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Map and Database of Quaternary Faults and Folds in Panama and Its Offshore Regions

By **Hugh Cowan, Michael N. Machette, Kathleen M. Haller, *and* Richard L. Dart**

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A project of the International Lithosphere Program Task Group II-2, Major Active Faults of the World

Data and map compiled by

[1] HUGH COWAN, [2] MICHAEL N. MACHETTE,
[2] KATHLEEN M. HALLER, AND [2] RICHARD L. DART

[1] Instituto de Geociencias
Universidad de Panamá
Panamá City, Panamá

[2] U.S. Geological Survey
Central Geologic Hazards Team
Denver, Colorado, USA

Regional Coordinator for Central America

HUGH COWAN
Instituto de Geociencias
Universidad de Panamá
Panamá City, Panamá

Current Address:
Institute of Geological & Nuclear Sciences Ltd.
P.O. Box 30 368
Lower Hutt, New Zealand

International Lithosphere Program
Task Group II-2 Co-Chairman (Western Hemisphere)

MICHAEL MACHETTE
U.S. Geological Survey
Central Geologic Hazards Team, MS 966
P.O. Box 25046
Denver, Colorado, USA

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INTRODUCTION

The U.S. Geological Survey (USGS) is assisting in the compilation of a series of digital maps of Quaternary faults and folds in Western Hemisphere countries as part of the International Lithosphere Program's (ILP) project for a "World Map of Major Active Faults." The maps from this project show the locations, ages, and activity rates of major earthquake-related features such as faults and fault-related folds. They are accompanied by databases that describe these features and document current information on their activity in the Quaternary. The project is a key part of the Global Seismic Hazards Assessment Program (ILP Project II-0) for the International Decade for Natural Hazard Disaster Reduction.

The project is sponsored by the International Lithosphere Program and funded by the USGS's National Earthquake Hazards Reduction Program. The primary elements of the project are general supervision and interpretation of geologic/tectonic information (Michael N. Machette, Project Chief), data compilation and entry for fault catalog (all personnel), database design and management (Kathleen M. Haller), and digitization and editing of fault and fold traces (Richard L. Dart) in [†]ARCINFO. For the compilation of data, we engaged experts in Quaternary faulting, neotectonics, paleoseismology, and seismology. These experts are the primary authors of this report, and questions about individual fault descriptions should be directed to them. Questions about the project, its status, and the GIS map should be directed to the USGS authors.

Prior to initiating this project, no modern or digital map of active or Quaternary faults existed for Panama or any other country within Central America, even though understanding the extent and character of active and older Quaternary faults are critical elements of seismic hazards analysis. Creation of this map and the accompanying database will help extend the relatively short record of instrumental and felt seismicity in Panama by creating a paleoseismic record of surface deformation associated with large (M>6.5) earthquakes.

Although basic fault data are available for most of the country, the degree of completeness varies greatly and often is a function of the degree of remoteness and vegetation cover. A few faults have been the subject of recent investigations involving modern paleoseismic techniques (see for example, Cowan and others, 1997). Other regions and faults have been studied in some detail, usually in association with concerns about hazards to urban areas or the safety of critical facilities such as lifelines, oil-and-gas pipelines, or power-generating facilities. Thus, considerable effort was required from the primary authors in order to compile information from a wide variety of sources and insure that the national product is up to date and provides fairly uniform coverage for the entire country. Nevertheless, the general state of knowledge for faulting in Panama is probably best described as being of a reconnaissance nature. Little is known in a collective sense about the overall rates of fault activity and fault chronology—information that is difficult to acquire but critical to seismic hazard assessments. Hopefully, additional paleoseismic studies will help augment this map and database.

STRATEGY AND PURPOSE

For the map of Panama, we relied on known, productive experts with strong local or regional knowledge of Panama who were willing to participate in this international project. Given the limited time to produce the map, the project was restricted to compilation of just those elements needed for ILP's Global Seismic Hazards Assessment Program (see database). We anticipate that the project will point out the shortcomings of past and current research on Quaternary faulting in Panama in terms of quantity, quality, scope, and regional coverage and should help promote new efforts to collect paleoseismological data in previously neglected or known critical areas.

In many cases, seismicity has been used to define some potentially active faults, especially along active plate margins. However, recent faulting events in the Western Hemisphere have shown that much of the faulting away from active plate margins occurs along faults with no significant level of seismicity and that only a fraction of active faults are characterized by ongoing seismicity. Thus, the information on Quaternary faulting included within this database should help extend the modern (past several hundred years) record of seismicity into prehistoric time, and allow better assessments of active and potentially active faults in Panama (Montero and others, 1998) and other Western Hemisphere countries.

TECTONIC SETTING

Panama comprises a zone of diffuse deformation, between the Caribbean plate to the north, the Cocos and Nazca plates to the west and south (respectively), and the South American plate to the east (for example, de Boer and others, 1988, 1995; Kellogg and Vega, 1995). The Provinces of Bocas del Toro and Chiriqui in the west, and San Blas and Darien to the east encompass the most seismically active regions of Panama. The southwestern Province of Los Santos, in the Azuero Peninsula, also borders the tectonically active southern margin of Panama. In

[†] Any use of trade names (such as this and others in the report) does not imply endorsement by the U.S. Geological Survey.

these areas, the steep topographic gradient of the highlands reflects the dynamic setting in a zone of active earth deformation and young volcanism. By contrast, central Panama is characterized by low topographic relief and a deeply weathered mantle of Miocene, or older, igneous and sedimentary rocks, which reflect a more stable, intraplate tectonic setting and much lower rates of tectonic deformation.

MAJOR STRUCTURAL ELEMENTS

Active subduction of the Cocos Plate occurs beneath the Pacific margin of the arc in southern Costa Rica, whereas the Nazca Plate is subducted obliquely, in a northeasterly direction, beneath the southwest margin of Panama. The Caribbean Plate is moving south with respect to Panama, underthrusting along the Caribbean margin of the isthmus. Westward relative motion of South America results in collision and shear deformation in the Darien Province, and underthrusting of the Nazca Plate in the Colombian subduction zone.

All major intervals of geological time since the mid-late Cretaceous (100 Ma) are represented in the rocks of Panama. However, the present configuration of the isthmus is the product of a major reorganization of regional tectonics that accompanied the collision of a volcanic arc with South America, between 25 and 7 Ma (for example, Weyl, 1980; Escalante, 1990). Most of the regions historical seismicity can be attributed to tectonic instability associated with relative movements between the neighboring plate boundary elements (for example, Wolters, 1986; Adamek and others, 1988) described as follows.

North Panama Deformed Belt (NPDB, PA-12)

The NPDB comprises an arcuate zone of distributed folding and thrust faulting that extends eastward from Costa Rica to the Gulf of Uraba, Colombia (Silver and others, 1990, 1995). The NPDB is drawn as a wide belt of deformation that contains thrusts and folds too numerous to show. The NPDB has been the source of several large earthquakes during the historical period (Mendoza and Nishenko, 1989; Camacho and Viquez, 1993; Boschini and Montero, 1994), including the largest recorded earthquake in southern Central America. That event, located offshore northeast of Colon, occurred in 1882 with an estimated magnitude of 7.5-7.7. The earthquake produced widespread surface effects including liquefaction in northern Panama and a tsunami that drowned more than 60 persons in the Province of San Blas (Mendoza and Nishenko, 1989).

Cocos Ridge Collision and Subduction Zone

On the Cocos Plate, west of the Panama Fracture Zone (PA-04), a thickened area of oceanic crust (Cocos Ridge) is subducting beneath the southwest margin of the Caribbean Plate and the Panama Block. The rate of convergence is between 70 and 95 mm/year. The Cocos Ridge is buoyant and thicker than normal oceanic lithosphere, so the angle of subduction is shallow. Shortening and uplift of the overlying plates characterize the associated deformation. Some fraction of the thrust deformation is expressed as uplifted former coastlines and intertidal shore platforms, such as along the Osa and Nicoya Peninsulas on the Pacific margin and along the Limon coast on the Caribbean margin (Gardner and others, 1992; Plafker and Ward, 1992).

The subduction zone is defined by seismicity only to a depth of about 50-km beneath southern Costa Rica (Protti and others, 1995). The subduction interface has ruptured twice during large (M 7.5) earthquakes this century (1941 and 1983) in the southern Costa Rica sector (Adamek and others, 1987, 1988, Tajima and Kikuchi, 1995). On the Caribbean margin, the overthrusting of the Panama Block onto the Caribbean Plate reflects a lateral transmission of stress through the arc from the Cocos Ridge collision zone (Plafker and Ward, 1992). The depth distribution of seismicity is poorly constrained, but no events deeper than about 50 km have been reported.

Longitudinal Fault Zone (PA-01)

In western Panama and southern Costa Rica, an elongate, arc-parallel fore-arc basin contains several thousand meters of sediment that have been eroded from the volcanic arc during the past 60 Ma (Escalante, 1990). Numerous, arc-parallel (NW-trending) thrust faults and folds are known to offset the basin sediment, particularly in Costa Rica (see for example, Mora, 1979; Kolarsky and others, 1995). Significant shortening has been accommodated during the subduction of the Cocos Ridge, since Pliocene time.

The principal fault zone in this area is the Longitudinal fault zone, an oblique-reverse, structure that strikes east-southeast, parallel to the volcanic arc across southern Costa Rica (CR-48; see Montero and others, 1998) and the Chiriqui lowlands (PA-01) of western Panama (Montero, 1994). The Longitudinal fault zone juxtaposes early Tertiary (50 Ma) and late Quaternary (<1 Ma) rock and sedimentary units across a thrust contact in the Costa Rica-Panama region.

Panama Fracture Zone (PFZ, PA-04)

The Panama Fracture Zone (PFZ) separates the Cocos and Nazca Plates south of the Burica Peninsula, at the Pacific Coast frontier of Panama and Costa Rica. The PFZ accommodates major right-lateral strike-slip motion at an estimated rate of 50-70 mm/yr (DeMets and others, 1990; Kellogg and Vega, 1995). Two subparallel fracture

zones—the Balboa and Coiba—splay off eastward from the PFZ and accommodate some of the right-lateral strike-slip motion (Lonsdale and Klitgord, 1978; Heil, 1988).

The PFZ intersects the Panama-Costa Rica mainland in the region of Burica Peninsula. The surface expression of the Cocos-Nazca plate boundary, landward of the PFZ, consists of narrow, dextral strike-slip fault zones (Medial fault zone, PA-03; Canoas fault zone, CR-49) that show evidence of rapid horizontal movement during the last 10,000 years (Corrigan and others, 1990; Kolarsky and others, 1995; Cowan and others, 1997). Rapid uplift of the Madre Vieja anticline (PA-03) may be associated with the northeastward expression of this dextral motion.

South Panama Deformed Belt (SPDB, PA-09)

East of the Panama Fracture Zone, the Nazca Plate is moving east-northeast, oblique to the southern margin of Panama, at a rate of about 35 mm/year. The PFZ and adjacent splays (Balboa and Coiba fracture zones) are being subducted obliquely beneath the southwest margin of Panama, and the associated deformation is accommodated by thrust faulting along the southern continental margin (MacKay and Moore, 1990; Moore and Sender, 1995). The South Panama Deformed Belt (SPDB) is drawn as a wide belt of deformation that contains thrusts and folds too numerous to show. Numerous earthquakes of moderate magnitude (5.5-6.0) have been recorded in the SPDB.

