouraged to check the listed references for each relevant structure. Note that for convenience and clarity in data entry and interpretation, if no appreciable uncertainty is included, the tuple may simply be written as `(most likely,,)` as in `(90.0,,)`.

2.3.1   Fault geometry and kinematics

Attributes relating to fault geometry and kinematics (`dip`, `dip_dir`, `downthrown_side_dir`, `average_rake`, `slip_type`)

15   are taken from the literature where available, and inferred elsewhere, as described below. The `dip` and `average_rake` parameters are tuples; rake is in the Aki and Richards convention (Aki and Richards, 1980). The `slip_type`, `dip_dir` and `downthrown_side_dir` attributes are categorical. `slip_type` gives the name of the kinematic type of the structure (e.g., `Reverse` or `Dextral-Normal`); in the case of an oblique-slip category, the first word is assumed to be dominant, i.e. a `Dextral-Normal` fault is more dextral than normal. `dip_dir` is the cardinal direction that a fault dips in, and

20   `downthrown_side_dir` is the cardinal direction of the downthrown block.

Fault kinematics are interpreted from the literature and from the base datasets. Fault kinematics in the region are far less ambiguous than in many others because the epistemic certainty resulting from the high strain rate (producing an abundance of earthquake focal mechanisms and a geodetic velocity field with a high signal to noise ratio) and generally young rocks (which do not show the scars of many previous orogenies) far outweigh the effects of tropical erosion which does not always preserve

25   obvious offset geomorphic markers. Aside from a few enigmatic structures such as the Tonalá Shear Zone in southern México, what kinematic uncertainty exists is usually whether individual faults in a transpressional or transtensional region each have oblique slip or whether the zones are slip partitioned (such as the faults in the Managua graben, Nicaragua). In questionable regions, we evaluate the kinematic obliquity of a given structure based on how oblique the local focal mechanisms are, and

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[1] A *continuous random variable* is a random variable (i.e., a variable that may take more than one value, or with an unknown value) that may take any value on the number line between minimum and maximum bounds. These bounds may be finite, as in the case of a fault scarp between 2 and 3 meters tall, or they may be infinite, as in the case of the normal distribution. In contrast, a *discrete random variable* may take one of a set of non-continuous values; a six-sided die is the canonical example.

[2] A *tuple* is a fundamental term in mathematics and computer programming, and is simply a finite, ordered list or sequence of items. An (*x,y*) coordinate pair, the instructions (*lather*, *rinse*, *repeat*), and a list of the months (April, May, June) are all examples of tuples.

whether there is a visible distinction between strike-slip and dip-slip faults. A very small number of faults, particularly in Costa Rica and Panamá, are not assigned fault kinematics because of very ambiguous geomorphology and strain fields.

Fault dip is similarly interpreted where not given in the literature. Strike-slip faults are given dips of 90° where there is no evidence for dip slip. Normal faults are given most-likely dips of ~50°-60°, unless geomorphic evidence indicates lower dip (i.e. clear, more shallowly-dipping triangular facets). Normal faults thought to have relatively high displacements (i.e. more than a few kilometers) may be given slightly shallower dips to account for back-rotation of the footwall (e.g., Buck, 1988). Uncertainties are evaluated on case by case basis but are typically 10°-15° on either side of the most-likely value. Reverse faults are given dips of ~20°-30° if they are relatively isolated but given more shallow dips if they appear to be basal decollements of a thrust wedge (e.g., Boyer and Elliott, 1982). Oblique-slip faults are given dips that are in between the 'pure' slip end-members.

2.3.2 Slip rate

Slip rates are generally taken from the literature, although in some instances they may be inferred based on those of well-studied faults in the same system. We include four slip rate components to account for the variation in measurable deformation using different techniques: `net_slip_rate` is the total slip rate on the fault plane, `strike_slip_rate` is the strike-slip component, `vert_slip_rate` is the vertical (not dip-slip) component, and `shortening_rate` is the horizontal component perpendicular to the fault. The first three components are absolute values but `shortening_rate` may take negative values to indicate extension across the fault. Values are given in mm a^{-1}. All of these slip rate attributes are continuous random variables with the 3-tuple format described above.

Slip rates are unknown for the majority of the structures in the database and remain unassigned, though fortunately these are generally known for the major structures such as plate boundary faults.

2.3.3 Additional attributes

The remaining attributes are metadata that characterize the state of knowledge of the structure, as well as ancillary information that may be useful for hazard modeling or other investigation.

The uncertainty of the structure (beyond what is included in the tuples described above) is given by four attributes, all of which are integers. `accuracy` describes the denominator of the scale the structure is mapped at. The next three attributes describe how certain we are about an individual structure. The values for each are integers, and can be `1` (indicating high confidence) or `2` (indicating low confidence). `activity_confidence` describes the certainty that the structure is active (i.e. accumulating shear stress or is otherwise considered to have seismogenic potential). This is determined using the criteria given in the 'Mapping methods' section above. `exposure_quality` indicates how obvious the structure is in topographic and satellite imagery of the region. `epistemic_quality` describes the certainty that an fault is actually located where the trace is.

These latter three attributes are somewhat interrelated, but are not the same. For example, a fault may have high `epistemic_quality` but poor `exposure_quality` if it is located in a well-defined valley that it has created, and has produced seismicity in the instrumental record, but lies buried underneath an active river channel and is not observable at the surface (the Septentri-

onal Fault in northern Haiti is a good example of this). Conversely, a fault may have high `exposure_quality` but poor `epistemic_quality` if it lies in a region with diffuse seismicity and clear photographic and geomorphic evidence for distributed or anastomosing faulting, but it is not obvious which trace best represents the active structure. (This last problem is less common in the present study area than in polydeformed desert regions that preserve expressions of faulting for tens or

5   hundreds of millions of years.)

The `fz_name` lists the name of the fault zone or fault system an individual fault segment may be a part of.

The `last_movement` attribute gives the calendar year of the last known major earthquake on a structure. This attribute is very incomplete in the database, both because it is simply unknown for so many structures, and because relatively little effort was made to collect information on it during the database construction phase, as it is not used in standard, time-independent

10 PSHA. Nonetheless it is of interest to many, so we have made a space for it.

The `reference` attribute lists one or more references for a structure. It is very important to note that (as described above) all structures here should be considered interpretations of both the literature and the base datasets, the reference listed for any structure should not be taken as the sole source for the information that we have used for the structure; it is better to consider the listed reference to be a starting point that an interested user can go to for more information. A related point is that no listed

15 reference should be considered responsible for any errors shown in the location or attributes of any structure in the database. Structures with 'DEM' listed as the reference are taken mostly from topographic expressions of faulting rather than from the literature; similarly structures with no reference at all given are taken from synthesis of all of the base datasets.

The `notes` attribute is simply a place to list any additional information that may be of use to users, particularly those interested in PSHA. Example information could describe down-dip changes in fault geometry, potentially associated historical

20 seismicity, or caveats to the information or interpretations given for that structure.

2.4   Data format

The CCAF-DB is a GIS-based product, and is given in several GIS-type vector formats. The dataset is mapped in a plain-text, human-readable GeoJSON format (primarily to track development with the Git version control system), and is converted into additional file formats (GeoPackage, ESRI Shapefile, GMT, Google Earth KML) either directly in QGIS or through a script

25 using the `OGR2OGR` utility.

As such, the GeoJSON (`.geojson`) format is the version of record. Some information (metadata) loss is possible when converting to any format other than GeoPackage as other formats are limited in their ability to store all information. For example, the ShapeFile format cannot handle attribute names beyond a certain number of characters, so they may be truncated. GIS users are encouraged to use the GeoJSON format preferentially as it is the most widely supported. GMT and Google Earth

30 users will likely find the native formats for each to be the most practical.

2.4.1   Version control

The CCAF-DB is managed using the `git` version control software. This allows us to track and revert changes made to the data over time, to gracefully evaluate and merge contributions from other scientists, and to distribute the most up-to-date version of

the software at all times. Because `git` is designed around text changes, the text-based versions of the data (i.e. the GeoJSON, GMT and KML formats) will track feature-by-feature changes while the binary formats (e.g., ShapeFile and GeoPackage) are replaced with every committed change.

3 Overview of regional faulting

5 Here, we give an overview of the active structures throughout Central America and the Caribbean. This overview presents the data compiled in the CCAF-DB, with an emphasis on fault slip rates and other information relevant to seismic hazard assessment. Additionally, major uncertainties or conflicting interpretations of fault configurations or rates in the literature are discussed along with our chosen fault representations in these instances.

This section is primarily intended to be a guide to the data in each region for seismic hazard analysts, so they may understand 10 the sources of the data and where uncertainties or data gaps may be important. We hope this section will also be of use to tectonics researchers or others who are interested in an up-to-date regional overview; however, many of the typical research interests such as the driving forces of deformation, and the evolution of plates and faults through time are not discussed as they are irrelevant to seismic hazard work.

We do not intend this section to be a comprehensive review of the tectonics or history of the region, and in our citations 15 we favor newer papers over older sources as these in general contain the highest quality slip rate data (particularly geodetic data) and the most legible maps; these references also typically contain more thorough and scholarly discussions of the older literature than we have space for here.

The subsections in this section are ordered from north to south along the western margin of the Caribbean plate, and then west to east along the northern and eastern margins of the Caribbean plate. Each subsection below describes a particular region 20 and has an associated map (figure) that displays all of the structures in the region; for readability, the figure will not be referred to repeatedly in the text.

3.1 Central America

Active faulting and seismicity is ubiquitous throughout Central America. In southern México, transpressional deformation occurs in the Chiapas Fold and Thrust belt and vicinity. The relatively slow and distirbuted deformation here transitions southward 25 into more rapid and localized sinistral slip along the Motagua-Polochic Fault Zone in Guatemala, which is the main CA-NA plate boundary structure in the continental crust, and links to the Swan Island–Oriente transform faults in the oceanic crust to the east. Deformation is transtensional south of the Motagua-Polochic Fault Zone through northern Costa Rica, with distributed normal faulting in the highlands of northern Central America as well as in the backarc of Central American volcanic arc. Rapid (10-15 mm a^{-1}) dextral shear occurs on faults located close to the volcanic arc, which separate the Central American Forearc 30 from the Caribbean continental crust.

3.1.1 Chiapas

The Chiapas region of southern México and neighboring northwestern Guatemala (Figure 2) is the southernmost part of the
North American plate, and contains distributed sinistral and reverse faulting in the Sierra Madre de Chiapas and the Chiapas
Fold and Thrust belt to the northeast (Witt et al., 2012), as well as the sinistral(?) faults associated with the Tonala Shear Zone

5 (e.g., Molina-Garza et al., 2015).

The Sierra Madre de Chiapas contains a set of W- to NW-striking sinistral faults through the highlands and along its south-
western margin (Witt et al., 2012). The range-bounding faults make up the Tuxtla-Malpaso Fault System, and are for the most
part in series. In the high interior, the strike-slip faults are W-striking and merge on their eastern ends with contractional struc-
tures. The northern and eastern Sierra Madre de Chiapas is lower and composed of discrete ranges making up the Chiapas Fold

10 and thrust belt.

NW-striking sinistral faulting may also occur in the Central Depression along the Concordia Fault System. However, most
of this fault system is under the Presa La Angostura reservoir, making assessment of its activity challenging. It is considered
sinistral by most workers (e.g., Meneses-Rocha, 2001; Guzmán-Speziale, 2010; Witt et al., 2012) but the Mexican active fault
dataset of Villegas et al. (2017) lists it as dextral; this may be due to interpretation of focal mechanisms consistent with dextral

15 slip on NW-striking fault planes, though these are deep (>150 km) and perhaps in the subducting slab rather than the crust.