Azuero-Sona Fault Zone (PA-11) and South Panama Fault Zone (PA-21)

Although the South Panama Deformed Belt (PA-09) accommodates shortening between the Nazca Plate and Panama's southern continental margin, several large strike-slip faults take up the shear along the margin and within the isthmus. The main structures include: 1) the Azuero-Sona fault zone (PA-11), which strikes northwest/southeast across the Azuero and Sona Peninsulas; and 2) the South Panama fault zone (PA-21), a left-lateral structure located offshore that extends eastward from the Azuero-Sona fault zone to the Colombian accretionary complex (PA-22) and associated Colombian (South American) subduction zone. The South Panama fault zone probably ruptured in 1904 and 1913, and another large (M>7) event occurred near the junction of the South Panama fault zone and the Colombian subduction zone in 1925.

PREPARATION OF MAP AND DATABASE

This compilation shows evidence for activity on Quaternary faults and folds in Panama and regions offshore of Panama. The data were compiled during 1996-98 from the available published literature (through 1998), recent geological investigations, and from interpretation of aerial photographs by Hugh Cowan. Michael Machette edited most of the text and map data and provided guidance for the project under the International Lithosphere Program's Task Group II-2 "Major Active Faults and Folds of the World," for which he is the Co-chairman (Western Hemisphere). The surface traces of the Quaternary faults and folds were compiled on topographic base maps at a scale of 1:200,000 by Hugh Cowan. Offshore traces are based primarily on marine geophysical studies and bathymetric maps; these traces are inherently less well defined and located, and should be considered approximate.

Richard Dart used GIS (Geographic Information System) technology to produce the fault and fold maps. The traces of Quaternary faults and fold were digitized, attributed for age, sense of slip, and line type (continuous, discontinuous, and concealed or inferred), and reprojected using a Mercator projection. The maps were prepared with ARC/INFO version 7.1.2 running under Solaris version 2.5.1 on a Unix workstation. The GIS data is scale independent but should not be used at scales greater (more detailed) than 1:200,000. Data for the fault endpoints, length, and average strike were generated from the ARC/INFO files.

The base-map information was taken from the Digital Chart of the World, which was created for use with ARC/INFO (copyright 1993 by the Environmental Systems Research Institute, Inc.). The Digital Chart of the World was compiled at a scale of 1:1,000,000, but is reasonably detailed at the printed scale of the map (1:750,000). It was originally developed for the United States Defense Mapping Agency (DMA) and is primarily derived from the DMA Operational Navigation Chart (ONC) Series.

MAP

The map of Quaternary faults and folds of Panama was compiled on and digitized from base maps at 1:200,000 scale (50-minutes of latitude by 1.5° of longitude). This scale allows output as a single-country map (1:500,000 to 1:750,000 scale) or provincial and regional maps (1:200,000 to 1:500,000 scale) while retaining all significant digital information. In addition to fault location and style, the map shows time of most recent movement and estimates of slip rate (as a proxy for fault activity). Although as many as five categories of Quaternary faults can be depicted on the Western Hemisphere maps, only three categories were used in Panama:

Historic (generally <200 years),

Holocene and latest Pleistocene (<15,000 years or <15 ka),

Quaternary (<1,600,000 years or <1.6 Ma).

Categories for differentiating late Quaternary (<130 ka) and late and middle Quaternary (<750 ka) ruptures were not used owing to the general lack of stratigraphic and chronological control needed to make these age differentiations. Nevertheless, this categorical time scheme allows some flexibility in reporting between countries owing to the differing levels of investigation and abilities to date prehistoric faulting.

Three ranges of slip rates depicted by differing lines are shown on the map in order to differentiate known rates of fault activity:

>5 mm/yr—Plate-boundary faults and subduction zones,
1-5 mm/yr—Lesser strike-slip and major extensional faults,
<1 mm/yr—Most extensional and intraplate faults.

Most faults in Panama with "unknown slip rates" are drawn with the <1-mm/yr line thickness.

DATABASE

The purpose of the database is to provide large quantities of fault data that can be readily accessed using a variety of search parameters. For this database, we anticipate that the user would want search-and-retrieve capabilities from a personal computer. The user may want to sort the data by such parameters as fault name, time of most recent movement (one of three categories), slip rate (one of three categories), sense of movement, or by multiple parameters.

The process of data compilation starts with data acquisition and synthesis. In the case of faults, the compiler must determine if the structure is a simple one, or if it qualifies as having sections (increasing complexity of geometry or fault history). Then using the appropriate form, the compiler tabulates information on the fault's parameters. The forms were built in Microsoft Word for the Macintosh.

After this report is released, we will incorporate suggested changes and additions; then import the data to the computer database. Each of the fields is a potential search object. The use of a computer database program allows us to custom format the reporting of data and to collapse unused fields or notes. The basic fields are restricted to 256 characters, but we use the note option for more explanatory information (shown under comments in this report).

The fault and fold data will be released in several forms. This open-file report constitutes a traditional hard-copy catalog (database and map) for Panama. The Panama data will eventually be part of a larger relational computer database for the Western Hemisphere that should be available on the World Wide Web (WWW). This interactive WWW product allows the user to browse, sort, and print the data. However, we do not anticipate allowing the database to be altered using only the run-time WWW version of the database program.

DEFINITION OF DATABASE TERMS

The following terms (in Spanish and English) provide data for specialized fields, most of which will be searchable when the computer database is released. In addition Specialized fields to the searchable fields, more detailed information is provided in the "Comments" section that follows some fields. If a field is empty or has been deleted, no pertinent information was found in the published literature. The following description provides definitions of fields (in alphabetic order) and indicates where various information, if known, can be found. Citations of references are in a traditional (USGS) format, although foreign language citations are as provided by the compilers.

Average dip General down-dip direction of the structure where known.

Average strike The length-weighted average strike of the trace of the structure is reported in the northwest and northeast quadrants of the compass (*i.e.*, N. 30° W., versus S. 30° E.). The error limits that follow the strike are standard deviations for all vectors contained with the trace of that particular fault or collection of faults. These values are included only to provide a general impression of the sinuosity or variability in strike of the mapped structure. Some fault zones include a number of faults with a wide variety of strikes, and thus the error limits are not meaningful values.

Compiler, affiliation and date of compilation The name and affiliation of the person(s) primarily responsible for compilation or update of data presented for the structure. Also shown is the date when data were compiled for this project (*e.g.*, January 1997).

Fault geometry This includes geographic information pertinent to the fault or fault being described. The data include length, average strike, average dip, and sense of movement.

Geomorphic expression General description of the structure's geomorphic expression including information on the the presence or absence of fault scarps, offset streams, monoclines, shutter ridges, associated landslides, etc.

Historical surface faulting When the timing of most recent movement is historic, then this field(s) describes evidence for surface faulting associated with historical earthquakes. Also included is seismological information for the historical earthquake.

Length This field specifies the end-to-end length of the Quaternary-age fault as measured from the most distal ends of the trace. The ends of overlapping or echelon traces are projected to a line defined by the average strike and the length is then determined from those projected end points. Also shown (in parentheses) is the cumulative length of all surface traces included in the fault, fault zone, or collection of faults.

Name (**Fault name** or **Section name**) The earliest referenced name for a structure, fault segment or fault section (where appropriate) generally is given preference, except in cases where a more commonly accepted name is widely used in the recent literature. "Comments" also contains other names and references in which they are used, the geographic limits of the structure, north to south or west to east, as shown in this compilation; various geographic limits that are different in other studies are also included. Minor changes in original name may have been made for reasons of clarity or consistency (such as segment to section) where appropriate. We have found no faults in Panama that justify using the term “segment”, owing to a lack of precise timing information.

Number

Structure number The structure (fault or fold) is assigned a number that is preceded by a two character abbreviation (PA, Panama; CR, Costa Rica; etc.) that is unique to each of the countries in the Western Hemisphere. References to the same structure shown in other compilations, such as CR-50 and PA-12 are included in "Comments".

Section number An alpha character is assigned to the northernmost or westernmost section of a fault (*e.g.*, fault CR-50 has two sections: CR-50A and CR-50B).

Number of sections (only used for faults with sections) Numeric value for number of sections (*e.g.*, 4) defined in studies that do not meet the minimum requirements for segments established for this compilation. "Comments" include reference in which sections are discussed; if the term "segment" is used in the literature, an explanation of why "section" is used in the database is provided.

Recurrence interval Time interval in yr (based on historic data, calendric or calibrated radiocarbon dates), in ^{14}C yr (based on uncalibrated radiocarbon dates), or in k.y. (thousand years, based on less precise dating methods, stratigraphy, or geomorphology). Unknown is shown if there is no published recurrence interval value. Also included is the time interval (in parenthesis) for which this recurrence interval is valid. (*e.g.*, 10-130 k.y.) Alternative published recurrence intervals, starting with that which applies to the most recent time interval, are included in "Comments. "

References A bibliographic citation (USGS style) is included for all references pertinent to each structure.

Section A geographic, geometric, structural portion of a fault or collection of faults that appear(s) to have a different character than adjacent portions of the fault (or fold). Typically, not enough information exists to show that this portion of the fault acts independently of adjacent portions, and thus does not qualify as a bona fide "segment" of a fault in a paleoseismic sense. There are no known faults with proven segments in Panama, although several faults are described as having sections. Further research is needed to document additional faults with sections or those with sections that may in fact be segments.

Section name (see **Name**)

Section number (see **Number**)

Sense of movement Includes thrust (T), less than 45° dip; reverse (R), greater than 45° dip; right-lateral strike slip (D, dextral); left-lateral strike slip (S, sinistral); or normal (N). For oblique slip, the principle sense of movement is followed by secondary sense (*i.e.*, DT). Ratios of the slip components are included, where known, in order to better characterize sense of movement (*i.e.*, DT 3:1).

Slip rate The primary field shows an actual value or one of several slip-rate categories used for the map part of this compilation: <0.2 mm/yr, 0.2-1 mm/yr, 1-5 mm/yr, or >5 mm/yr. "Unknown" precedes the suspected slip-rate or slip rate category if no published slip rate is known. "Comments" may include a synopsis of published slip rates and pertinent documentation. Generally speaking, there are two types of slip rates. The first type is termed a "Geologic slip rate" and is derived from the age and amount of offset of surficial geologic deposits. These rates are not precise, but allow one to place broad limits on possible slip rates, and hence characterize the fault in one of the above-mentioned categories. The second type of slip rate is termed a "Paleoseismic slip rate" and is derived from times of faulting events and amounts of offset of geologic datums or piercing point. This type of slip rate is more precise, but are rare owing to the extensive amount of work involved (*i.e.*, detailed paleoseismologic studies involving trenching and numeric dating).

Fault/fold name (see **Name)**

Fault/fold number (see **Number)**

Synopsis and geologic setting This field provides a short summary that describes the level of study, provides a snapshot of the scope of data that follows in the database and provides a generalized perspective of the fault in terms of its regional geologic setting, amount of total offset, and general age of offset strata

Timing of most recent event (faulting or folding event) The primary field shows one of the two prehistoric time categories: latest Quaternary (Holocene and latest Pleistocene, <15 ka) or Quaternary (<1.6 Ma). This field may document historic surface faulting, although details of the earthquake related to the faulting will follow.