Slip rates in the region are poorly constrained. Witt et al. (2012) estimate strike-slip rates on the Tuxtla-Malpaso Fault
System of 5-8 mm a^{-1} averaged over the Pliocene to present (i.e. ~6 Ma to present), and they attribute a 1902 M 7.2 event to
the Tuxtla Fault; however, Guzmán-Speziale (2010) considers this event (or an additional 1902 event) to have been a M 7.6-7.8
earthquake on the Concordia Fault, following extensive reports of damage along that fault zone. He also reports additional

20 events in the region since 1500. Regardless of the records of historical seismicity, GPS velocity vectors indicate only a few mm
a^{-1} strain across the entire region, so individual fault slip rates may be low (Kreemer et al., 2014).

To the southwest, an enigmatic structure known as the Tonala Shear Zone separates the highlands of the Chiapas Massif
from the low Pacific coastal plain. The structure was originally a Miocene sinistral-reverse fault zone that assisted in the uplift
of the Chiapas Massif (Molina-Garza et al., 2015) and may be currently active. The kinematics of the structure are unclear, but

25 hinge on the configuration of the Caribbean-North American-Cocos triple junction, as different configurations make different
kinematic predictions for the Tonala Shear Zone. Recent analysis of this problem concludes that slip from the sinistral Polochic
fault may be transferred to the Tonala Shear Zone (Authemayou et al., 2011). Following this logic, we consider the structure to
be sinistral, with highly uncertain slip rates. However, given its geometry and location above a subduction zone, the fault could
easily have a large reverse component.

30 Though the population in Chiapas is lower than some other locations in the study area, the faults are very understudied given
their length and proximity to population centers. For example, the capital and largest city, Tuxtla Gutierrez, is built on top of the
Tuxtla-Malpaso Fault System which may be the most rapidly-slipping fault in the region (Witt et al., 2012). To our knowledge,
no fault in Chiapas has received any sort of neotectonic or focused geodetic study.

3.1.2 Motagua-Polochic Fault Zone

The continental segment of the North American-Caribbean plate boundary is expressed as the Motagua-Polochic Fault System (Figure 3). This sinistral fault system is made up of two dominant faults, the Motagua Fault in the southeast and the Polochic fault in the northwest of the fault zone. Additional, parallel sinistral faults are present (such as the Los Amates and Ixcan faults),

5 and both the Motagua and Polochic faults themselves show topographic evidence for many strands, though most authors choose the strands we have mapped as the main active structures.

Slip rates on the Motagua-Polochic Fault System are high in the east and decrease to the west. The Motagua fault seems to accommodate most of the slip in the fault system. A recent GPS study (Franco et al., 2012) indicates slip rates of ~20 mm a^{-1} for the central Motagua Fault, which is close to the total NA-CA relative plate velocity (DeMets et al., 2010). To the west,

10 slip on the Motagua Fault drops progressively. Some of this slip is probably picked up along the Polochic fault to the north (estimated at 4 mm a^{-1}) but much of the decrease seems to be linked to E-W extension of the Central American Highlands in the south.

The Motagua Fault ruptured in the 4 February 1976 Mw 7.6 earthquake. Nearly the entirety of the fault, well over 200 km, slipped in the event (Bucknam et al., 1978); slip also occurred on the Mixco fault that bounds the western end of the

15 Guatemala City Graben (Plafker, 1976), which is kinematically linked to the Motagua Fault. The geomorphic expression of active slip on the Motagua fault in 30m SRTM data becomes more ambiguous west of the Mixco Fault, which suggests that the two faults work together to accommodate eastward relative motion of crust to their south and east, and that the kinematic

linkage displayed during the 1976 event is a recurrent phenomenon. Despite the apparent westward decrease in slip rate along the Motagua Fault, the highest measured slip in the 1976 earthquake was in the west, between El Progreso and the Guatemala

20 City Graben, where 2-3 meters of displacement was observed, as compared to the ~1 m of displacement observed consistently along the hundred kilometers of rupture to the east (Bucknam et al., 1978). This pattern may be explained by larger and less frequent slip in the west as compared to the east, but a considerable paleoseismic effort is required to test this hypothesis.

The Polochic Fault parallels the Motagua Fault some 45 km to its north, and extends over a hundred km farther west. Though the Polochic Fault is longer than the Motagua Fault, its slip rate is lower, estimated at 4-5 mm a^{-1} for the central segments

25 using both neotectonic and geodetic techniques (Lyon-Caen et al., 2006; Authemayou et al., 2012; Franco et al., 2012). Slip rates may decrease progressively west, as they do over the entire fault system.

The western end of the Polochic Fault terminates into two groups of fault splays, the Necta fault in the north, and a set of faults here called the Tonala-Polochic Fault System that links these two structures. none of these faults has received any tectonic study. Nonetheless we consider all of these faults to be sinistral based on their geometries. Slip rates are similarly

30 unknown but based on the regional deformation field are not expected to be above 2 mm a^{-1} for any structure.

Two relatively small sinistral faults exist to the north of the eastern Polochic Fault, the Ixcan Fault (Guzmán-Speziale, 2010) and an unnamed structure along strike of that structure to the east near the village of Las Conchas, where small to moderate earthquakes have clustered over the past several decades.

Nearby subparallel faults to the south of the Motagua Fault do not seem to be active. The Jocotan-Chamelecon Fault System, for example, does not display the same topographic evidence for neotectonic slip as the faults discussed above (e.g., Schwartz et al., 1979), so it has not been included in this compilation.

3.1.3 Central American Highlands

5 South of the Motagua-Polochic fault system, a broad elevated zone exists through much of Guatemala and Honduras (Figure 4). East-west extension of ~10 mm a^{-1} (Rodriguez et al., 2009; Franco et al., 2012; Kreemer et al., 2014) is accommodated through an array of north-trending grabens spanning the breadth of the subcontinent. The grabens are best expressed at high elevations (where vertical stress from topography may be highest, increasing differential stress in the crust) and are generally interpreted to be kinematically linked to the Motagua fault, so that extension to the south of the Motagua fault along these

10 grabens causes an eastward increase in the slip rate on the fault (e.g., Guzmán-Speziale, 2001). However, of the 10-15 graben systems, only the largest two (the Guatemala City and Sula Grabens) display a hard kinematic linkage with the Motagua fault. Therefore we suspect that the mid-elevation region immediately south of the Motagua Fault undergoes distributed extension. Indeed, this zone displays tectonic geomorphology (i.e. subdued basin and range topography) consistent with many small normal faults, but evidence for active slip localized on major normal faults is lacking in the SRTM data and seismic catalogs.

15 Slip rates on individual structures are generally unknown. The three systems generally considered the most active are the Guatemala City Graben, the Ipala Graben and the Honduras Depression (comprising the Sula and Comayagua Grabens, and possibly extending to the transtensional Gulf of Fonseca to the south). Franco et al. (2012) attribute about half of the extension (~5 mm a^{-1}) to the Guatemala City graben based on a GPS transect, though their transect passes well south of the Sula Graben. Rodriguez et al. (2009) estimate ~1 mm a^{-1} extension in the region of the Sula graben, also from GPS. It is worth noting that

20 unlike GPS-derived slip rates for major strike-slip faults given here, these quoted rates are simply derived from differencing of sparse GPS velocities across their study areas and are not the result of formal inversions, and may not properly account for distributed deformation on many faults. These rates should be considered quite tentative. Nonetheless, the GPS data present clear evidence for reasonably high regional strain rates and attendant seismic hazard to some of the region's largest cities, which occupy these grabens (the San Pedro Sula metro area has ~1.5 million inhabitants, and the Guatemala City metro area

25 has ~4.5 million). More systematic investigation of the slip rates and paleoseismological histories of these faults should be a top priority for seismic hazard-related studies in the region.

The Ipala Graben, which has hosted several significant normal faulting events in the historical record (Guzmán-Speziale, 2001), has no available slip rate estimates; the same holds for other normal faults in the region.

East-striking normal and possibly sinistral faults line the northern coast of Honduras (Rogers and Mann, 2007). The Nombre

30 de Dios range is the uplifted footwall of the north-dipping La Cieba normal fault. The Río Viejo fault lies within the eastern part of range, and is interpreted by us as sinistral-normal in the west and sinistral farther east. The La Esperanza normal fault lies farther south, on the southeastern margin of the Río Aguan valley. Rogers and Mann (2007) interpret additional faults in this valley, including the Aguan and Lepaca sinistral faults, but to us the fault traces look too degraded for our consideration of them as active structures.

Normal and sinistral faulting continues offshore to the north towards the Swan Islands Fault Zone. A large normal fault south of Roatan Island separates the island (on a horst) from the Tela Basin which lies between Roatan and the mainland (Rogers and Mann, 2007; Cox et al., 2008). On Roatan itself, Cox et al. (2008) have mapped the Flowers Bay Fault, which has uplifted corals on the island and is a potential source of the August 1956 tsunami. They interpret the fault as normal to the southwest

5 and sinistral to the northeast. They also find rates of uplift of the island to be ~3 mm a^{-1}.

The Central American Highlands are bound to the east by the Guayape Fault, a very linear NE-striking structure that is nearly continuous across the breadth of Honduras. However, geologic mapping discussed by Gordon and Muehlberger (1994) indicate that no units younger than Miocene are demonstrably offset; this is consistent with our interpretation of the fault as an inactive structure, given the lack of instrumental seismicity, geodetic strain, or any evidence of deformation of Quaternary

10 units in the base datasets. (Note that this is not the conclusion arrived at by Gordon and Muehlberger (1994); supporting our interpretaion, the fault is not included in the active fault traces of Rogers and Mann (2007).)

3.1.4 Central American Forearc

The Central American Forearc extends from Chiapas south for >1200 km to the Costa Rican-Panamánian border (Figure 5). The forearc itself does not display much evidence for substantial internal deformation along faults; instead, strain and seismicity

15 are localized on NW-striking dextral strike-slip faults that run along (underneath or slightly inboard of) the Central American volcanic arc, and transtensional zones where this fault system contains releasing bends.

From a purely kinematic perspective (disregarding the forces that drive deformation), the faults system along the volcanic arc may be thought of as a conjugate strike-slip system to the Motagua-Polochic Fault Zone, with the northwestern Caribbean plate undergoing extrusion or tectonic escape (e.g., McKenzie, 1972) to the east. The trailing edge of the extruding block

20 undergoes extension, producing the graben system in the Central American Highlands which is accommodated through slip rate and magnitude gradients on the kinematically linked Motagua-Polochic and volcanic arc fault zones, such that slip on those fault systems increases to the east and southeast, respectively (e.g., Burkart and Self, 1985; Gordon and Muehlberger, 1994; Authemayou et al., 2011).

The northwestern-most mapped fault of the volcanic arc fault system is the Jalpatagua Fault (Carr, 1976) in western

25 Guatemala. This dextral fault is somewhat segmented especially to the northwest near the Guatemala City Graben (Carr, 1976), but becomes more well-defined and linear to the southeast. It is easily traceable in the topographic data to near the Guatemala-El Salvador border, where it intersects small normal faults (and possibly northeast-striking sinistral faults (Carr, 1976) though we did not observe them clearly enough to map them). The fault is along strike of the volcanic arc to the northwest, but inboard of the proximal volcanic arc segment, as in El Salvador. The slip rate on the Jalpatagua fault system is unknown, but based on

30 regional trends, probably varies from 1-3 mm a^{-1} in the northwest to 4-6 mm a^{-1} in the southeast.