Type of studies: This field briefly summarizes the types of studies conducted on the fault.

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PA-01, LONGITUDINAL FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PA-01

NOMBRE DE LA FALLA/FAULT NAME: Longitudinal (zone)
Comentarios/Comments: In Costa Rica, the zone is referred to as the Rio Esquinas fault (Dengo, 1962), Esquinas fault (Berrange, 1989), Ballena-Celmira fault zone (Mann and Corrigan, 1990) and the Longitudinal fault system (CR-48) (Montero, 1994). In Panama, the preferred usage has been Falla Chiriqui (Direccion General Recursos Minerales de Panamá, 1976) or Ballena-Celmira fault zone (Mann and Corrigan, 1990); however, the term Longitudinal fault zone is preferred herein since the structure extends across two countries (thus superceding local names).

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: A WNW-ESE trending fault zone that has been inferred to extend from Azuero Peninsula, Panama in the southeast, to central Costa Rica in the west (e.g. Mann and Corrigan, 1990). West of the Panama-Costa Rica border this part of the fault is mapped as the Longitudinal fault (CR-48); it separates uplifted, thrust-bounded forearc basin sediments of early Tertiary to Quaternary age to the NE, from uplifted outerarc sediments and oceanic basement of Cretaceous to Quaternary age on the southwest. The sense of strike-slip motion on this zone is controversial. The fault zone may accommodate both arc-parallel strike-slip, and arc-normal shortening in this region of Costa Rica, since it lies arcward of the converging Cocos Ridge. Farther east in Panama, the Longitudinal fault is probably dominantly strike-slip. Recent unpublished work by Cowan in western Panama suggests that the fault may be traced eastward from the Panama-Costa Rica border to the region of David, where the trace of the fault appears to die out. Strain may be transferred to other faults located along the coast and offshore farther southeast (see PA-05a). The sense of movement is inferred to be left-lateral strike-slip in Panama based on regional kinematic modeling and limited seismicity data (e.g. Mann and Corrigan, 1990), but the Longitudinal (CR-48) and other associated faults in Costa Rica have been variously interpreted as being left-lateral strike-slip (e.g. Mann and Corrigan, 1990), dominantly SW-verging thrusts (Montero, 1994), and right-lateral strike-slip (Berrange, 1989; Kolarsky and others, 1995). The slip rate of the Longitudinal fault zone may be <1 mm/yr in Panama, and there is no evidence of Holocene movement east of the intersection with the Canoas fault zone (CR-49). West of this intersection (in Costa Rica), there is clear evidence of late Holocene rupture from radiocarbon dating of charcoal (Beta-117478, 2,580±60 yr B.P.) and pottery that are offset by the fault zone in a trench at Rio Abrojo (Cowan and others, 1997).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996.

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Regional mapping, satellite and air-photo interpretation, a few localized studies, including recent mapping in western Panama (H. Cowan, unpubl. data, in prep.).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 64.5 km (cumulative 69.4 km)
Comentarios/Comments: Length in Panama only. Continues westward into Costa Rica as the Longitudinal fault (CR-48) (see Costa Rican database; Montero and others, 1998).
RUMBO PROMEDIO/AVERAGE STRIKE: N. 78° W. ± 16°
Comentarios/Comments: Continues westward into Costa Rica as the Longitudinal fault (CR-48) (see Costa Rican database; Montero and others, 1998).

NUMERO DE SECCIONES/NUMBER OF SECTIONS: (2)
Comentarios/Comments: Two sections (A, B) on Panamanian territory, with a continuation into Costa Rica as the Longitudinal fault (CR-48, see Costa Rican database). Sections are defined solely on the basis of differences in the strike of cuestas that define the approximate location of the fault in Panama.

PA-01A, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-01A

NOMBRE DE LA SECCION/SECTION NAME: Unnamed (section of Longitudinal fault zone)

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 39.6 km (cumulative 40.8 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 77° W. ± 20°
INCLINACION PROMEDIO/AVERAGE DIP: Unknown
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Probably left-lateral strike-slip, with a component of extension; throw down to the southeast.
Comentarios/Comments: See comments under Synopsis (above).

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Defined by relatively linear hills comprising uplifted inliers of Tertiary sediment, including prominent ridges of Eocene Limestone above the hanging-wall in the border region with Costa Rica. The transition from the Longitudinal fault in Costa Rica (CR-48) and this section (to the southeast) is somewhat arbitrary, but the Tertiary rocks that form linear outcrops along the supposed line of this fault section have a more north-trending strike. The transition from section a to section b is similarly based on a change in the strike of bedding and associated topography. Section b terminates in an area of upright open folds NE of the town of David. The precise location of the fault is weakly defined. There are no documented exposures of the fault, nor observations of Holocene or late Quaternary displacement in Panama.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown.

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)

PA-01B, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-01B

NOMBRE DE LA SECCION/SECTION NAME: Unnamed (section of Longitudinal fault zone)

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 28.4 km (cumulative 28.6 km)
Comentarios/Comments: Continues westward into Costa Rica as the Longitudinal fault (CR-48) (see Costa Rican database; Montero and others, 1998).
RUMBO PROMEDIO/AVERAGE STRIKE: N. 74° W. ± 9°
INCLINACION PROMEDIO/AVERAGE DIP: Unknown
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT Probably left-lateral strike-slip, with a component of extension and throw down to the southeast. The dip direction has not been observed.
Comentarios/Comments: See comments under synopsis (above).

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Defined by relatively linear hills comprising uplifted inliers of Tertiary sediment. Eocene limestone is the oldest unit exposed, but in this section it is only occasionally exposed as small outcrops that rarely project above the vegetation. The limestone generally dips more steeply (50-65° N) than other units inferred to be farther from the fault (20-45° N). The transition from section a to section b is similarly based on a change in the strike of bedding and associated topography. Section b terminates in an area of upright open folds NE of the town of David. The precise location of the fault is weakly defined. There are no documented exposures of the fault. The fault does not offset river terraces of Holocene or late Quaternary age in Panama.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)

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PA-02, MADRE VIEJA ANTICLINE

NUMERO DE PLIEGUE/FOLD NUMBER PA-02

NOMBRE DEL PLIEGUE/FOLD NAME: Madre Vieja Anticline

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Forms a NW-SE trending (elongate) dome with about 10 m of relief of Holocene fluvial surface. Fold is located southeast of the southern termination of the surface trace of the Canoas fault (CR-49), 2 km west of the town of Esperanza, Panama. The dome was drilled (Corotu 1-B, Corotu 2) for hydrocarbons in the 1950s. The holes penetrated several hundred meters of Pleistocene sediment, but little more is known about the subsurface structure (Kolarsky and others, 1995).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1998.

TIPO DE ESTUDIOS/TYPE OF STUDIES: Field mapping (Hugh Cowan, 1988, unpubl. commercial reports).

GEOMETRIA DEL PLIEGUE/FOLD GEOMETRY
LONGITUD DEL EJE/LENGTH OF FOLD AXIS: End-to-end 10.1 km (cumulative 10.2 km)
RUMBO PROMEDIO DEL EJE/AVERAGE STRIKE OF FOLD AXIS: N. 38° W. ±8°
INCLINACION DE LOS FLANCOS/DIP OF LIMBS: <2°
INCLINACION DEL EJE/PLUNGE: North and south

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Doming of Holocene/Pleistocene sediment. Also, gentle warps Holocene terraces of Rio Chiriqui Viejo, west of Esperanza. Former channel of Rio Chiriqui Viejo crosses the dome axis as a series of tight meanders that are almost abandoned now. Drainage canals that cross the dome were engineered and constructed in the 1920s-1930s; now all are dry.

TASA DE LEVANTAMIENTO/UPLIFT RATE: Probably >1 mm/yr
Comentarios/Comments. Based on 10 m of surface relief that is believed to have occured in the Holocene (past 10,000 yrs).

EDAD DEL MOVIMIENTO MAS RECIENTE/TIME OF MOST RECENT MOVEMENT: Possibly Historic (1934), certainly Holocene or post glacial (<15 k.y.)
Comentarios/Comments. Young movement indicated by deformation of Holocene and Pleistocene sediment, and modification of young drainages.

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown

DEFORMACIONES HISTORICAS/HISTORICAL UPLIFT (SOLO SI CORRESPONDE): Possibly 1934
Comentarios/Comments. Drainage canals that cross the dome were engineered and constructed in the 1920s-1930s; now all are dry. Certainly movement in <15 k.y. for the anticline.

REFERENCIAS/REFERENCES

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PA-03, MEDIAL FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PA-03 (same as CR-47)
Comentarios/Comments: Fault extends across Panama/Costa Rica boundaries.

NOMBRE DE LA FALLA/FAULT NAME: Medial (zone)
Comentarios/Comments: Named by orrigan and others (1990) who conducted a detailed investigation.

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Fault zone is well defined in its general characteristics. It comes onshore on the Burica Peninsula of Costa Rica and Panama as the continental expression of the Panama fracture zone (PA-04), and extends north into Panama and northwest into Costa Rica. It is a high-angle, right-lateral strike-slip fault displaying 800-2,500 m of up-to-west vertical displacement. Offshore, the Panama fracture zone (PA-040 accommodates deflection of the Middle America Trench along the eastern edge of the subducted Cocos Ridge (Corrigan and others, 1990). Onshore, the Medial fault zone offsets Pleistocene and Pliocene rocks of the Charco Azul Formation and Late Cretaceous basement rocks of the Upper Nicoya Complex. Fault trace was transferred by inspection from the small-scale map of Corrigan and others (1990). Northern portion of the fault is based on photogeologic interpretation by Montero (unpubl. data). The northwestern limit of the fault is the headwaters of the Río Corotu, a small river located on the Burica Peninsula. To the south, the fault splays into several strands as it becomes the Panama fracture zone offshore, so its southern border it is not determined.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Walter Montero-Pohly, Central American School of Geology, University of Costa Rica; November 11, 1994.

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Geologic mapping and photogeologic interpretation

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 35.8 km (cumulative 89.2 km)
Comentarios/Comments: Continues south as the Panama fracture zone, and probably merges to the northwest (in Costa Rica) with the Golfito fault (CR-45).
RUMBO PROMEDIO/AVERAGE STRIKE: N. 19° W. ± 23°
INCLINACION PROMEDIO/AVERAGE DIP: Unknown
Comentarios/Comments Poorly exposed fault zone without reported dip or trend measurements.
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Dextral thrust
Comentarios/Comments: Magnitude of dextral-slip component is undetermined. Thrust component was defined by a left-stepping segment of the Medial fault zone near its northwest termination.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Fault forms a prominent 15-km-long and 600- to 1800-m-wide linear valley that strikes northward from the southwest coast of the Burica Peninsula to the headwaters of the Río Corotu. Near the headwaters of this river, the valley assumes a more northwestward trend and becomes poorly defined topographically (Corrigan and others, 1990).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown
Comentarios/Comments: More detailed studies are required to define individual paleoevents and thus recurrence intervals.

TASA DE MOVIMIENTO/SLIP RATE: Unknown, probably >10 mm/yr
Comentarios/Comments: High rate inferred because the fault zone must be a major element of the Cocos-Nazca plate boundary in this area. Plate motion predicts >50 mm/yr total across the zone, but considerably less on individual faults.

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Holocene or post glacial (<15 k.y.)
Comentarios/Comments: The fault offsets Pleistocene and Pliocene rocks of the Charco Azul Formation, but more detailed studies are required to define individual paleoevents or the timing of the most recent movement. Movement is likely Holocene or post glacial (<15 k.y.) owing to the high slip rate ascribed to the fault.

REFERENCIAS/REFERENCES

Corrigan, J., Mann, P., and Ingle, J.C., 1990, Forearc response to subduction of the Cocos Ridge, Panama-Costa Rica: Geological Society of America Bulletin, v. 102, p. 628-652.

PA-04, PANAMA FRACTURE ZONE (PFZ)

NUMERO DE LA FALLA/FAULT NUMBER: PA-04

NOMBRE DE LA FALLA/FAULT NAME: Panama fracture (zone)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: The Panama fracture zone (PFZ) is a north-south-trending, right-lateral strike-slip oceanic transform that separates the Cocos and Nazca plates south of the Burica Peninsula of Panama/Costa Rica. The PFZ and associated splay faults (see PA-08, Balboa fracture zone) intersect the accretionary prism thrust-fault complex along the southern continental margin of Panama (see PA-09, South Panama Deformed Belt). The PFZ is mapped as a rather wide fracture zone offshore (for example, poor definition), but elements of the PFZ extend farther north onshore (Burica Peninsula) in Panama and Costa Rica as the Medial fault zone (PA-03, CR-47) and the Canoas Fault (CR-49).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismological studies, sea-floor magnetic anomaly studies, and GPS surveys have defined the kinematics of the fault zone. Seismic-reflection profiling and bathymetric mapping have defined the structure.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end >261 km; continues beyond map area (cumulative unknown)
Comentarios/Comments: Fracture zone is comprised of many subparallel faults across which a high rate of lateral slip is distributed.
RUMBO PROMEDIO/AVERAGE STRIKE: N. 0° W. ± 4°, continues beyond map area
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Right-lateral strike-slip

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Prominent ridge shown on bathymetric maps.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown
Comentarios/Comments: Although the recurrence is unknown, the PFZ is one of the most seismically active structures in Panama.

TASA DE MOVIMIENTO/SLIP RATE: Probably >50 mm/yr.
Comentarios/Comments: Relative plate motion (Cocos-Nazca) indicates 52 mm/yr offshore, south of the Burica Peninsula.

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Historic (1934)
Comentarios/Comments: Although the Puerto Armuelles earthquake is on this zone, the entire structure is shown as Holocene or post glacial (<15 k.y.) owing to the high slip rate ascribed to the fault. Inferred to be the (general) source of 1934 Puerto Armuelles earthquake. Mainshock was reputedly offshore in the Gulf of Chiriqui, but wide pattern of aftershocks (radius at least 50 km) makes it difficult to discriminate among several possible fault sources (see also PA-03, CR-49).

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown

NOMBRE DEL TERREMOTO/NAME OF EARTHQUAKE: Puerto Armuelles (southwestern Panama)

COMENTARIOS/COMMENTS: See comments under PA-03 and CR-49.

FECHA/DATE: 0136 hrs UT, July 18, 1934.

MAGNITUD O INTENSIDAD/MAGNITUDE OR INTENSITY: Ms 7.6 and Modified Mercalli Intensity IX at Puerto Armuelles.
Comentarios/Comments: An aftershock of Ms 6.75 at 1039 hrs UT, July 21, 1934, produced similar levels of shaking and more damage than the mainshock at Puerto Armuelles. Review of felt effects is from unpublished data.

MOMENT MAGNITUDE: Unknown

LONGITUD DE RUPTURA/LENGTH OF SURFACE RUPTURE: Unknown

DESPLAZAMIENTO MAXIMO/MAXIMUM SLIP AT SURFACE: Unknown

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Right-lateral strike-slip on NNW-trending fault plane constrained by first-motion data. Reasonable azimuthal distribution of stations for mechanism (see Camacho, 1991).

REFERENCIAS/REFERENCES

Seismological Studies:

Adamek, S., Frolich, C., and Pennington, W., 1988, Seismicity of the Caribbean-Nazca boundary: constraints on microplate tectonics of the Panama region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Camacho, E., 1991, The Puerto Armuelles Earthquake (southwestern Panama) of July 18, 1934: Revista Geologica de America Central, v. 13, p. 1-13.

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Lonsdale, P., and K.D., 1978, Klitgord, Structure and tectonic history of the eastern Panama basin: Geological Society of America Bulletin, v. 89, p. 981-999.

Lowrie, A., Aitken, T., Grim, P., and McRaney, R., 1979, Fossil spreading center and faults within the Panama Fracture Zone: Marine Geophysical Research, v. 4, p. 153-166.

MacKay, M.E., and G.F. Moore, 1990, Variation in deformation of the South Panama accretionary prism—Response to oblique subduction and trench sediment response: Tectonics, v. 9, p. 683-698.

Moore, G.F., and Sender, K.L., 1995, Fracture zone collision along the South Panama margin, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 201-212.

Geological and Geodetic Studies:

Corrigan, J., 1986, Geology of the Burica Peninsula, Panama-Costa Rica—Neotectonic implications for the southern Middle America convergent margin: Austin, University of Texas, unpubl. M.S. thesis, 152 pp.

Corrigan, J., Mann, P., and Ingle, J.C. 1990, Forearc response to subduction of the Cocos Ridge, Panama-Costa Rica: Geological Society of America Bulletin, v. 102, p. 628-652.

Kellogg, J.N., and three others, 1995, Tectonic development of Panama, Costa Rica and the Colombian Andes—Constraints from global positioning system geodetic studies and gravity, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean Plate boundary in Southern Central America: Geological Society of America Special Paper 295, p. 75-90.

PA-05, UNNAMED FAULTS

NUMERO DE LA FALLA/FAULT NUMBER: PA-05

NOMBRE DE LA FALLA/FAULT NAME: Unnamed series of faults.

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: This WNW-ESE trending series of normal or oblique-normal faults encompass a region of extension or transtension in the northern Gulf of Chiriqui and the Cordillera of eastern Chiriqui Province. The offshore faults have been known for several years from interpreted industry seismic-reflection profiles (see references below), but the on-shore elements of this zone have been reported only in unpublished mineral-exploration reports and from new neotectonic studies.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Offshore multichannel seismic-reflection survey (published first by Okaya and Ben-Avraham, 1987; reprocessed and reinterpreted by Kolarsky and Mann, 1995). Onshore, reconnaissance mapping for minerals exploration (Direccion General Recursos Minerales de Panamá, 1976; Swedish Geological International 1991), and recent neotectonic field mapping (Cowan unpubl. data, 1996).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 69.1 km (cumulative 136.1 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 66° W. ± 4°

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 3
Comentarios/Comments: PA-05A and PA-05B are separate faults; fault PA-05C is a group of three closely spaced, parallel faults.

PA-05A, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-05A

NOMBRE DE LA SECCION/SECTION NAME: Unnamed

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 26.7 km (cumulative 26.7 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 71° W. ± 3°
INCLINACION PROMEDIO/AVERAGE DIP: Northeast, 72°
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Dip slip (normal)
Comentarios/Comments: Slickensides indicate predominantly dip-slip (normal) displacement. The fault may have a left(?)-lateral component at depth.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Forms a linear channel (Estero Boca Chica) between Isla Boca Brava and the mainland, and topographically low saddles where the fault crosses peninsulas southeast of Boca Chica.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, but probably Holocene or post glacial (<15 k.y.)
Comentarios/Comments: Probably Holocene based on lack of weathering or annealing of associated fault gouge.

PA-05B, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-05B

NOMBRE DE LA SECCION/SECTION NAME: Unnamed

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 59.9 km (cumulative 59.9 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 64° W. ± 4°
INCLINACION PROMEDIO/AVERAGE DIP: Northeast, sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Dip-slip normal, probably with a component of left-lateral strike-slip.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Offshore, no bathymetric expression

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)

PA-05C, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-05C

NOMBRE DE LA SECCION/SECTION NAME: Unnamed
Comentarios/Comments: Includes three unnamed faults.

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 22.1 km (cumulative 49.4 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 65° W. ± 3°
INCLINACION PROMEDIO/AVERAGE DIP: Southwest, sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Offsets and geomorphology indicate dip-slip (normal) displacement. The faults may have a left-lateral component at depth.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: 100-200 m wide steps in topography within the San Felix caldera, northeast of San Felix township.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)

REFERENCIAS/REFERENCES

Onshore:

Cowan, unpubl. data, 1996.

Direccion General Recursos Minerales de Panamá, 1976, Mapa Geologico Hoja 1 “Region Occidental, Bocas y Chiriqui”, Edicion 1: Panamá City, Republic of Panamá, escala 1:250,000.

Swedish Geological International, 1991, Geologia y ocurrencias de minerales en tres sectores de Panamá: Unpubl. report held at Direccion General Recursos Minerales de Panamá, Panamá City, Republic of Panamá.

Offshore:

Kolarsky, R.A., and Mann, P., 1995, Structure and neotectonics of an oblique-subduction margin, southwestern Panama, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean Plate boundary in Southern Central America: Geological Society of America Special Paper 295, p. 131-157.

Okaya, D.A., and Ben-Avraham, Z., 1987, Structure of the continental margin of southwestern Panama: Geological Society of America Bulletin, v. 99, p. 792-802.

PA-06, UNNAMED FAULTS

NUMERO DE LA FALLA/FAULT NUMBER: PA-06

NOMBRE DE LA FALLA/FAULT NAME: Unnamed faults
Comentarios/Comments: Includes three unnamed faults (PA-6A, 6B, 6C) at northeastern margin of Montuosa Basin, Gulf of Chiriqui.

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Three normal faults define the NE margin of a Neogene sedimentary basin (Montuosa Basin), 30 km northwest of Coiba Island in the Gulf of Chiriqui. The basin is an elongate 1,250 km^2, NE-trending structure that contains as much as 2,700 m of sediment of inferred Pliocene-Pleistocene age (Okaya and Ben-Avraham, 1987; Kolarsky and Mann, 1995).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismic stratigraphic study of multichannel reflection seismic lines.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 18.6 km (cumulative 40.3 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 2° W. ± 42°

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 3 (A, B, C)

PA-06A, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-06A

NOMBRE DE LA SECCION/SECTION NAME: Unnamed

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 11.3 km (cumulative 12.8 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 16° W. ± 30°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, down to the east.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: No bathymetric expression

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)

PA-06B, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-06B

NOMBRE DE LA SECCION/SECTION NAME: Unnamed

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 13.6 km (cumulative 14.3 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 50° W. ± 19°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, down to the southwest.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: No bathymetric expression

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)

PA-06C, UNNAMED SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-06C

NOMBRE DE LA SECCION/SECTION NAME: Unnamed

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 13.2 km (cumulative 13.2 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 33° E. ± 2°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, down to the northwest.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: No bathymetric expression

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)

REFERENCIAS/REFERENCES

Kolarsky, R., and P. Mann, 1995, Structure and neotectonics of an oblique subduction margin, southwestern Panama, *in* Mann, P. (ed.) Geological and Tectonic Development of the Caribbean plate Boundary in southern Central America: Geological Society of America Special Paper 295, 131-157.