Dextral faulting continues along strike to the northwest, as evidenced by a shallow Mw 6.2 strike-slip earthquake in 1991 near Lago de Atitlan (White and Harlow, 1993), but faulting is not sufficiently well expressed geomorphically to map with confidence. Furthermore, as noted by White and Harlow (1993), the northwestern segment of the volcanic arc produces less seismicity.

Farther southeast in El Salvador, forearc-bounding faulting is expressed as the El Salvador Fault System (e.g., White and Harlow, 1993; Martínez-Díaz et al., 2004; Corti et al., 2005), which is a series of disconnected dextral to dextral-normal faults in the backarc. The El Salvador Fault System is the best-studied part of the volcanic arc fault system. Due in part to the locally dry climate and distance from the volcanic arc, the fault traces are quite apparent and most authors map them similarly. Slip

5 rates on these faults seem to be generally constant along strike at 7-12 mm a^{-1}: Staller et al. (2016) find rates from 7-12 mm a^{-1} on four geodetic transects spanning most of the fault zone, though they give a much lower value (2 mm a^{-1}) for the easternmost segment. In this last transect, the total rate of shear across El Salvador remains at ~10 mm a^{-1}, but some of the strain may be taken up on small faults near the coast. Additionally, we suspect that deformation may be more complicated here, nearing the Gulf of Fonseca. Corti et al. (2005) find a late Quaternary slip rate of 11 mm a^{-1} for the central-eastern Berlin

10 segment, which is slightly higher than the estimates of Staller et al. (2016).

Observations of instrumental, historical and paleoseismological earthquakes along the El Salvador Fault Zone reveal plentiful moderate seismicity. The most well-constrained event is the 2001 Mw 6.6 event on the San Vicente segment (Martínez-Díaz et al., 2004), which had a maximum surface displacement of 60 cm (Canora et al., 2010). Additional M~6 events have occurred in 1917, 1919, 1951, and 1986 on the fault zone (White and Harlow, 1993; Martínez-Díaz et al., 2004). Paleoseismological

15 studies of the San Vicente segment show surface-breaking ruptures with displacements of 0.5-5 m per event and a mean recurrence interval of 800 yrs (Canora et al., 2012).

The Gulf of Fonseca is a shallow depression at the junction of El Salvador, Honduras and Nicaragua. Following recent work (Funk et al., 2009; Alvarado et al., 2011), we view the Gulf as part of a transtensional stepover in the Middle American forearc fault system. Faulting here seems to be somewhat distributed, with volcanic centers coinciding with small N-trending rifts.

20 Strike-slip faulting is less clearly observed in the topography or bathymetry data, but strike-slip focal mechanisms are found throughout the gulf, especially towards the mainland.

The location and nature of faults continuing into Nicaragua is also unclear, though given the abundant seismicity, deformation is certainly present. Geodetic studies (e.g., Turner et al., 2007; Styron, 2008; Alvarado et al., 2011) indicate that the northwestern Nicaraguan is translating ~15-20 mm/yr with respect to the stable Caribbean plate. This is the fastest arc-parallel

25 motion observed in Central America. The location of the faults accommodating the forearc translation is not obvious, but most evidence points towards a zone of dextral shear located underneath the volcanic arc (called the Marabios Range). The Marabios Range is remarkably linear, with the major active volcanic centers located within 1 km of a straight line through the range. Furthermore, seismicity extends continuously along the range, not only along the active volcanoes, and focal mechanisms are consistent with dextral slip on a vertical fault aligned with the volcanic arc. These focal mechanisms have been interpreted to

30 reflect sinistral 'bookshelf' faulting on structures orthogonal to the arc (LaFemina et al., 2002) but this interpretation is not supported by the alignment of lower-magnitude seismicity and no evidence for these faults is present away from the southwestern terminus of the Marabios range, on the margins of the Managua graben, which is widely interpreted as a releasing stepover in the system (as described below). GPS geodetic data are also best explained by a dextral fault underneath the arc (Styron, 2008). Confusingly, very little geomorphic evidence for dextral shear in the forearc or backarc; the most convincing is the presence

35 of low hills near El Congo that are interpreted as a small restraining stepover in between the Marabios Range and Volcan

Coseguina (Funk et al., 2009). Styron (2008) suggested that the very high productivity of the Marabios volcanoes is sufficient to bury evidence of strike-slip faulting, but this is not a very satisfying conclusion. The only obvious surficial evidence of faulting is N-trending grabens emanating from the volcanic vents, but these are short and likely insufficient to accommodate 1-2 cm a^{-1} of forearc translation. The collocation of the volcanic arc and the strike-slip fault is surely not coincidental, but the

5   direction of causation is uncertain: it is possible that the existence of the magmatic conduits resulted in a plane of weakness in the crust that was reactivated; alternatively, the fault may have provided an easy path for magma migration. Funk et al. (2009) suggested that the Marabios range volcanoes lie along older normal faults now reactivated as dextral, based on interpretation of geophysical data collected in Lake Managua. Those authors do not favor the hypothesis of a single, through-going strike-slip fault under the arc, instead calling for the reactivation of many small north-striking normal (or normal-dextral) faults that may

10   act as a broad shear zone. Unfortunately, any suggestion of dip-slip faulting taking up ~15 mm a^{-1} dextral shear would result in vertical separation rates of at least several mm a^{-1} at minimum which would leave a much larger mark in the landscape than the quite subdued offsets produced by the observed N-striking normal faults. Though we have chosen to represent the structure as a single dextral fault under the arc, it is worth keeping in mind that this representation produces the largest contiguous fault surface of the several competing hypotheses, and therefore the largest maximum magnitude for earthquakes along this

15   segment of the volcanic arc. Other hypotheses positing smaller, distributed faults predict a commensurately smaller maximum earthquake magnitudes. If these latter hypotheses are more accurate, it may mean that the recent M_w~6 dextral events on either edge of the volcanic chain (e.g., Suárez et al., 2016) are representative of seismicity in the dextral shear zone, and much larger events are not possible.

The Managua area contains an array of N- to NE-striking transtensional faults that are typically interpreted as a releasing

20   stepover in the arc-parallel strike-slip fault system (e.g., Brown et al., 1973; Cowan et al., 2002; Funk et al., 2009), although these faults extend farther into the backarc than the inferred zone of dextral shear; the faults may link with a potentially-active graben near Sebaco. We have included four faults in the Managua area: the Tiscapa, Aeropuerto and Cofradia (also called the Tipitapa) Faults on the south and east shores of Lake Managua, and the Punta Huete Fault in the north; the latter may be the northern continuation of the Tiscapa Fault. These faults are the longest and most geomorphically clear of the many faults in

25   the zone, and likely to be the most seismically active. The 1972 Managua earthquake (m$_b$ 5.6, M$_s$ 6.2) occurred on the Tiscapa fault (e.g., Brown et al., 1973). Though field studies (Brown et al., 1973; Freundt et al., 2010) suggest several times more rapid vertical that horizontal displacement on the Tiscapa fault, the focal mechanism from the 1972 event indicates purely sinistral slip on a very steeply (80°-90°) east-dipping fault plane. This may be an expression of strain partitioning on closely-spaced faults, or changes in slip kinematics on the same plane during different events.

30   A zone of inferred dextral strike slip continues to the southeast into Lake Nicaragua along the volcanic arc. The evidence for and against dextral strike slip along this segment of the arc is similar to that in the Marabios range, with the additional caveat that most of the area is underwater. Seismicity from the INETER catalog is less continuous along the arc than in the Marabios range (Styron, 2008). Based on interpretation of geophysical and stratigraphic data, Funk et al. (2009) suggest that the southern Nicaraguan volcanic arc also overlies one or more normal faults now reactivated as strike-slip.

3.1.5 Southern Central America

To the south of Lake Nicaragua into Costa Rica, active faulting seems to change in style and kinematics, though observations are sparse. In northern Costa Rica, trench-perpendicular strain changes from extensional to contractional (Figure 6), and is distributed throughout the narrow isthmus. On the northeast flank flank of the Cordillera Central, active faults are mostly

5   reverse (e.g., Montero et al., 2013) as well as a few of indeterminate kinematics. The NW-striking reverse faults continue through Limón area, where the Cordillera Central merges with the northwestern Cordillera Talamanca, and where the 1991 M_w 7.7 Limón thrust event was located (Suárez et al., 1995). Reverse faulting continues offshore to the southeast, where it forms the active thrust front of the North Panamá Deformed Belt, which wraps around southern Central America to its juncture with Colombia. Additional active faulting may be present between the northeastern flank of the Cordillera Talamanca and the

10   coast in far eastern Costa Rica and western Panamá; the Limón Basin area (south of the 1991 earthquake) is often shown on petroleum-oriented maps with generally N-dipping thrusts (e.g., Barboza et al., 1997), which may be optimally oriented in the modern stress field.

    Between the Central and Talamanca Cordilleras, the Río Sucio and Río Atirro Faults (Montero et al., 2013) likely make up most of the hazard to San José, though smaller faults are present throughout the area. It is unclear if the southwestern rangefront

15   of the Cordillera Talamanca has active faulting, though faulting is documented along the Pacific Coast along the Fila Costeña Fault System. These faults seem to be dextral (or dextral-reverse) in the northwest, transitioning into reverse in southern Costa Rica. Faulting along this trend becomes sinsitral in western Panamá. Geodetic studies show interseismic strain replicating this pattern (LaFemina et al., 2009).

    Shortening rates on the Fila Costeña thrusts have been thought to be extremely high: Sitchler et al. (2007) estimate ~40

20   mm a^{-1} shortening, which would place the basal thrust as the second fastest-slipping continental thrust on Earth, after the Ramu-Markham thrust system in Papua New Guinea where the New Britain Megathrust comes ashore (e.g., Abbott et al., 1994; Wallace et al., 2004; Koulali et al., 2015), and twice as fast as the Main Himalayan Thrust in Nepal (Lavé and Avouac, 2000; Ader et al., 2012), which would then become the third fastest-slipping (to the best of our knowledge). Though it is part of a plate boundary region, it is not the actual subduction interface (being 100 km into the overriding plate), and this would

25   make it far and away the fastest-slipping intraplate fault in the world. As Sitchler et al. (2007) estimate the shortening rate using balanced cross-sections and a time of initiation based on a plate reconstruction (rather than directly dated marker beds), this rate needs independent confirmation before it can be used for PSHA and so we do not include it in the database; nonetheless, their work does provide strong evidence of rapid deformation in the area.

    Additional active faulting on small faults (many below our minimum cutoff) is distributed throughout the country in the

30   Central Costa Rica Deformed Belt (e.g., Marshall et al., 2000). This zone likely accommodates much of the geodetic velocity gradient between the rapidly-deforming crust above the Cocos Ridge, where upper-plate velocities are in excess of 50 mm a^{-1} relative to the stable Caribbean plate, and the northern part of the country which (though poorly instrumented) moves essentially with the Caribbean plate (e.g., LaFemina et al., 2009). It is unclear what the maximum size of earthquakes produced on distributed faults in the Central Costa Rica Deformed Belt is, though crustal seismicity is frequent throughout the region.