Okaya, D.A., and Z. Ben-Avraham, 1987, Structure of the continental margin of southwestern Panama: Geological Society of America Bulletin, v. 99, p. 792-802.

PA-07, CENTRAL AND SOUTH COIBA FAULT ZONES

NUMERO DE LA FALLA/FAULT NUMBER: PA-07

NOMBRES DE LA FALLA/FAULT NAMES: Central (PA-07A) and South (PA-07B) Coiba fault zones

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Northwest trending, left-lateral strike-slip faults mapped across Coiba Island and correlated with sub-vertical faults recognized on adjacent offshore multichannel industry seismic-reflection lines (Texaco 4 and 3; Shell P-1502, P-1504) in the Gulf of Chiriqui. These faults have been interpreted as part of the broad zone of left-lateral faulting between the Caribbean and Nazca plates in western Panama (Kolarsky and Mann, 1995). To the east of Coiba Island, these faults curve to the northeast and merge with elements of the Cebaco Basin complex (see PA-10).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Field mapping and photo interpretation, Coiba Island, and seismic stratigraphic analysis of seismic surveys offshore.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 122.2 km (cumulative 223.7 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 63° W. ± 23°

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 2
Comentarios/Comments: Faults PA-07A and PA-07B are separate but associated faults; they are herein described as sections of the Coiba fault zone.

PA-07A, CENTRAL COIBA FAULT ZONE

NUMERO DE LA SECCION/SECTION NUMBER: PA-07A

NOMBRE DE LA SECCION/SECTION NAME: Central Coiba fault zone
Comentarios/Comments: Referred to as the Central Coiba fault zone (Kolarsky and Mann, 1995) and Fault "F3" (Okaya and Ben-Avraham, 1987).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 83.0 km (cumulative 85.2 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 64° W. ± 17°
INCLINACION PROMEDIO/AVERAGE DIP: Subvertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Probable left-lateral, oblique-normal slip.
Comentarios/Comments: Interpreted as an upward-splaying flower structure with basement down thrown to the north.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The Central Coiba fault zone divides Coiba Island into elevated northern and southern blocks that are separated by a linear, northwest-trending valley.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)
Comentarios/Comments: Fault movement influenced Pliocene-Pleistocene sedimentation and growth of the Montuosa Basin. The area is seismically active and the source region for several moderate-to-large (M 6-7) earthquakes.

PA-07B, SOUTH COIBA FAULT ZONE

NUMERO DE LA SECCION/SECTION NUMBER: PA-07B

NOMBRE DE LA SECCION/SECTION NAME: South Coiba fault zone
Comentarios/Comments: Referred to as the South Coiba fault zone (Kolarsky and Mann, 1995) and Fault "F2" (Okaya and Ben-Avraham, 1987).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 122.3 km (cumulative 138.4 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 62° W. ± 26°
INCLINACION PROMEDIO/AVERAGE DIP: Subvertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Probable left-lateral, oblique-normal slip.
Comentarios/Comments: Interpreted as an upward-splaying flower structure with basement down thrown to the north.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The South Coiba fault zone bounds the southern margin of Coiba Island but is best expressed on seismic lines (Texaco Line 4 and Shell Line P-1504).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown.

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)
Comentarios/Comments: Fault movement influenced Pliocene-Pleistocene sedimentation. The area is seismically active and the source region for several moderate-to-large (M 6-7) earthquakes.

REFERENCIAS/REFERENCES

Kolarsky, R.A., and Mann, P., 1995, Structure and neotectonics of an oblique-subduction margin, southwestern Panama, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean Plate boundary in Southern Central America: Geological Society of America Special Paper 295, p. 131-157.

Okaya, D.A., and Ben-Avraham, Z., 1987, Structure of the continental margin of southwestern Panama: Geological Society of America Bulletin, v. 99, p. 792-802.

PA-08, BALBOA FRACTURE ZONE (BFZ)

NUMERO DE LA FALLA/FAULT NUMBE: PA-08

NOMBRE DE LA FALLA/FAULT NAME: Balboa fracture zone

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: The Balboa fracture zone (BFZ) is a N-S-trending splay of the Panama fracture zone (PA-04) in the northern part of the Nazca Plate. The Balboa fracture zone is defined by a bathymetric ridge located 60 km east of the Panama fracture zone at a depth of 2,200 m that intersects the accretionary prism complex of the South Panama Deformed Belt (PA-09) approximately 60 km southwest of Coiba Island. The Balboa fracture zone is seismically active and accommodates some fraction of the right-lateral strike-slip motion across the Cocos-Nazca boundary.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismological studies (for example, Adamek and others, 1988) and marine geophysical surveys (for example, Lonsdale and Klitgord, 1978; Lowrie and others, 1979; Heil, 1988; MacKay and Moore, 1990; and Moore and Sender, 1995).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end >133.1 km, continues beyond map area
RUMBO PROMEDIO/AVERAGE STRIKE: N. 0° W. ± 4°, continues beyond map area
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Right-lateral strike-slip

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Bathymetric ridge with crest at 2,200 m depth.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Probably >5 mm/yr
Comentarios/Comments: Based on distribution of instrumentally recorded seismicity and consideration of total Cocos-Nazca relative plate motions (>50 mm/yr).

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Holocene or post glacial (<15 k.y.)
Comentarios/Comments: The entire structure is shown as <15 k.y. owing to the high slip rate ascribed to the fault. Camacho (1991) suggested a possible correlation between the 1934 Puerto Armuelles earthquake (see faults CR-49, PA-03, PA-04) and the Balboa fracture zone, based on the inferred mainshock location in the central Gulf of Chiriqui. However, recent interpretation of a multi-channel seismic-reflection profile oriented WNW-ESE across the northern Gulf of Chiriqui (Kolarsky and Mann, 1995) does not indicate significant structures in that region. This information, taken together with the spread of aftershock locations for the 1934 earthquake (Camacho, 1991), casts doubt on the Balboa fracture zone as a source for that earthquake. The entire structure is shown as Holocene or post glacial (<15 k.y.) owing to the high slip rate ascribed to the fault.

REFERENCIAS/REFERENCES

Seismological Studies:

Adamek, S., Frohlich, C., and Pennington, W.D., 1988, Seismicity of the Caribbean Nazca Boundary—Constraints on microplate tectonics of the Panama Region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Camacho, E., 1991, The Puerto Armuelles Earthquake (southwestern Panama) of July 18, 1934: Revista Geologica de America Central, v. 13, p. 1-13.

Marine Geophysical Studies:

Heil, D.J., 1988, Response of an accretionary prism to transform ridge collision south of Panama: Santa Cruz, University of California, unpubl. M.S. thesis, 88 pp.

Lonsdale, P., and K.D., 1978, Klitgord, Structure and tectonic history of the eastern Panama basin: Geological Society of America Bulletin, v. 89, p. 981-999.

Lowrie, A., Aitken, T., Grim, P., and McRaney, R., 1979, Fossil spreading center and faults within the Panama Fracture Zone: Marine Geophysical Research, v. 4, p. 153-166.

MacKay, M.E., and G.F. Moore, 1990, Variation in deformation of the South Panama accretionary prism—Response to oblique subduction and trench sediment response: Tectonics, v. 9, p. 683-698.

Moore, G.F., and Sender, K.L., 1995, Fracture zone collision along the South Panama margin, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 201-212.

PA-09, SOUTH PANAMA DEFORMED BELT (SPDB)

NUMERO DE LA FALLA/FAULT NUMBER: PA-09

NOMBRE DE LA FALLA/FAULT NAME: South Panama deformed belt

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: The South Panama deformed belt (SPDB) is a complex of landward-dipping thrust faults developed in an accretionary prism above the obliquely-subducted Nazca plate south of Panama (*e.g.* MacKay and Moore, 1990; Silver *and others*, 1990). The geometry of the thrust front is convex to the southwest, reflecting the effects of collision and subduction of the Panama, Balboa and Coiba fracture zones. The zone of observed thrusting extends 7-15 km landward of the thrust front, and the zone is broadly associated with historical seismicity.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismic reflection profiling and side-scan swath mapping, and regional seismological studies.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end >555.3 km (cumulative length unknown)
Comentarios/Comments: Cumulative length of faults and folds in belt unknown since boundaries of zone are only shown
RUMBO PROMEDIO/AVERAGE STRIKE: N. 74° W. ± 37°, continues beyond map area
INCLINACION PROMEDIO/AVERAGE DIP: <45 degrees to landward
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Thrust

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Prominent bathymetric expression 7-15 km landward of frontal thrust.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Probably 1-5 mm/yr
Comentarios/Comments: Based on distribution of instrumentally recorded seismicity and consideration of total Cocos-Nazca relative plate motions (>50 mm/yr).

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Probably Holocene or post glacial (<15 k.y.)
Comentarios/Comments: Probably Holocene based on association with seismicity and high slip rate assigned to the fault zone.

REFERENCIAS/REFERENCES

Adamek, S., Frolich, C., and Pennington, W., 1988, Seismicity of the Caribbean-Nazca boundary: constraints on microplate tectonics of the Panama region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Heil, D.J., 1988, Response of an accretionary prism to transform ridge collision south of Panama: Santa Cruz, University of California, unpubl. M.S. thesis, 88 pp.

MacKay, M.E., and G.F. Moore, 1990, Variation in deformation of the South Panama accretionary prism—Response to oblique subduction and trench sediment response: Tectonics, v. 9, p. 683-698.

Moore, G.F., and Sender, K.L., 1995, Fracture zone collision along the South Panama margin, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 201-212.

Silver, E., Reed, D.L., Tagudin, J.E., and Heil, D.J., 1990, Implications of the North and South Panama thrust belts for the origin of the Panama orocline: Tectonics, v. 9, p. 261-281.

PA-10, UNNAMED FAULT SYSTEM

NUMERO DE LA FALLA/FAULT NUMBER: PA-10

NOMBRE DE LA FALLA/FAULT NAME: Unnamed fault system
Comentarios/Comments: System of mostly unnamed faults of the Cebaco Basin Complex (Mann and Corrigan, 1990; Kolarsky and Mann, 1995).

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: The Cebaco Basin complex (CBC) consists of several northeast-striking, en echelon half grabens extending between the left-lateral strike-slip Central and South Coiba fault zones (PA-07a and b, respectively) and the Azuero-Sona fault zone (PA-11a). The CBC is interpreted as a pull-apart basin produced by slip transfer between the parallel strike-slip fault zones. The CBC contains as much as 2,600 m of sedimentary fill and is inferred to have formed since the Pliocene (Kolarsky and Mann, 1995; Kolarsky *and others*, 1995). The Cebaco Basin complex has been the locus of considerable seismic activity (see for example, Adamek and others, 1988).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismic stratigraphic analysis of multichannel seismic surveys combined with reconnaissance field mapping and associated biostratigraphic studies on Coiba and Cebaco islands and the Azuero Peninsula (Kolarsky and others, 1995).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end >102.6 km (cumulative >290.0 km), continues beyond map area
RUMBO PROMEDIO/AVERAGE STRIKE: N. 67° W. ± 16°, continues beyond map area

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 4
Comentarios/Comments: Four different faults are described as “sections” in the context of treating the Cebaco Basin Complex as an integrated structural unit.