Two major fault systems have been studied in central Panamá. The longest is the northeast-striking sinistral Río Gatun Fault, which may slip as fast as a 6-10 mm a^{-1}, decreasing slightly to the southwest (Rockwell et al., 2010b, a). The dextral Limón and Pedro Miguel faults extend south from the central Río Gatun Fault. The Pedro Miguel Fault in particular is a major hazard to both Panamá City and the Panamá Canal infrastructure, as it passes within a few kilometers of each and has a slip rate of

5   3.5-8 mm a^{-1} (Rockwell et al., 2010b, a). Bennett et al. (2014), however, find far lower slip rates on these faults, with 0.2-1 mm a^{-1} net slip on the Río Gatun Fault and 1.4-1.9 mm a^{-1} on the Limón-Pedro Miguel Faults chain, from a GPS study of a 4-year time series; they explain the difference between the geodetic and geologic rates as from earthquake cycle effects lowering the modern geodetic rates relative to geologic rates averaged over multiple earthquake cycles. Therefore we use the geologic rates of Rockwell et al. (2010a).

10   Farther east into the Darien zone of Panamá and northwest Colombia, on-shore deformation is evident from seismicity, but the lightly-populated jungle region has received very little field study. Offshore deformation also takes place along the frontal thrusts of the North and South Panamá Deformed Belts, as well as in the fracture zones of the Cocos and Nazca plates.

Southwestern Panamá contains active strike-slip faults as well. The sinistral Azuero Fault cuts through the Azuero Peninsula, and may slip up to 9±2 mm a^{-1} (Rockwell et al., 2010b), though given the lack of seismic or geomorphic evidence of slip

15   this rapid, we view this as an upper bound (though rapid, enigmatic arc-parallel strike-slip faults seem to be ubiquitous in the Middle American forearc). A few unstudied ancillary faults are observed in topographic data, but kinematics and slip rates are uncertain. Along strike to the northwest of the Azuero Fault, Camacho (2003) has mapped a set of sinistral faults that may be the continuation of the Azuero Fault across the Gulf of Chiriqui.

3.1.6   Middle America Trench

20   Subduction of the Cocos Plate underneath the Caribbean Plate occurs at the Middle America Trench. This megathrust is very seismically active due to the rapid plate convergence rate, which varies between roughly 75 and 85 mm a^{-1} along strike (e.g., DeMets, 2001). Subduction is for the most part perpendicular to the trench, but due to geometric changes is slightly oblique in places; though minor (<30°), the arc-parallel component reaches ~15 mm a^{-1} in Nicaragua because of the large magnitude of the overall velocity vector. This may be a driver of dextral translation of the Central American Forearc (DeMets, 2001; Turner

25   et al., 2007).

Coupling on the trench is highly variable. In Costa Rica, GPS geodesy clearly indicates strong locking of the trench and rapid strain accumulation, which may be enhanced by subduction of the Nazca Ridge (e.g., LaFemina et al., 2009). However, to the northwest in Nicaragua and El Salvador, the geodetic data shows little motion consistent with coupling at the trench, a hypothesis supported by mechanical modeling of the plate interface (e.g., Alvarado et al., 2011). Nonetheless, 'moderate'

30   subduction zone earthquakes of M <7.7 have occurred in the past several decades on the less coupled part of the trench, including the 1992 M_w 7.6 Nicaragua event (Kanamori and Kikuchi, 1993) and the 2012 M_w 7.3 El Salvador event (Borrero et al., 2014).

3.2 Antilles

The islands of the Antilles are historically broken into two groups, the Greater Antilles (including Cuba, Jamaica, Hispaniola and Puerto Rico) and the Lesser Antilles, which is the chain of small, mostly volcanic islands stretching from the Virgin Islands near Puerto Rico in the north to Trinidad and Tobago in the south near Venezuela. This distinction applies to the geology as well: the Greater Antilles are astride the northern, dominantly strike-slip portion of the North American-Caribbean plate boundary, while the Lesser Antilles are for the most part arc volcanoes and other subduction-related islands formed by the subduction of North and South American oceanic lithosphere under the Caribbean plate at the Antilles Trench. The patterns of active faulting reflect these plate boundary configurations; faulting in the Greater Antilles is dominated by strike-slip faults with dip- or oblique-slip structures at stepovers (Figure 7), while faulting in the Lesser Antilles is mostly localized on the Antilles megathrust with minor upper-plate structures accommodating arc-parallel extension and translation of forearc blocks (Figure 8).

3.2.1 Cuba, Jamaica and the Swan Islands Transform

The Caribbean-North American plate boundary offshore to the east of Central America is the sinistral Swan Islands Transform, which extends to the Cayman Spreading Center south of the Cayman islands (Figure 1). Relative plate motion here is about 19 mm a^{-1} (DeMets et al., 2010), and seems to be accommodated exclusively on the Swan Islands transform with the exception of some structures in the Tela Basin near Roatan that accommodate the slight component of extension across the plate boundary (these are discussed in Section 3.1.3). Therefore we ascribe the full relative plate motion rate to the Swan Islands Transform. Where it is a single strand, this is ~19 mm a^{-1} and where it is broken into two strands (around Swan Island) we split the rate; the southern branch is more or less continuous to the east, so we give it two thirds of the total rate, and the remainder is applied to the northern branch.

The Swan Islands Transform ruptured in a M_w 7.3 event in 2009. Graham et al. (2012) modeled the coseismic slip distribution from GPS and teleseismic data, and showed continuous rupture from onshore Guatemala and Honduras not far east of the eastern terminus of the 1976 Motagua rupture (e.g., Plafker, 1976) to east of the Swan Islands. Slip was located on the northern rather than the southern branch at the Swan Islands split. The rupture was ~350 km long, and maximum slip was found to be ~1 m.

The Swan Islands Transform terminates in the east at the Cayman Spreading Center, which is extending at 10-15 mm a^{-1} (Leroy et al., 2000; Hayman et al., 2011; Benford et al., 2012a), though like most mid-ocean ridges, the seismogenic crust is probably very thin and it may not produce moderate to large earthquakes. To the east, the North American-Caribbean strike-slip boundary is broken into two parallel strike-slip faults, the Oriente Fault in the north and the Walton Fault Zone in the south; the intervening oceanic crust is the western portion of the Gônave Microplate (e.g., Rosencrantz and Mann, 1991; DeMets and Wiggins-Grandison, 2007).

The Oriente Fault west of Cuba is the major plate-bounding structure, slipping at ~10-15 mm a^{-1} and accommodating 60-80% of the total relative plate motion (e.g., Benford et al., 2012a; Symithe et al., 2015). The fault system undergoes an

extensional stepover off the southwestern coast of Cuba (Figure 7), and farther east becomes transpressional once again (e.g., Calais and de Lepinay, 1991). N-S convergence across the plate boundary here occurs in the Santiago Deformed Belt. This contractional zone bears structural resemblence to an accretionary prism, and may contain several stacked thrusts (Calais and de Lepinay, 1991; Leroy et al., 2015) but given the lack of detailed information on potential out-of-sequence thrusts activity

5 we choose to represent the zone with a single, north-dipping basal thrust. The major strike-slip Oriente Fault trace continues to northern Hispaniola through the Windward Passage, where it merges with the Septentrional fault system (Calais et al., 1992; Leroy et al., 2015).

Within the interior of Cuba, several zones of seismicity, inferred as faults or fault zones, cross the island. Two of these, the Pinar del Fault in northwestern Cuba and the Nipo-Guacanayabo Fault southeastern Cuba, were included in this

10 compilation. Some other notable fault zones exist, such as the Camaguey and La Trocha Faults (e.g., García et al., 2003), but these lack sufficient topographic expression to map as through-going structures consistently with the criteria applied elsewhere in the GEM fault databases. Slip rates and kinematics on these faults are all unknown, and the lack of geodetic data from Cuba makes it very difficult to quantify internal strain on the island. Offshore to the northeast of Cuba, the North Cuban Fault separates Cuban crust from the Bahamas platform. The North Cuban Fault is mapped here as a reverse fault, given its

15 geomorphology, but current kinematics are unknown. Farther north, the Cay Sal Fault is present between Cay Sal and Androes Island, and a 40 km long scarp evident in bathymetric and seismic data suggests neotectonic activity (Kula, 2014).

To the south of the western Oriente Fault, the parallel Walton Fault Zone accommodates the remainder of the North American-Caribbean motion, some 4-7 mm a^{-1} (Benford et al., 2012b) (though Symithe et al. (2015) give it a higher rate, 9-10 mm a^{-1}). As with the Oriente Fault, this structure becomes more complicated to the east near Jamaica, and may split into

20 active northern and southern strands (Rosencrantz and Mann, 1991); however, in the absence of available bathymetric data of sufficient resolution to map these splays, we draw the structure as a single strike-slip fault intersecting central-western Jamaica.

Jamaica itself is the location of a restraining bend between the Walton Fault Zone to the west and the Enriquillo-Plantain Garden Fault Zone to the east. Faulting on the island occurs on east-striking sinistral faults and north-striking reverse faults (Benford et al., 2015). The most rapid slip seems to be in an east-west zone through the center of the country (the Río Minho-

25 Crawle River Fault, the Cavaliers Fault, and the Plantain Garden Fault), which slips at 5 ± 2 mm a^{-1} (Benford et al., 2012b; Koehler et al., 2013); rapid slip on the northern Duanvale Fault Zone does not seem to be supported by the geodetic data. Some slip in the central faults may be transferred to the south through the reverse faults to the sinistral South Coast Fault, or to other (possibly undocumented) faults on the island. This interpretation of distributed slip, primarily by Koehler et al. (2013), is in light of paleoseismic evidence indicating no Holocene (and possibly no mid to late Quaternary) seismicity on the

30 Plantain Garden Fault. Nonetheless, it is generally agreed that faulting to the east of the Plantain Garden Fault is localized on the offshore segment of the Enriquillo-Plantain Garden Fault (e.g., Benford et al., 2012b; Leroy et al., 2015).

3.2.2 Hispaniola and the Mona Rift

The Oriente and the Enriquillo-Plantain Garden Faults continue to northern and southern Hispaniola, respectively (Figure 7). The Oriente Fault lies just offshore the northern coast of Haiti, south of the island of La Tortue (Tortuga), and then reaches the

shore in the northeastern Dominican Republic, very close to the Hatian border (e.g., Leroy et al., 2015). Slip on the Oriente Fault north and west of Haiti may be slightly slower than farther west (9-10 mm a^{-1}), as some strike-slip motion may be taken up on the North Hispaniola Fault (Benford et al., 2012a), part of the North Caribbean Megathrust.

At its eastern terminus, the Oriente Fault is kinematically linked to the Septentrional Fault, which is a parallel >250 km long (ESE-striking) sinistral fault cutting across northern Hispaniola and continuing east. The western end of the Septentrional Fault is about 20 km north of the Oriente Fault, on the other side of the Cibao Valley. This alluvial valley is covered by Quaternary sediments, and may be underlain by additional faults between the Septentrional and Oriente Faults that have no surface expression. Nonetheless, older sediments on the southern valley sides do not display deformation suggestive of continued slip on the Oriente Fault into the interior of the island. The Septentrional Fault is estimated to slip at 10-11 mm a^{-1} based on geodetic block modeling (Benford et al., 2012a; Symithe et al., 2015).

The Enriquillo-Plantain Garden Fault enters Hispaniola at its farthest west, crossing the length of the Tiburon Peninsula. The fault has a sinistral slip rate of 5-7 mm a^{-1}, and may be transpressional; geodetic modeling ranges from contraction of 0 (Symithe et al., 2015) to 5 mm a^{-1} (Benford et al., 2012a). The geomorphology of the fault zone suggests mild transpression, as the fault zone runs through the highest topography of the peninsula. The fault is also segmented here; its trace suggests a slight break in the west north of Les Cayes, and a more prominent extensional stepover south of Miragôane. Farther east towards Port-au-Prince, contractional structures are more evident in the landscape and seismicity. The devastating 2010 Haiti earthquake is thought to have occurred on the previously-unknown Léogâne Fault, a north-dipping blind reverse-oblique structure that seems to merge into the Enriquillo Fault near its trace (Calais et al., 2010); as the fault does not seem to have a distinct trace, it is not included in this dataset.