PA-10A, RIO FLORES FAULT ZONE

NUMERO DE LA SECCION/SECTION NUMBER: PA-10A

NOMBRE DE LA SECCION/SECTION NAME: Rio Flores fault zone (Kolarsky and Mann, 1995).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 102.6 (cumulative 128.0 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 75° E. ± 9°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, downthrown to the northwest.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The projected onshore extension of the fault zone bounds the south margin of a flat-bottomed, east-trending valley, landward of the SW coast of Azuero Peninsula.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)
Comentarios/Comments: Quaternary based on seismic-stratigraphic data, but seismicity in the Cebaco Basin Complex probably is associated with movement on known faults.

PA-10B, UNNAMED FAULT

NUMERO DE LA SECCION/SECTION NUMBER: PA-10B

NOMBRE DE LA SECCION/SECTION NAME: Unnamed fault
Comentarios/Comments: Unnamed fault located offshore, north of Rio Flores fault and south of Cebaco Island. Strikes WSW and probably merges with South Coiba fault zone (PA-7B) (Kolarsky and Mann, 1995).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 56.3 km (cumulative 70.3 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 71° E. ± 11°
INCLINACION PROMEDIO/AVERAGE DIP: Master fault sub-vertical dip to northwest. Antithetic splays dip steeply southeast (Kolarsky and others, 1995: Fig.3).

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, downthrown to the northwest.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Unknown

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)
Comentarios/Comments: Quaternary based on seismic-stratigraphic data, but seismicity in the Cebaco Basin Complex probably is associated with movement on known faults.

PA-10C, UNNAMED FAULT

NUMERO DE LA SECCION/SECTION NUMBER: PA-10C

NOMBRE DE LA SECCION/SECTION NAME: Unnamed fault
Comentarios/Comments: Unnamed fault that bounds the northern coast of Cebaco Island and extends southwest, probably merging with the Central Coiba fault zone [PA-07A] (Kolarsky and Mann, 1995).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 40.4 km (cumulative 54.3 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 48° E. ± 13°
INCLINACION PROMEDIO/AVERAGE DIP: Master fault has sub-vertical dip to northwest. Antithetic fault splays dip steeply southeast (Kolarsky and Mann, 1995, fig.6).

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, downthrown to the northwest

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Unknown

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)
Comentarios/Comments: Quaternary based on seismic stratigraphic data, but seismicity in the Cebaco Basin Complex probably is associated with movements on known faults.

PA-10D, UNNAMED FAULT

NUMERO DE LA SECCION/SECTION NUMBER: PA-10D

NOMBRE DE LA SECCION/SECTION NAME: Unnamed fault
Comentarios/Comments: Unnamed fault that bounds the northwest margin of the Cebaco Basin Complex, extending from the SE corner of Sona Peninsula southwest towards the east coast of Coiba Island (Kolarsky and Mann, 1995).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 36.2 km (cumulative 37.4 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 59° E. ± 16°
INCLINACION PROMEDIO/AVERAGE DIP: Master fault has sub-vertical dip to southeast.

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal, downthrown to the southeast.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Unknown

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)
Comentarios/Comments: Quaternary based on seismic stratigraphic data, but seismicity in the Cebaco Basin Complex probably is associated with movements on known faults.

REFERENCIAS/REFERENCES

Adamek, S., Frolich, C., and Pennington, W., 1988, Seismicity of the Caribbean-Nazca boundary: constraints on microplate tectonics of the Panama region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Kolarsky, R.A., and Mann, P., 1995, Structure and neotectonics of an oblique-subduction margin, southwestern Panama, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean Plate boundary in Southern Central America: Geological Society of America Special Paper 295, p. 131-157.

Kolarsky, R., Mann, P., and Monechi, S., 1995, Stratigraphic development of southwestern Panama as determined from integration of marine seismic data and onshore geology, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean Plate boundary in Southern Central America: Geological Society of America Special Paper 295, p. 159-200.

Mann, P., and Corrigan, J., 1990, Model for late Neogene deformation in Panama: Geology 18, p. 558-562.

PA-11, AZUERO-SONA FAULT ZONE (ASFZ)

NUMERO DE LA FALLA/FAULT NUMBER: PA-11

NOMBRE DE LA FALLA/FAULT NAME: Azuero-Sona (zone)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Northwest-striking left-lateral fault zone that can be traced 150 km from the southeastern coast of the Azuero Peninsula to the northwestern coast of the Sona Peninsula (Mann and Corrigan, 1990). The Azuero-Sona fault zone (ASFZ) may extend offshore to the southeast, into the South Panama deformed belt (PA-08), as the Southern Panama fault zone (PA-21) (Westbrook and others, 1995). Historically, the southeastern end of the ASFZ has been the source region of several large earthquakes (for example, Adamek and others, 1988) and background levels of seismicity have been persistently higher than farther to the northwest (H. Cowan, unpubl. data, 1996).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Satellite and air-photo interpretation, reconnaissance field mapping.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 196 km (cumulative 251 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 63° W. ± 9°

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 2
Comentarios/Comments: One section (PA-11A) is linear and continuous from northwest Sona Peninsula to southeast Azuero Peninsula. The second section (PA-11B) is used to describe unnamed normal or oblique-normal splays of the ASFZ in the Tonosi area of the southeast Azuero Peninsula. This designation is solely for convenience of classification.

PA-11A, AZUERO-SONA FAULT

NUMERO DE LA SECCION/SECTION NUMBER: PA-11A

NOMBRE DE LA SECCION/SECTION NAME: Azuero-Sona fault

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 195.9 km (cumulative 196.9 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 61° W. ± 6°
INCLINACION PROMEDIO/AVERAGE DIP: Subvertical

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Left-lateral strike-slip.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Prominent linear valley striking northwest across southern Azuero Peninsula and Sona Peninsula (Mann and Corrigan, 1990). Possible left-lateral offset of drainage features near west coast of Azuero Peninsula.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, but probably Quaternary (<1.6 m.y.)
Comentarios/Comments: River terraces of early(?) (Holocene age that cross the fault in the valley of Rio San Rafael on the Sona Peninsula are not deformed (Cowan, unpubl. data, 1996), but many parts of the fault have not been inspected by geologists.

PA-11B, UNNAMED FAULT

NUMERO DE LA SECCION/SECTION NUMBER: PA-11B

NOMBRE DE LA SECCION/SECTION NAME: Unnamed fault
Comentarios/Comments: Unnamed normal or oblique-normal faults of the Tonosi Basin, southeastern Azuero Peninsula.

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 39.3 km (cumulative 54.1 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 71.1° W. ± 11.3°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal or oblique-normal

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Relatively linear valley margins with locally faceted spurs, bounding the Tonosi Basin west of the town of Tonosi, and along the north side of the Guanico valley. No surface traces have been reported.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)

REFERENCIAS/REFERENCES

Adamek, S., Frohlich, C., and Pennington, W., 1988, Seismicity of the Caribbean-Nazca boundary—Constraints on microplate tectonics of the Panama region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Kolarsky, R., and Mann, P., 1995, Structure and neotectonics of an oblique subduction margin, southwestern Panama, *in* Mann, P. (ed.,) Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 131-157.

Kolarsky, R., Mann, P., and Monechi, S., 1995, Stratigraphic development of southwestern Panama as determined from integration of marine seismic data and onshore geology, *in* Mann, P. (ed.) Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 159-200.

Mann, P., and Corrigan, J., 1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Westbrook, G.K., Hardy, N.C., and Heath, R.P., 1995, Structure and tectonics of the Panama-Nazca plate boundary, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p., 91-109.

PA-12, NORTH PANAMA DEFORMED BELT (NPDB)

NUMERO DE LA FALLA/FAULT NUMBER: PA-12
Comentarios/Comments: Equivalent to CR-50 in Costa Rica.

NOMBRE DE LA FALLA/FAULT NAME: North Panama deformed belt

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: The North Panama deformed belt (NPDB) is a landward-dipping thrust fault complex associated with an accretionary prism that bounds the northern margin of Panama and the northeast coast of Costa Rica. Several different explanations have been advanced to explain the development of the NPDB; all involve differential shortening across the southern margin of the Caribbean plate boundary. End-member models of the driving mechanism include (1) collision between the Panama arc and South America, (2) cross-ithsmus left-lateral strike-slip block displacement relative to the Colombian Basin, and (3) collision of Costa Rica across the Caribbean plate boundary resulting from subduction of the buoyant Cocos Ridge (for introduction to all interpretations, see Silver and others, 1995, and references therein).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismological studies (see Adamek and others, 1988 and references therein), marine seismic-reflection and bathymetric swath-mapping surveys (see Reed and Silver, 1995; Silver and others, 1995, and references therein).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end >699.3 km (cumulative >900 km), continues beyond map area
RUMBO PROMEDIO/AVERAGE STRIKE: Basically east-west, but varies along length, continues beyond map area

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 3
Comentarios/Comments: Three sections are defined for this compilation as follows: Sections 12B and 12C represent “western” and “eastern” sections of the NPDB based solely on the differing strike of the respective elements. Section 12A denotes a thrust fault in the “western sector” inferred to have ruptured in the April 22, 1991, Limon (Costa Rica) earthquake.

PA-12A, UNNAMED FAULT

NUMERO DE LA SECCION/SECTION NUMBER: PA-12A
Comentarios/Comments: Equivalent to CR-50A in Costa Rica.

NOMBRE DE LA SECCION/SECTION NAME: Limón fault
Comentarios/Comments: Unnamed but probable surface projection of the thrust fault that ruptured in the April 22, 1991, Limon, Costa Rica earthquake (Plafker and Ward, 1992). This is a continuation of fault CR-51 in offshore Costa Rica.

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
END POINTS: 10°0'19.31"N, 83°6'37.64" (upper or left); 9°37'43.78"N, 82°29'59.84"W (lower or right).
LONGITUD/LENGTH: End-to-end 74.3 km (cumulative 87.6 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N 66° W ± 32°(offshore of Panama and Costa Rica)
INCLINACION PROMEDIO/AVERAGE DIP: <30 degrees, southwest.
Comentarios/Comments: Flattens at depth. According to modeling by Tajima and Kikuchi (1995), the rupture surface had a dip of 39°at 7 km, decreasing to 16° at 17 km.
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: NE-vergent thrust fault.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Unknown
Comentarios/Comments: Trace everywhere beneath Caribbean Sea.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: 200 to 1,100 years
Comentarios/Comments: Plafker and Ward (1992) suggested a recurrence of 200 to 1,100 yrs based on uplifted Holocene coral platforms and assumptions about partitioning of Cocos-Caribbean plate motion.

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Historic (1991)
Comentarios/Comments: Extensive coastal uplift and localized subsidence were reported (Plafker and Ward, 1992). Analysis of aftershock distribution indicates blind-thrusting (Tajima and Kikuchi, 1995).

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown
Comentarios/Comments: No surface faulting was reported in the onshore area, but faulting is possible offshore (Plafker and Ward, 1992).

NOMBRE DEL TERREMOTO/NAME OF EARTHQUAKE: Costa Rica earthquake
Comentarios/Comments: Costa Rica earthquake (for example, Plafker and Ward, 1992; Tajima and Kikuchi, 1995). Also termed the Limón earthquake (for example, Silver and others, 1995) and Valle de Estrella earthquake (for example, Protti and others, 1995). Possible earlier historical ruptures (1822, 1904, and 1916) based on reported (onshore) effects (Camacho and Viquez, 1993).

FECHA/DATE: April 22, 1991

MAGNITUD O INTENSIDAD/MAGNITUDE OR INTENSITY: Ms 7.5

MOMENT MAGNITUDE: Mw 7.6

LONGITUD DE RUPTURA/LENGTH OF SURFACE RUPTURE: Unknown, trace underwater.

DESPLAZAMIENTO MAXIMO/MAXIMUM SLIP AT SURFACE: No surface rupture observed (mostly offshore).

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Thrust

PA-12B, WESTERN SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-12B
Comentarios/Comments: Equivalent to CR-50b in Costa Rica.

NOMBRE DE LA SECCION/SECTION NAME: Western
Comentarios/Comments: Sections 12b represents the “western” section of the NPDB based solely its orientation. Section boundary arbitrarily chosen at east-west tangent of arc in deformation zone. Section contains many faults and folds, which are not shown within boundaries of deformation zone. To the northwest, offshore from Costa Rica, section 12B is represented by fault CR-51.

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 457 km (cumulative length unknown, only boundaries of zone are shown)
Comentarios/Comments: Length based on arbitrary subdivision into fault sections 12B and 12C based on geometry.
RUMBO PROMEDIO/AVERAGE STRIKE: N. 89° E. ± 34° (not meaningful, strike is only for boundaries of zone)
INCLINACION PROMEDIO/AVERAGE DIP: <30°, south and southeast
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: N- and NW-vergent thrust faults.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Unknown

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Probably Holocene or post glacial (<15 k.y.)
Comentarios/Comments: Probably Holocene on basis of inferred deformation rate across North Panama deformed belt, PA-12). Possible earlier historical ruptures (1822, 1904, and 1916) based on reported (onshore) effects (Camacho and Viquez, 1993).

PA-12C, EASTERN SECTION

NUMERO DE LA SECCION/SECTION NUMBER: PA-12C

NOMBRE DE LA SECCION/SECTION NAME: Eastern

Comentarios/Comments: Sections 12C represents the "eastern" section of the NPDB based solely its orientation. Section boundary arbitrarily chosen at east-west tangent of arc in deformation zone. Section contains many faults and folds, which are not shown within boundaries of deformation zone.

GEOMETRIA DE LA SECCION/SECTION GEOMETRY

LONGITUD/LENGTH: End-to-end >276 km, continues beyond map area (cumulative length unknown, only boundaries of zone are shown)

Comentarios/Comments: Length based on arbitrary subdivision into fault sections 12B and 12C based on geometry.

RUMBO PROMEDIO/AVERAGE STRIKE: N. 49° E. ± 20° (not meaningful, strike is only for boundaries of zone)

INCLINACION PROMEDIO/AVERAGE DIP: <30°, south and southwest

SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: N- and NE-vergent thrust faults.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Unknown

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Probably 1-5 mm/yr

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Historic, 1882

Comentarios/Comments: Historic (1882) based on reports of Mendoza and Nishenko (1989) and Camacho and Viquez (1993). Also, in 1914 there was a magnitude 7.2 event at about 70 km depth beneath Servania de San Blas (Toral, 1998). Entire section is shown as <15 k.y. based on assigned slip rate and association with sections 12a and 12b.

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown

REFERENCIAS/REFERENCES

Adamek, S., Frohlich, C., and Pennington, W., 1988, Seismicity of the Caribbean-Nazca boundary—Constraints on microplate tectonics of the Panama region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Camacho, E., and Viquez, V., 1993, Historical seismicity of the North Panama Deformed Belt: Revista Geologia de America Central, no. 15, 49-64.

Mendoza, C., and Nishenko, S., 1989, The North Panama earthquake of 7 September, 1882—Evidence for active underthrusting: Bulletin of the Seismological Society of America, v. 79, p. 1264-1269.

Plafker, G., and Ward, S.N., 1992, Thrust faulting and tectonic uplift along the Caribbean Sea coast during the April 22, 1991, Costa Rica earthquake: Tectonics, v. 11, p. 709-718.

Protti, M., Güendel, F., and McNally, K., 1995, Correlation between the age of the subducting Cocos plate and the geometry of the Wadati-Benioff zone under Nicaragua and Costa Rica, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 309-326.

Reed, D.L., and Silver, E.A., 1995, Sediment dispersal and accretionary growth of the North Panama Deformed Belt Rica, *in* Mann, P. (ed.) Geological and Tectonic Development of the Caribbean plate Boundary in southern Central America: Geological Society of America Special Paper 295, p. 213-223.

Silver, E.A., Galewsky, J., and McIntosh, K.D., 1995, Variation in structure, style, and driving mechanism of adjoining segments of the North Panama deformed belt, *in* Mann, P. (ed.) Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 225-233.

Tajima, F., and Kikuchi, M., 1995, Tectonic implications of the seismic ruptures associated with the 1983 and 1991 Costa Rica earthquakes, *in* Mann, P. (ed.) Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 327-340.

Toral, J., 1998, Earthquake studies in the Choco Block: Uppsala, University of Uppsala, Sweden, unpubl. M.Sc. thesis.

PA-13, UNNAMED FAULT SYSTEM

NUMERO DE LA FALLA/FAULT NUMBER: PA-13

NOMBRE DE LA FALLA/FAULT NAME: Unnamed (system)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: This unnamed fault system comprises two faults (described as sections herein). The first is an ENE-striking unnamed fault (PA-13A) 500 m inland (south) from Palmas Bellas. Geomorphic offsets on ancestral (Holocene) channels of Rio Largarto are consistent with strike-slip motion, but only dip-slip (southeast-side down) is obvious with throws of 10-15 m on a late Quaternary surface cut across Pliocene marine sandstone. The ENE strike suggests that this unnamed fault could be associated with the Rio Gatun fault (RGF, PA-13B), east of Lago Gatun.
The second fault, the Rio Gatun bounds the NW margin of the Madden Basin in the Canal Zone of Central Panama. The RGF also strikes ENE and separates middle/late Tertiary sediment of the Madden Basin from older (probably Mesozoic) sedimentary and igneous rocks. The fault kinematics are poorly constrained but evidence indicates predominantly normal dip-slip displacement. No late Quaternary offsets have been documented on alluvial terraces or fans, and recent observations of the fault zone in basement rocks indicate partial annealing of the crushed zone.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; March 30, 1997.

TIPOS DE ESTUDIOS/TYPE OF STUDIES: For PA-13A, aerial photograph interpretation combined with field mapping (Cowan and Schweig, unpubl. data, 1997). For PA-13B, aerial and satellite interpretation combined with field mapping (Jones, 1950; Stewart and Stewart, 1980; Mann and Corrigan, 1990; Cowan and Schweig, unpubl. data, 1997).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 67.2 km (cumulative 53.6 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 66° E. ± 9°

NUMERO DE SECCIONES/NUMBER OF SECTIONS: 2

PA-13A, UNNAMED FAULT SOUTH OF PALMAS BELLAS

NUMERO DE LA SECCION/SECTION NUMBER: PA-13A

NOMBRE DE LA SECCION/SECTION NAME: Unnamed fault south of Palmas Bellas

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 8.5 km (cumulative 8.5 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 61° E. ± 6°
INCLINACION PROMEDIO/AVERAGE DIP: Subvertical to south.
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal or oblique-normal
Comentarios/Comments: Kinematics unclear. Possibly normal or oblique-normal, down thrown to southeast.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Straight trace across topography consistent with strike-slip, but only dip-slip offset (southeast side down) is obvious with throws of 10-15 m on late Quaternary surfaces. Geomorphic offsets are documented for ancestral (Holocene) channels of Rio Largarto.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)
Comentarios/Comments: Fault deforms late Quaternary surfaces 10-15 m, which are formed on Pliocene marine sandstone (Chagres Sandstone) (Cowan and Schweig, unpubl. data, 1997).

PA-13B, RIO GATUN FAULT (RGF)

NUMERO DE LA SECCION/SECTION NUMBER: PA-13B

NOMBRE DE LA SECCION/SECTION NAME: Rio Gatun fault (RGF)
Comentarios/Comments: The Rio Gatun fault has been mapped between Lago Gatun and Rio Boqueron at the north end of the Madden Basin.

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 41.4 km (cumulative 45.2 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 66° E. ± 9°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical dip to south.
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT Normal or oblique-normal
Comentarios/Comments: Down thrown to south.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The fault forms a prominent topographic lineament along the south margin of the Sierra Maestria, which rises to an elevation of 600 m and is comprised of pre-Tertiary basement rocks.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Probably < 1mm/yr

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)
Comentarios/Comments: No late Quaternary offsets have been documented on alluvial terraces or fans, and recent observations of the fault zone in basement indicate partial annealing of the crushed zone. Seismicity is weakly correlated with the RGF.

REFERENCIAS/REFERENCES

Jones, S., 1950, Geology of Gatun Lake and vicinity, Panama: Geological Society of America Bulletin, v. 61, p. 893-922.

Mann, P., and Corrigan, J.,1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Stewart, R.H., and Stewart, R.L., 1980, Geologic map of the Panama Canal and vicinity, Republic of Panama: U.S. Geological Survey Miscellaneous Investigations Series Map I-1232, scale 1:100,000.

PA-14, UNNAMED FAULT SYSTEM

NUMERO DE LA FALLA/FAULT NUMBER PA-14

NOMBRE DE LA FALLA/FAULT NAME: Unnamed (system)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: System of N-S-trending, predominantly east-facing normal faults, west and south of the western termination of the Rio Gatun fault (PA-13B), Panama Canal Zone. Mann and Corrigan (1990) postulated that this fault system accommodates east-west extension at the western termination of a left-lateral Rio Gatun fault.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Aerial and satellite interpretation combined with field mapping (Mann and Corrigan, 1990; Jones, 1950; Stewart and Stewart, 1980; Schweig, unpubl. data, 1996).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 50.0 km (cumulative 94.6 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 10° E. ± 15°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical dip to east.
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Normal or oblique-normal, down thrown to east.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: This fault system defines a topographically low region occupied by Gatun and Madden reservoirs in which Cenozoic sediment is preserved between elevated blocks of Mesozoic oceanic basement (Jones, 1950; Stewart and Stewart, 1980; Mann and Corrigan, 1990).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Quaternary (<1.6 m.y.)

REFERENCIAS/REFERENCES

Jones, S., 1950, Geology of Gatun Lake and vicinity, Panama: Geological Society of America Bulletin, v. 61, p. 893-922.

Mann, P., and Corrigan, J.,1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Stewart, R.H., and Stewart, R.L., 1980, Geologic map of the Panama Canal and vicinity, Republic of Panama: U.S. Geological Survey Miscellaneous Investigations Series Map I-1232, scale 1:100,000.