Contraction occurs on thrust faults through a valley stretching from Port-au-Prince (Haiti) in the west through Barahona (Dominican Republic) in the east, called the Plain Cul-de-Sac in Haiti and the Nieba or Enriquillo Valley in the D.R. This valley is bordered on its northern and southern margins by active thrusts; the signs of sedimentation and subsidence in the footwall as well as fault propagation folds deforming Quaternary sediments attest to rapid slip on these faults. Saint Fleur et al. (2015) map several of these thrusts in Haiti from field and remote sensing observations, and extend the mapping to the west into Port-au-Prince Bay. Northwest of the city, the 80 km long Matheux Thrust (Pubellier et al., 2000) poses a seismic and tsunami hazard to the region. Into the Dominican Republic, the faults have not received geological study but their characteristics remain the same as those along strike in Haiti. Geodetic slip rates through the zone indicate 3-8 mm a^{-1} contraction (Benford et al., 2012a; Symithe et al., 2015) but it is not clear how this is distributed onto individual structures.

Though Haiti has long been identified as the location of a restraining bend in the northern Caribbean strike-slip boundary (e.g., Mann et al., 1984), there is a lack of known active faults in central Hispaniola. Although bedrock fault traces are readily observable in digital elevation data in the Cordillera Central and the San Juan Valley to the south, there is little sign of Quaternary offset. The San Juan Valley in particular shows the hanging walls of the range-bounding reverse faults to be uplifted and actively eroding, instead of subsiding and accumulating sediment. Furthermore, river traces and Quaternary landforms do not appear to be modified by active faulting. The major exception to this is the Bonao Fault on the east of the Cordillera Central, which is a fairly short, west-dipping reverse fault that has a very sharp trace and a footwall basin that seems to be

filling rather than eroding. However, slip rates on this structure are unknown, and its separation from regional structures may mean that any slip on it is rather slow. Though the newer geodetic block models place the boundary between the Gônave plate and blocks to the east through the San Juan Valley (e.g., Symithe et al., 2015), it is suggested here from the patterns of active faulting that relative motion between blocks is taken up through distributed deformation in western Hispaniola and through the

5 Cul-de-Sac–Enriquillo Valley in the south; the latter representation is also used by researchers such as Benford et al. (2012a).

Between Hispaniola and Puerto Rico, both the Septentrional and Enriquillo Fault Zones terminate offshore into more enigmatic structures. The Septentrional Fault Zone splits into the transtensional Bunce Fault (which strikes northeast and merges with the Puerto Rico Trench) and the north-trending Mona Rift northwest of Puerto Rico (e.g., ten Brink et al., 2004; Grindlay et al., 2005). The thrust of the eastern Enriquillo Valley continue southeastward into the Muertos Thrust, a north-dipping thrust

10 where Caribbean oceanic crust underthrusts the continental and transitional crust of the eastern Greater Antilles (Mauffret and Leroy, 1999; Granja Bruña et al., 2009).

This transition marks a change in the nature of the North American-Caribbean plate boundary. To the west of the Mona Rift (and the Yuma Rift to its southwest), the 'geologic' plate boundary fault is the North Hispaniola Thrust, where crust of the Bahamas Bank underthrusts (or has underthrust) the Hispaniola block (e.g., Dolan et al., 1998); however, modern slip on this

15 fault as evident in geodetic data is ~2 mm a^{-1}, less than 10% of the relative plate motion. Instead, the Hispaniola block deforms internally via the aforementioned structures, and also moves at moderate rates with respect to the stable oceanic crust of the Caribbean to its south, mostly along the Muertos Thrust (Symithe et al., 2015). To the east of the Mona Rift, the situation is different. The plate-bounding Puerto Rico Trench (and likely the Bunce and Bowin faults in the hanging wall) accommodates most of the relative plate motion (e.g., Symithe et al., 2015). Internal deformation of Antilles crust, represented by the Puerto

20 Rico-Virgin Islands block, is minimal, and slip rates on the Muertos Thrust are similarly low, <2 mm a^{-1} (e.g., Jansma and Mattioli, 2005; Benford et al., 2012a). In addition to demarcating the different styles of deformation to the east and west, the Mona and Yuma Rifts also serve as the zone of strain between the two domains: extension across the rifts between the Puerto Rico and Hispaniola blocks is 3-4 mm a^{-1} (Jansma and Mattioli, 2005; Benford et al., 2012a; Symithe et al., 2015). Chaytor and ten Brink (2010) mapped an intricate network of small to moderate-length normal faults in the transition zone between

25 the Mona and Yuma Rifts. The complexity of faulting here suggests either distributed oblique extension or multiple phases of extension. The largest faults are ~70 km long, and capable of M ≤ 7 earthquakes. Kinematic linkage between the Mona Rift and the Cerro Goden fault in western Puerto Rico is also likely based on the bathymetric data and interpretation (e.g., Grindlay et al., 2005a).

3.2.3 Offshore faulting

30 Some of the longest faults in the northeastern Caribbean are found in the Mona Rift and the Bunce and Bowin fault systems of the northern plate margin. These structures are located in deep water (4-8 km depth) and are consequently poorly understood (Figure 8). Nonetheless they likely accommodate the strike-slip component of North American-Caribbean convergence, and may slip rapidly (up to ~15 mm a^{-1}) although direct slip rate measurements are not currently possible. The southeastern Bowin Fault Zone appears to have some contractional component, while the northern and western Bunce Fault Zone has some

extensional component. Given the very slow (and probably dextral) slip rates on the faults extending southeast from the Mona Rift in Puerto Rico (discussed below) it is likely that the majority of slip from the Septentrional Fault is transferred to these structures.

The Puerto Rico Trench may not be a source of major interplate thrust earthquakes. ten Brink and López-Venegas (2012)
5   find that the trench is not accumulating significant contractional strain, though sinistral slip is possible.

Farther west, north of Hispaniola, the plate interface becomes contractional again, due to a northward bend in the strike (making it transpressional). The convergence of thick, buoyant continental crust of the Bahamas Bank with the plate interface (here called the North Hispaniola Thrust) is the only part of the entire megathrust where contractional strain is being accommodated. Symithe et al. (2015) model coupling ratios of 0.5-1 over much of this boundary, leading to elastic strain accumulation
10   rates consistent with ~2 mm a^{-1} of reverse slip, which may be higher in the west towards Cuba, but there is no geodetic data in Cuba to make accurate estimates.

3.2.4   Puerto Rico and the Virgin Islands

Puerto Rico has several ESE-striking fault zones that cut through the interior of the island and are fairly well expressed topographically (Figure 8). These are, from east to west, the Great Northern Puerto Rico Fault Zone, the Great Southern Puerto
15   Rico Fault Zone, and the Cerro Goden Fault. Despite the names, these faults are in an east-west belt along the island. The faults show more deformation in Eocene and older rocks than in Neogene rocks (Mann et al., 2005a), and their expression in the landscape is largely a consequence of this Paleogene activity. The modern kinematics of these faults is also unclear. GPS studies (e.g., Jansma and Mattioli, 2005) indicate that strain rates across Puerto Rico are below the noise level, something of a rarity in this part of the world. The geometry of the Cerro Goden and Great Southern Puerto Rico Fault Zone at first glance
20   appear to be part of a chain of faults from the Septentrional Fault in the Dominican Republic through the Mona Rift, across Puerto Rico and into the Anegada Rift. However, assuming sinistral-oblique kinematics for the chain of faults (based on the Septentrional Fault and Caribbean-North American relative motion), the Mona Rift would represent a right step in a left-lateral system, which would be a restraining bend. This is clearly not consistent with the bathymetric and seismic expression of extension across the Mona Rift.

25   If the Cerro Goden and Great Southern Puerto Rican Faults are linked to the Mona Rift in the classic strike-slip–to–stepover fashion, this implies right slip along the Puerto Rican faults, which is more consistent with reconnaissance field observations by Mann et al. (2005b) indicating dextral-normal slip on the Cerro Goden Fault. This latter interpretation is hard to place in a regional tectonic framework, but given the low strain rates, the most appropriate response to the question *"What are the Puerto Rican faults doing?"* may be *"Not much."* For this reason, the lack of inclusion of terrestrial Puerto Rican faults in geodetic
30   block models is understandable and probably accurate.

Holocene activity on these faults is poorly documented, in part because of an apparent lack of investigation. Work by Mann et al. (2005b) on the Cerro Goden Fault near Mayagüez provides support for slow, dextral-normal slip on that structure. Better evidence is found on the short (<10 km) South Lajas Fault. Prentice and Mann (2005) map and trench a scarp on the South Lajas

Fault and find evidence for one oblique-slip earthquake ~5040 years B.P. on a near-vertical fault. This is the only documentation of active surface faulting on Puerto Rico.

The southeastern margin of the relatively rigid Puerto Rico-Virgin Islands crustal block is the Anegada Rift, a normal-sinistral rift separating this crust with the Lesser Antilles. This rift is estimated to be opening obliquely at >1.5 mm a^{-1}

5 (Benford et al., 2012a; Liu and Wang, 2015), though some variability exists in the relative amounts of normal to sinistral motion.

3.2.5 Lesser Antilles

Faulting in the Lesser Antilles occurs on three sets of faults that are all typical components of variably-oblique subduction systems. The first is the Lesser Antilles Megathrust, which slips at 18-20 mm a^{-1} (e.g., Symithe et al., 2015). The megathrust

10 daylights >200 km to the east of the islands of the Lesser Antilles, which move more or less with the stable Caribbean plate geodetically. This makes estimating locking on the megathrust difficult. Small to moderate seismicity is common in the north but decreases south towards Venezuela; the accretionary prism becomes extremely thick here, which may lubricate the trench or otherwise suppress seismicity.

The second and third sets of fault are found in the upper plate of the central and northern Lesser Antilles (Figure 8). One

15 is a set of normal faults that are perpendicular to the arc and trench that extend from the arc towards the trench, and the other is a set of arc-parallel normal-sinistral faults located near the modern arc (e.g., Feuillet al., 2011). These accommodate fragmentation and translation of the arc crust due to variably-oblique convergence.

The normal faults cut not only the modern arc but the thick crust of the former outer arc that exists east of the active volcanic islands. As they are mostly undersea, study of them is minimal, though Feuillet et al. (2004) has studied found a vertical slip

20 rate of ~0.5 mm a^{-1} on the southern Morne Piton Fault. Though escarpments reminiscent of normal faults are found between the blocks of the inactive outer arc to the northwest of Antigua, shallow seismicity decreases substantially, and the scarps are less well-defined; therefore they are not mapped here. This is consistent with theory and observations from other zones of variably-oblique convergence with an arcuate upper plate (e.g., McCaffrey and Nabelek, 1998; Styron et al., 2011): arc-parallel extension is concentrated in the center of the arc, where the arc-parallel velocities are low but the velocity *gradient* is highest,

25 and the margin-parallel strike-slip faults continue, likely with increasing slip rates, away from the center of the arc.

None of these structures have been mapped in the southern half of the Lesser Antilles. Some of this may be due to insufficient study and the thick blanket of sediments from the Orinoco River, but this region is relatively aseismic. If the trench is lubricated by the sediments or otherwise accumulates little or no elastic strain, then shear stresses on the base of the overriding plate may not be enough to cause it to deform.

4 Discussion and conclusions

4.1 Distribution of deformation

The patterns of deformation in Central America and the Caribbean region are largely the result of the interaction of the Caribbean plate with the adjacent North American, Cocos, and South American plates; very little internal deformation of
5 the Caribbean plate, or deformation due to non-plate-tectonic processes such as gravitational collapse, seem to be present. The width of the deforming zones around the Caribbean margin is variable and ostensibly linked to lithospheric composition: Where the plate boundary type is between ocean-ocean crust, strain is commonly localized to one or two faults, but where continental or transitional crust is involved, strain may be spread out over zones several hundred km wide. This is consistent with observations elsewhere on earth, and is likely linked to the contrasting strength characteristic of the two types of lithosphere; oceanic
10 plates are stronger and more homogeneous, while continental crust is weaker and may contain many pre-existing planes of particular weakness due to rock layering or previous deformation events. This crustal heterogeneity may aid in in distributing deformation over broad fault zones.

Many of the zones of complicated deformation are at stepovers in the major strike-slip fault systems, the northern Caribbean-North American plate boundary and the Central American Forearc-bounding fault zone. An interesting aspect of the northern
15 Caribbean-North American plate boundary through the Greater Antilles is that restraining bends in the sinistral plate boundary are mostly localized to the islands (particularly Hispaniola and Jamaica) while the undersea segments of the plate boundary are relatively straight. It is possible that it is mechanically favorable to localize the necessarily more complex and distributed faulting that occurs at stepovers in the weaker continental crust making up the islands.

4.2 Faulting, seismic risk and uncertainty

20 The majority of the region's ~100 million inhabitants live with substantial seismic hazard. ~80 million people live within 50 km of the fault traces here presented; most of the population outside of this distance is in western Cuba or the southern Dominican Republic (including the Santo Domingo metro area). The former region is relatively safe, but the latter overlies the Los Muertos Thrust though the trace is >50 km south. The probabilistic seismic hazard and risk assessment done through the CCARA project is quantitatively assessing the hazard and risk in the study area (e.g., Calderon and Silva, 2019), in part
25 through modeling of faults presented here.

Though we have coverage of the entire study region, much of the mapping should be considered provisional and several areas are in need of additional, focused neotectonic mapping and studies of slip rates and paleoseismic history. The uncertainty in the slip rates and fault geometries for known faults in the area translate directly to greater variance in the PSHA results. The possibility for additional faults that are currently unknown is also quite high, and represents potential seismic fault sources
30 that are unaccounted for in existing fault source datasets and hazard models. The following areas are, from the perspective of seismic risk, the sites where focused geologic study would do most to increase the accuracy and decrease the epistemic uncertainty in the hazard models.

The faults surrounding Guatemala City (the Mixco and Guatemala City faults), San Pedro Sula in Honduras (the Sula graben), and San José in Costa Rica are all areas of active faulting in urbanized areas with very little local information on the geometries and slip rates of the faults. While the broad tectonic configuration of the Guatemala City and Sula grabens are relatively well understood, central Costa Rica is less so; it is densely vegetated, incompletely mapped, and at a transition

5   from transtension in the northwest to transpression in the southeast along the arc-parallel fault zone. Similarly, understanding more accurately where in Hispaniola strain is being accommodated, particularly whether strain is transferred south from the Oriente fault in the north through contractional faults along the island's west coast (as interpreted here) or through the San Juan valley in the center of the island, could be of both geological interest and hazard interest as it shifts faulting farther from Port-au-Prince and towards Santo Domingo. Similarly, though strain rates are likely 1-2 orders of magnitude lower than in

10   these areas, a better understanding of the kinematics, slip rates and paleoseismic history of the Great Northern Puerto Rico Fault Zone would greatly improve our knowledge of the seismic hazard of the San Juan area.

5   Conclusions

The Caribbean and Central American region shows rapid deformation along the densely-populated periphery of the Caribbean plate. A dataset of ~250 active fault traces, with geometric, kinematic and seismic hazard attributes, is presented here to

15   characterize regional deformation, and to serve as seismic hazard.

Central American deformation is caused by the interaction between the North American, Caribbean and Cocos plates. Regional deformation in northern Central America is transpressional, with reverse faults in the Chiapas Fold and Thrust belt and sinistral faults in southeastern Chiapas. South of Chiapas, the E-striking, sinistral Motagua–Polochic Fault System forms the continental, western segment of the Caribbean–North American plate boundary. South of the MPFS, distributed normal

20   faulting is present through the highlands of Guatemala, Honduras and El Salador, with dextral faulting along the Central American Volcanic Arc associated with oblique subduction of the Cocos plate and northwestward translation of the Central American forearc. Southern Central America also shows transpressional deformation, with distributed reverse and strike-slip faulting in Costa Rica and reverse and sinistral faulting in Panama.

Faulting along the northern and eastern margins of the Caribbean plate result from the eastward translation of the Caribbean

25   plate relative to the North and South American plates. The Greater Antilles lie along the east-striking, sinistral plate boundary between the CA and NA plates. This boundary contains restraining bends that cut through Jamaica and Hispaniola, which have a mix of reverse and sinistral faults. The northeastern Caribbean plate contains sinistral and reverse faults near the Puerto Rico Trench, and normal faults in the upper plate. The Lesser Antilles islands lie on or near the volcanic arc created by subduction of Americas lithosphere underneath the Caribbean plate. Here, reverse faulting seems to be isolated at or near the megathrust

30   while dextral and normal faults are found near the arc, likely accommodating the extension and translation of forearc slivers in this region of variably-oblique plate convergence.

Though a formal, quantitative seismic hazard and risk analysis is forthcoming, the distribution of faults and the available slip rate information suggests that the highest seismic risk is found in the large cities close to the Caribbean plate margins.

The slip rates and seismic behavior of the proximal shallow faults in Central America have much greater uncertainty than in the Greater Antilles; neotectonic and paleoseismologic investigations of faults around Guatemala City (Guatemala), San Pedro Sula (Honduras) and San Jose (Costa Rica) would have a large impact in increasing the accuracy and reducing the epistemic uncertainty in seismic hazard and risk assessments of the areas.

5   The GEM CCAF-DB is a vector GIS database, and provided in a range of purposes for different computing environments. The database is open-source with a Creative Commons attribution license (CC-BY-4.0). The database is mean to be incrementally updated as information becomes available, with changes and releases managed through the *git* version control system.

Data availability.   The CCAF-DB (Styron et al., 2018) is publicly available at https://github.com/GEMScienceTools/central_am_carib_faults.

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Attribute	Data Type	Description	Example
dip	tuple	Dip	(40,30,50)
dip_dir	string	Dip direction	W
downthrown_side_id	string	direction of downthrown side	NE
average_rake	tuple	Slip rake of fault	(45,25,55)
slip_type	string	Kinematic type	Sinistral
strike_slip_rate	tuple	Strike slip rate on fault	(1.5,0.5,2.5)
dip_slip_rate	tuple	Dip slip rate	(1.5,0.5,2.5)
vert_slip_rate	tuple	Vertial slip rate	(1.5,0.5,2.5)
shortening_rate	tuple	Horizontal shortening rate	(1.5,0.5,2.5)
activity_confidence	integer	Certainty of neotectonic activity	1
exposure_quality	integer	How well exposed (visible) fault is	2
epistemic_quality	integer	Certainty that fault exists here	1
last_movement	string	Date of last earthquake	1865
name	string	Name of fault or segment	Polochic
fs_name	string	Name of fault system	Motagua-Polochic
reference	string	Paper used	Rogers and Mann, 2007
notes	string	Any relevant notes	may be creeping

Table 1. Attributes for active structures.
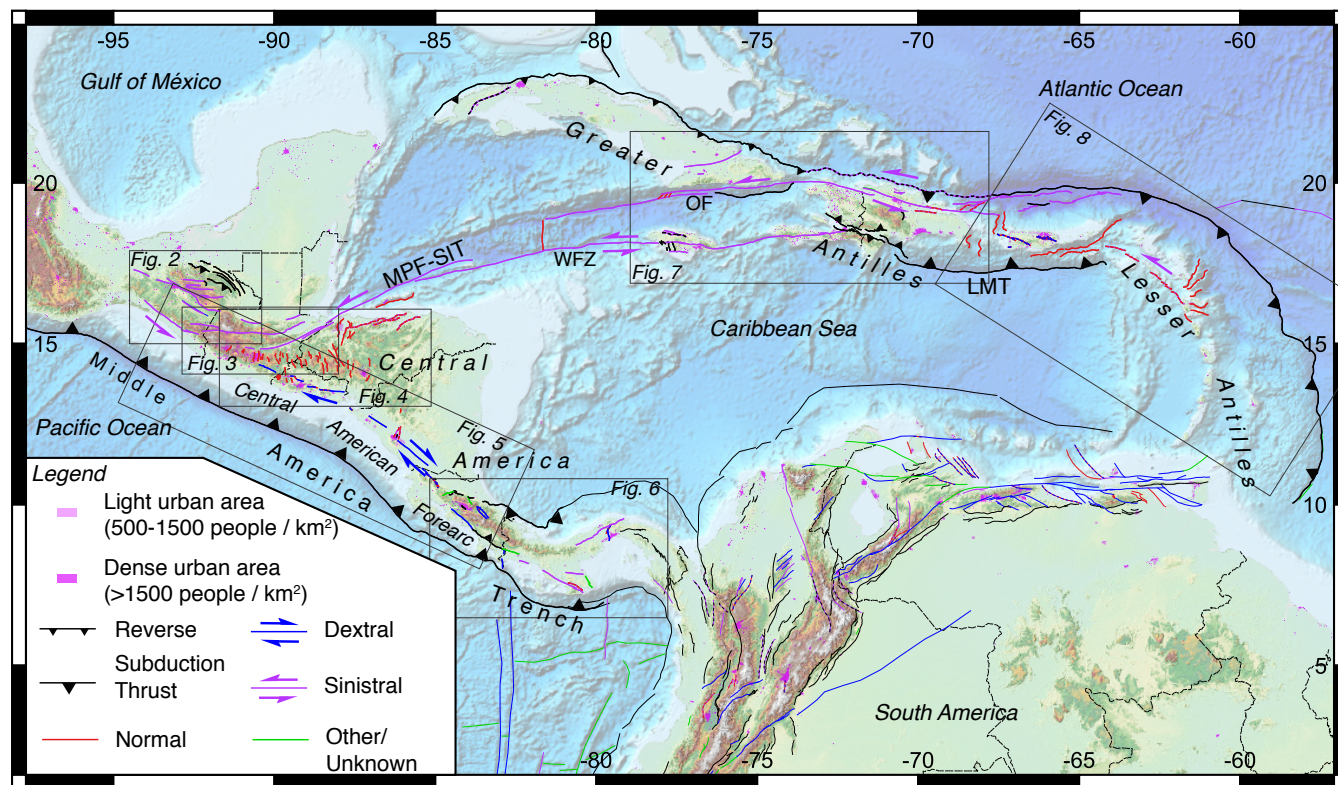
Figure 1. Active faults of the Caribbean and Central America. Faults with thicker lines are in the CCAF-DB, while faults with thinner lines in South America are from the SARA (https://sara.openquake.org/) and ATA (Veloza et al., 2012) datasets. LMT = Los Muertos Trough. MPF–SIT = Motagua–Polochic Fault and Swan Islands Transform. OF = Oriente Fault. WFZ = Walton Fault Zone. Names given in italicized text are geographic features, while those in regular text are structural features.
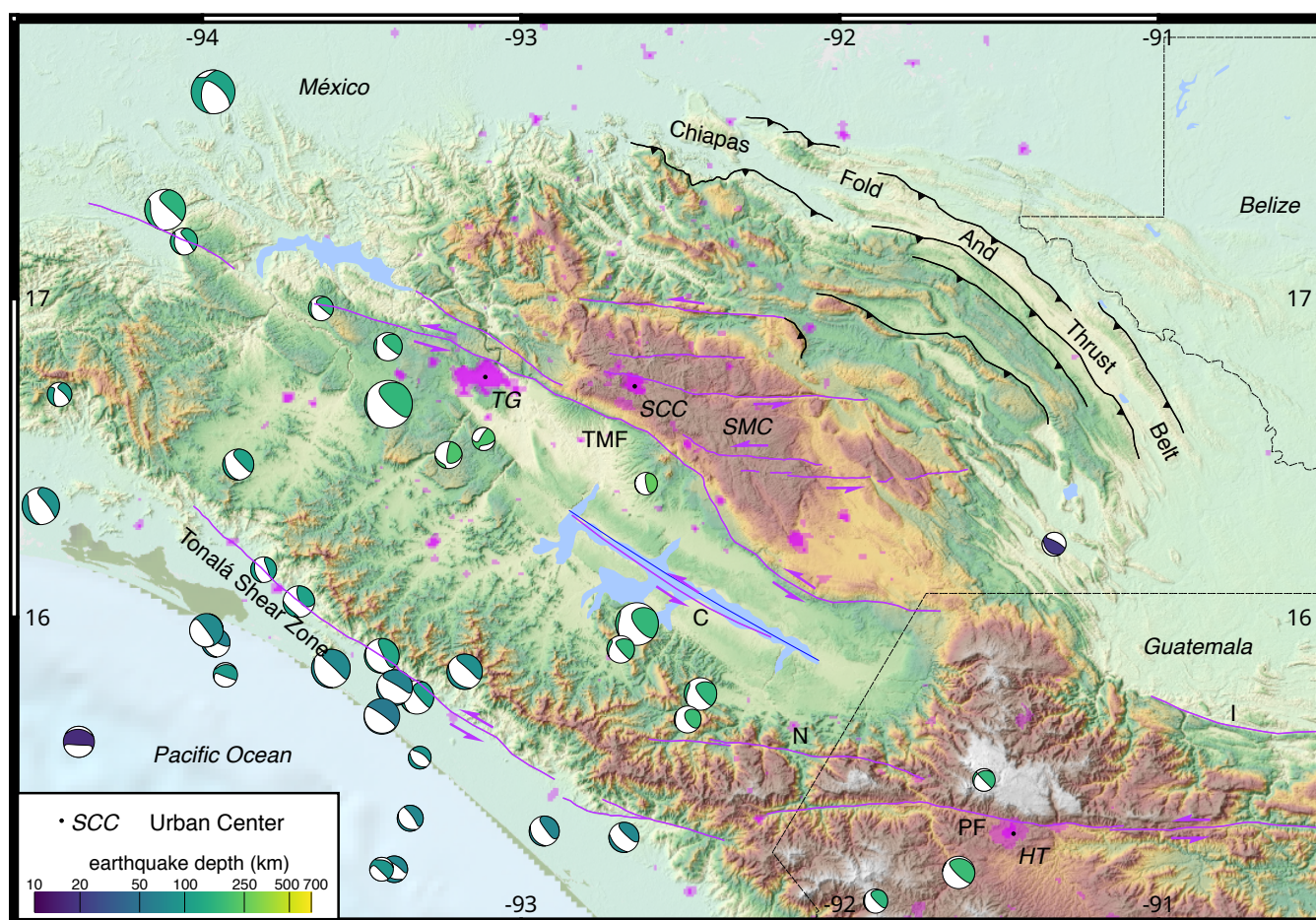
Figure 2. Active faults in Chiapas and vicinity. Symbology the same as in Figure 1. TMF = Tuxtla-Malpaso Fault. I = Ixcán Fault. C = Concordia Fault. N = Necta Fault. PF = Polochic Fault. SMC = Sierra Madre de Chiapas. TG = Tuxtla Gutiérrez. SCC = San Cristóbal de las Casas. HT = Huehuetenango. Focal mechanisms from the Global Centroid Moment Tensor catalog.
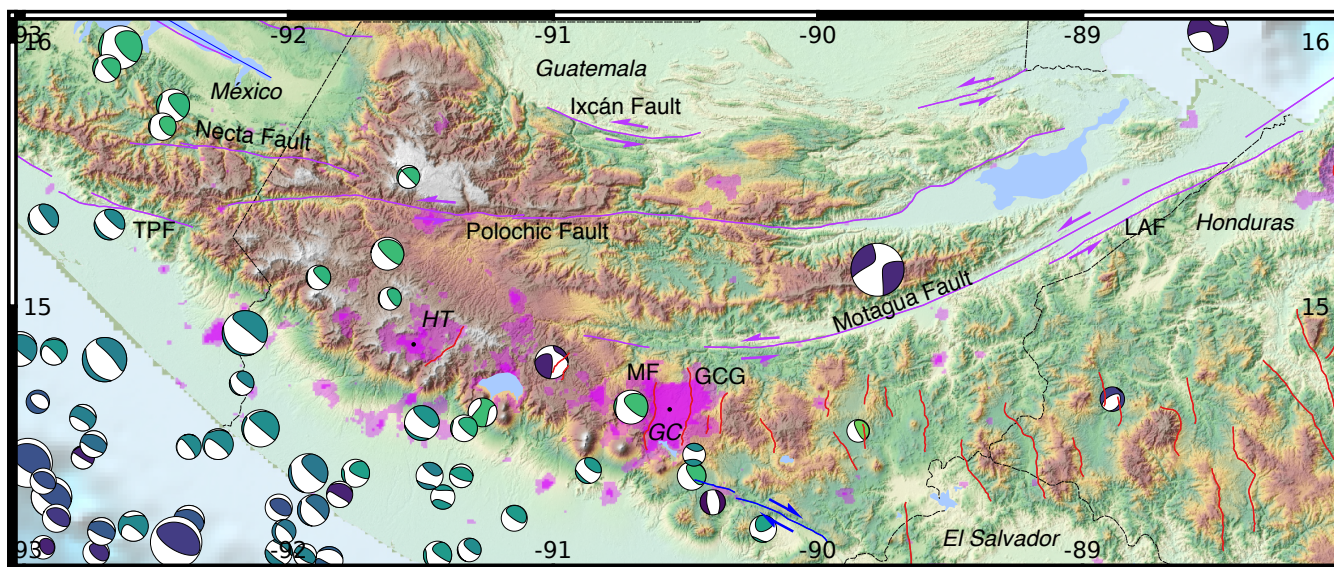
Figure 3. The Motagua-Polochic Fault Zone. MF = Mixco Fault. GCG = Guatemala City Graben. TPF = Tonalá-Polochic Fault Zone. LAF = Los Amates Fault. HT = Huehuetenango. GC = Guatemala City.
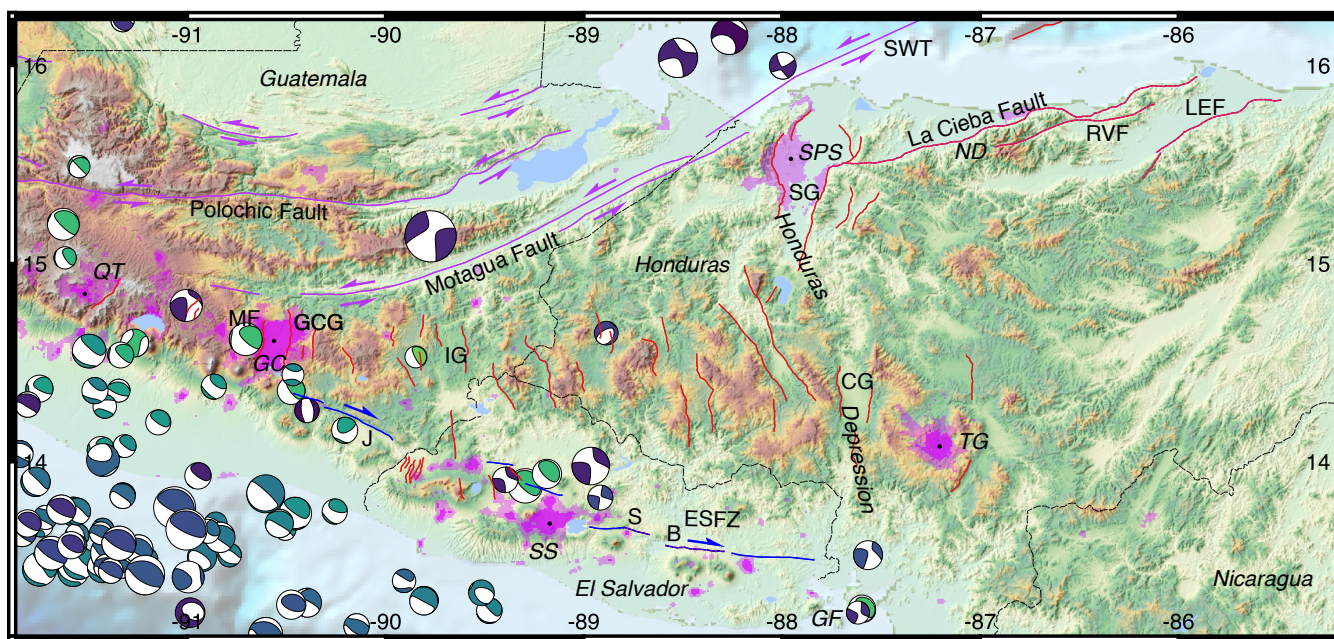
Figure 4. Active faults in the Central American Highlands. SWT = Swan Islands Transform. LEF = La Esperanza Fault. RVF = Río Viejo Fault. SG = Sula Graben. IG = Ipala Graben. GCG = Guatemala City Graben. MF = Mixco Fault. CG = Comayagua Graben. J = Jalpatagua Fault. ESFZ = El Salvador Fault Zone. S = San Vicente Segment (ESFZ). B = Berlin Segment (ESFZ). ND = Nombre de Dios Range. SPS = San Pedro Sula. GF = Gulf of Fonseca. SS = San Salvador. GC = Guatemala City. QT = Quetzaltenango.
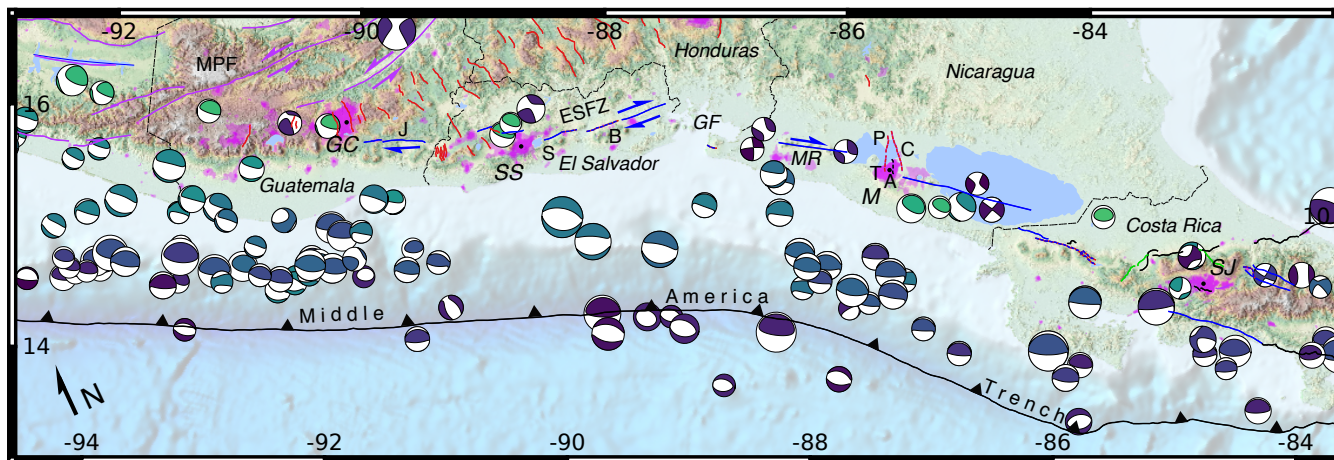
Figure 5. the Central American Forearc. MPF = Motagua-Polochic Fault Zone. J = Jalpatagua Fault. ESFZ = El Salvador Fault Zone. S = San Vicente Segment (ESFZ). B = Berlin Segment (ESFZ). P = Punta Huete Fault. C = Cofrádia Fault. A = Aeropuerto Fault. T = Tiscapa Fault. GC = Guatemala City. MR = Marabios Range. M = Managua. SH = San José.
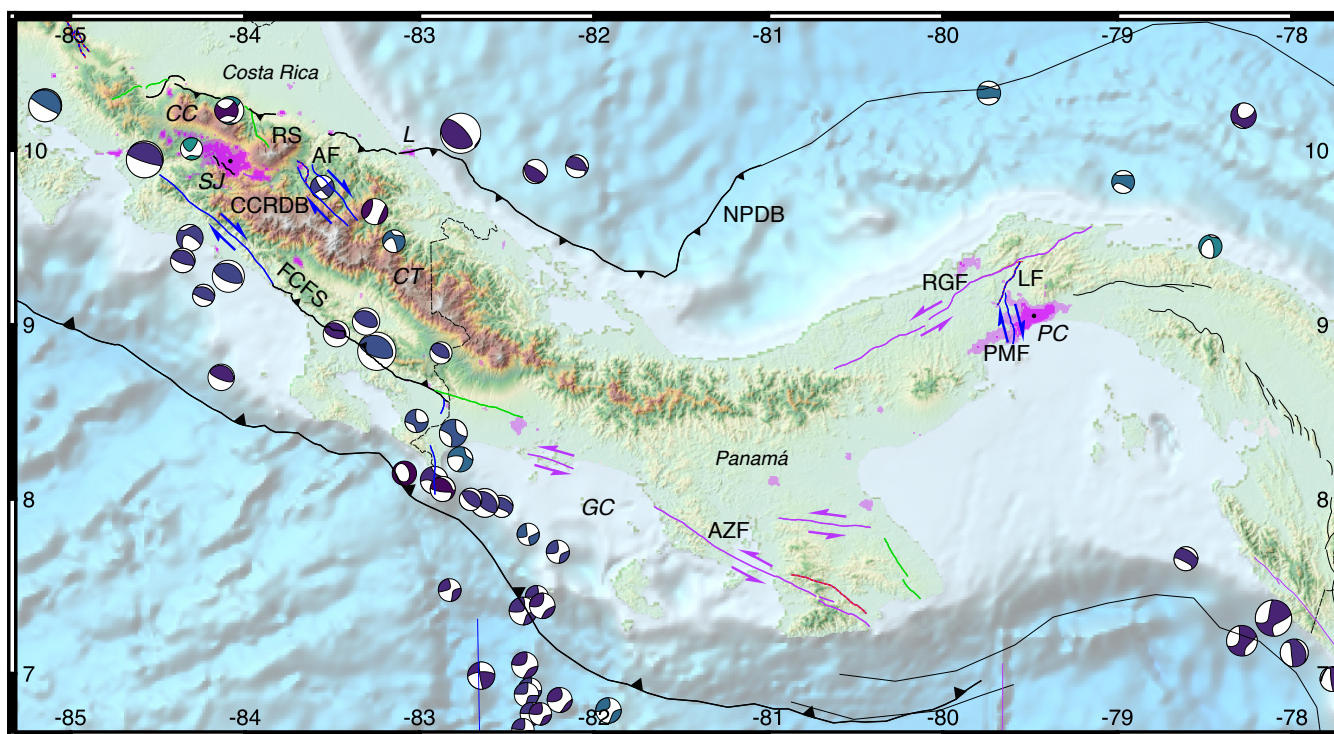
Figure 6. Active faults of Costa Rica and Panamá. RS = Río Sucio Fault. AF = Atirro Fault. CCRDB = Central Costa Rica Deformed Belt. FCFS = Fila Costena Fault System. RGF = Río Gatun Fault. LF = Limón Fault. PMF = Pedro Miguel Fault. AZF = Azuero Fault.
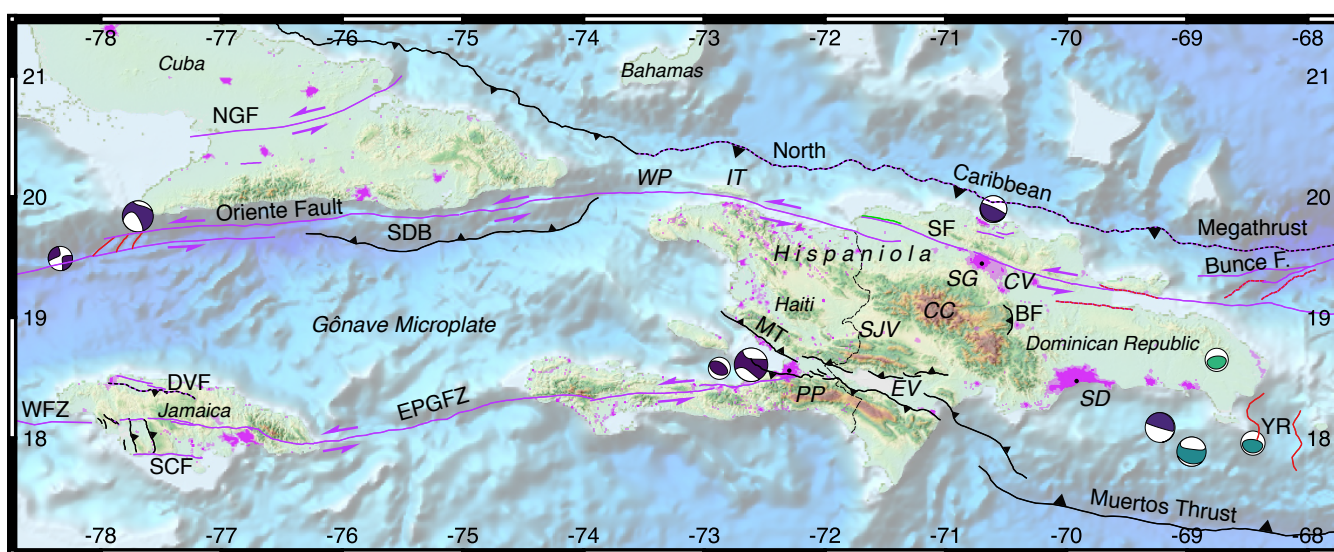
Figure 7. Active faults of the Greater Antilles. NGF = Nipo-Guacanayabo Fault Zone. SDB = Santiago Deformed Belt. SF = Septentrional Fault. BF = Bonao Fault. MT = Matheux Thrust. EPGFZ = Enriquillo–Plantain Garden Fault Zone. YR = Yuma Rift. DF = Duanvale Fault. SCF = South Coast Fault. WFZ = Walton Fault Zone. WP = Windward Passage. IT = Isla Tortuga. SG = Santiago de los Caballeros. CV = Cibao Valley. CC = Cordillera Central. SJV = San Juan Valley. SD = Santo Domingo. PP = Port-au-Prince. EV = Enriquillo Valley.
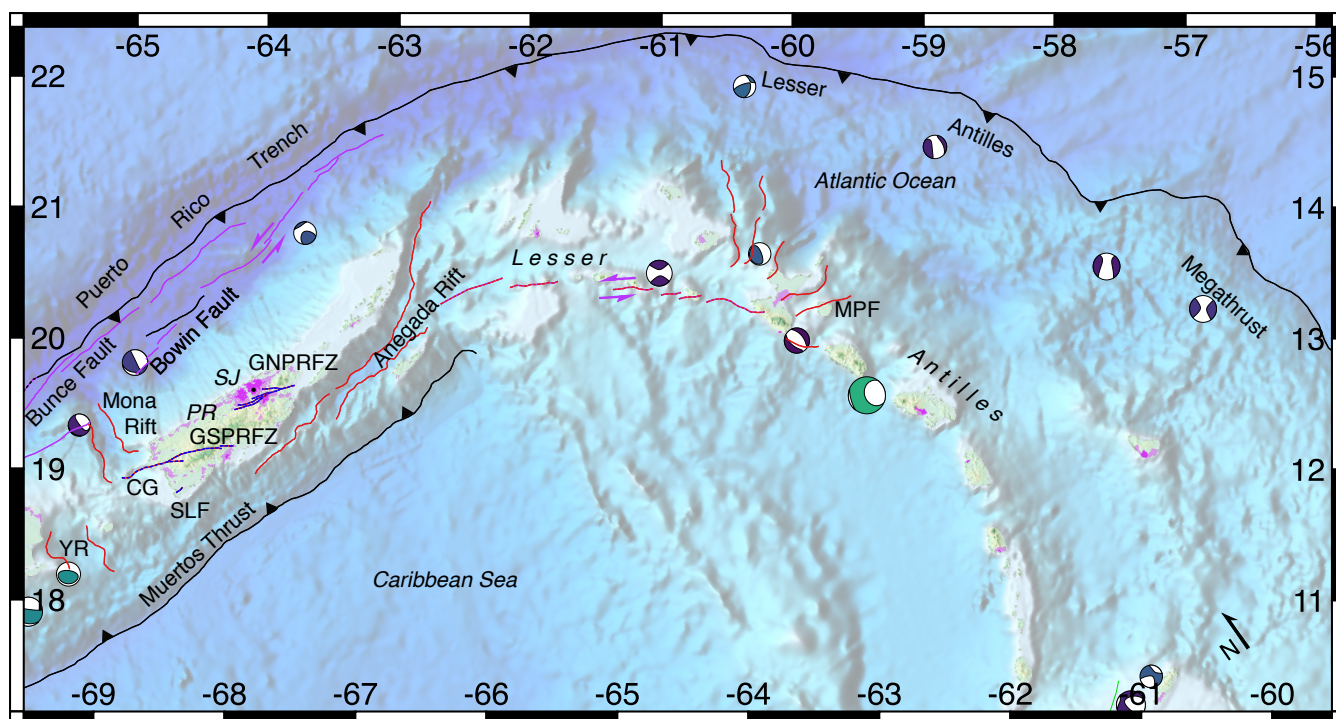
Figure 8. Active faults of the Lesser Antilles. YR = Yuma Rift. CG = Cerro Goden Fault. SLF = South Lajas Fault. GSPRFZ = Great Southern Puerto Rico Fault Zone. GNPRFZ = Great Northern Puerto Rico Fault Zone. MPF = Morne Piton Fault. SJ = San Juan.