PA-15, UNNAMED FAULTS OF THE EAST PANAMA DEFORMED BELT (EPDB)

NUMERO DE LA FALLA/FAULT NUMBER: PA-15

NOMBRE DE LA FALLA/FAULT NAME: Unnamed faults of the East Panama Deformed Belt (EPDB).

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Nine NW-striking, west-verging thrust faults offset rocks of Oligocene to Pliocene-Pleistocene age, and at some localities in the eastern Gulf of Panama, sediment of the sea-floor. The longest and most westerly of these faults bounds the western margin of the Pearl Islands, which form the emergent part of an associated hanging-wall anticline (see Mann and Kolarsky, 1995, figs. 5 and 8).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Seismic stratigraphic analysis of multichannel seismic surveys tied to two exploration wells, integrated with geological outcrop data from the Pearl Islands and mainland Panama (see Mann and Kolarsky, 1995, and references therein).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 85.5 km (cumulative 182.8 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 30° W. ± 18°
INCLINACION PROMEDIO/AVERAGE DIP: <30°
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Seaward- (westward-) directed thrusts.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Arching of the sea-floor is evident on Mobil line 18, SE of the Pearl Islands (see Mann and Kolarsky, 1995, fig. 8).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Probably Holocene or post glacial (<15 k.y.)
Comentarios/Comments: Probable Holocene age is assigned based on bathymetric expression of some elements of this fault system, together with correlation and accordance between earthquake locations and focal mechanisms (Adamek *and others,* 1988, see also Mann and Kolarsky, 1995, fig. 5).

REFERENCIAS/REFERENCES

Adamek, S., Frohlich, C., and Pennington, W.D., 1988, Seismicity of the Caribbean Nazca Boundary—Constraints on microplate tectonics of the Panama Region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Mann, P., and Corrigan, J.D., 1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Mann, P., and Kolarsky, R., 1995, East Panama Deformed Belt—Structure, age and neotectonic significance, *in* Mann, P. (ed.,) Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 111-130.

PA-16, SANSON HILLS FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PA-16

NOMBRE DE LA FALLA/FAULT NAME: Sanson Hills (zone)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: NW-SE-striking left-lateral strike-slip fault zone that juxtaposes a thick sedimentary sequence of upper Cretaceous to upper Miocene age in the Bayano-Chucunaque basin (on the northeast) against an upper Cretaceous, oceanic igneous and sedimentary sequence (on the southwest) (see Mann and Corrigan, 1990, and Mann and Kolarsky, 1995, fig. 6).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Satellite- and radar-image interpretation, integrated with geological outcrop data (see Mann and Kolarsky, 1995, p.117, and references therein).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 91.2 km (cumulative 210.0 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 25° W. ± 15°
INCLINACION PROMEDIO/AVERAGE DIP: Probably sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Left-lateral strike-slip

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The fault zone is well-defined by a series of seven en echelon, doubly-plunging anticlines along its northeastern flank (see Wilcox *and others*, 1973; Mann and Corrigan, 1990, fig. 2; Mann and Kolarsky, 1995, fig. 6). To the northwest the Sanson Hills, the fault zone terminates in a half-graben developed at an inferred releasing bend in the fault; to the southeast, the fault terminates against north-trending highlands (Serrania de Pirre) bounded by the Pirre Fault (see PA-17).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)

REFERENCIAS/REFERENCES

Mann, P., and Corrigan, J.,1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Mann, P., and Kolarsky, R., 1995, East Panama Deformed Belt—Structure, age and neotectonic significance, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate Boundary in southern Central America: Geological Society of America Special Paper 295, p. 111-130.

Wilcox, R.E., Harding, T.P., and Seely, D.R., 1973, Basic wrench tectonics: American Association of Petroleum Geologists Bulletin, v. 57, p. 74-96.

PA-17, PIRRE HILLS FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PA-17

NOMBRE DE LA FALLA/FAULT NAME: Pirre Hills (zone)
Comentarios/Comments: Preferred name is Pirre Hills fault zone (MacDonald, 1969; Mann and Corrigan, 1990; Mann and Kolarsky, 1995), but it is also known as Falla del Rio Balsas (Direccion General Recursos Minerales de Panamá, 1976).

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: NNE-striking and northwest-verging reverse or thrust fault that bounds the northwestern flank of the Serrania de Pirre south of the town of Yaviza, Darien. The Pirre Hills fault zone accommodates locally northwest-directed shortening across the Colombia-Panama border region, and abruptly truncates the NW-SE-striking, left-lateral strike-slip Sanson Hills fault zone (PA-16) (see Mann and Corrigan, 1990, fig. 2, or Mann and Kolarsky, 1995, fig. 6 and p.115).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Satellite- and radar-image interpretation, integrated with geological outcrop data (see Mann and Kolarsky, 1995, p.115-116, and references therein).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 81.1 km (cumulative 103.5 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 10° E. ± 25°
INCLINACION PROMEDIO/AVERAGE DIP: High-angle reverse fault where observed at surface.
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Reverse or thrust, west or northwest directed.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The Pirre Hills fault zone is defined by a topographically prominent highland block developed in the hanging wall of the fault. It appears to be bounded to the east in the border region of Colombia by the sinuous, west-dipping northern part of the Unguia fault (MacDonald, 1969; Mann and Corrigan, 1990; Mann and Kolarsky, 1995).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Possibly Historic (1974)
Comentarios/Comments: Possibly historic based on association with July 13, 1974, M 7.3 earthquake that has shallow (<15 km) source centered in this area. Liquefaction occurred at Jaque, and the highest intensities were reported in the El Real Yaviza area (Viquez and Toral, 1987). Entire fault zone is shown as <15 k.y. based on association with historic earthquakes.

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown

REFERENCIAS/REFERENCES

Direccion General Recursos Minerales de Panamá, 1976, Mapa Geologico Hoja 8 “Region Sur de Darien”: Panamá City, Republic of Panamá, Edicion 1, escala 1:250,000.

Mann, P., and Corrigan, J.,1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Mann, P., and Kolarsky, R., 1995, East Panama Deformed Belt—Structure, age and neotectonic significance, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 111-130.

MacDonald, H.C., 1969, Geologic evaluation of radar imagery from Darien province, Panama: Modern Geology, v. 1, p. 1-63.

Viquez, V., and Toral, J., 1987, Sismicidad historical sentida en el Istmo de Panamá: Revista Geofisica, v. 27, p. 26-70.

PA-18, SAMBU FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PA-18

NOMBRE DE LA FALLA/FAULT NAME: Sambu fault zone is the preferred name (MacDonald, 1969; Mann and Corrigan, 1990; Mann and Kolarsky, 1995). Also known as Falla del Rio Sambu (Direccion General Recursos Minerales de Panamá, 1976).

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: NW-striking inferred left-lateral strike-slip fault that bounds the southeast margin of the Sambu Basin, Darien (see Lowrie and others, 1982; Mann and Corrigan, 1990, Fig. 1, or Mann and Kolarsky, 1995, fig. 5 and p. 115).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES Satellite and radar-image interpretation (see Mann and Kolarsky, 1995, p. 115-116 and references therein).

GEOMETRIA DE LA SECCION/SECTION GEOMETRY
LONGITUD/LENGTH: End-to-end 38.0 km (cumulative 38.3 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 45° W. ± 7°
INCLINACION PROMEDIO/AVERAGE DIP: Inferred sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Inferred left lateral strike-slip

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The Sambu fault bounds the southwest flank of the Serrania de Bagre and the onshore extension of the Sambu Basin, along the linear Rio Sambu valley (MacDonald, 1969; Mann and Corrigan, 1990; Mann and Kolarsky, 1995).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 m.y.)

REFERENCIAS/REFERENCES

Direccion General Recursos Minerales de Panamá, 1976, Mapa Geologico Hoja 8 “Region Sur de Darien”: Panamá City, Republic of Panamá, Edicion 1, escala 1:250,000.

Lowrie, A., Stewart, J., Stewart, R.H., van Andel, R.J., and L. McRaney, 1982, Location of the eastern boundary of the Cocos plate during the Miocene: Marine Geology, v. 2, p. 73-108.

Mann, P., and Corrigan, J.,1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Mann, P., and Kolarsky, R., 1995, East Panama Deformed Belt—Structure, age and neotectonic significance, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 111-130.

MacDonald, H.C., 1969, Geologic evaluation of radar imagery from Darien province, Panama: Modern Geology, v. 1, p. 1-63.

PA-19, JAQUE RIVER FAULT ZONE

NUMERO DE LA FALLA/FAULT NUMBER: PA-19

NOMBRE DE LA FALLA/FAULT NAME: Jaque River (zone)
Comentarios/Comments: Preferred name is Jaque River fault zone (MacDonald, 1969; Mann and Corrigan, 1990; Mann and Kolarsky, 1995). Also known as the Falla del Rio Jaque (Direccion General Recursos Minerales de Panamá, 1976).

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: NW-striking inferred left-lateral strike-slip fault that bounds the southwest margin of the Serrania de Sapo, Darien (Mann and Corrigan, 1990, fig. 1, or Mann and Kolarsky, 1995, fig. 5 and p. 116).

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Satellite and radar-image interpretation (see Mann and Kolarsky, 1995, p. 115-116, and references therein).

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 63.6 km (cumulative 63.6 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 44° W. ± 3°
INCLINACION PROMEDIO/AVERAGE DIP: Inferred sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Inferred left lateral strike-slip

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: The Jaque River fault zone bounds the southwest flank of the Serrania de Sapo and Serrania de Jungurudo, along the landward margin of a narrow coastal plain; it may possibly extend into Colombia (MacDonald, 1969; Mann and Corrigan, 1990; Mann and Kolarsky, 1995).

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown

TASA DE MOVIMIENTO/SLIP RATE: Unknown

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Unknown, probably Quaternary (<1.6 Ma)

REFERENCIAS/REFERENCES

Direccion General Recursos Minerales de Panamá, 1976, Mapa Geologico Hoja 8 “Region Sur de Darien”: Panamá City, Republic of Panamá, Edicion 1, escala 1:250,000.

Mann, P., and Corrigan, J.,1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Mann, P., and Kolarsky, R., 1995, East Panama Deformed Belt—Structure, age and neotectonic significance, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 111-130.

MacDonald, H.C., 1969, Geologic evaluation of radar imagery from Darien province, Panama: Modern Geology, v. 1, p. 1-63.

PA-20, UNAMED SERIES OF FOLDS

NUMERO DE PLIEGUE/FOLD NUMBER: PA-20

NOMBRE DEL PLIEGUE/FOLD NAME: Unnamed series of folds
Comentarios/Comments: Unnamed series of folds developed in Pliocene and older sedimentary rocks in the region of Bocas del Toro and Changuinola, northwest Panama.

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: In the Bocas del Toro and Changuinola regions of northwest Panama, fold and thrust structures of the North Panama deformed belt (PA-12, NPDB) pass WSW across the continental shelf and extend landward into northwesternmost Panama and eastern Costa Rica (see PA-12A, PA-12B). This region has been explored extensively for hydrocarbons and numerous fold structures and associated reverse or thrust faults have been identified (Champlin Oil, 1958).
The dominant structural grain is NW-SE and the sedimentary sequence becomes younger from southwest to northeast, ranging in age from Upper Cretaceous to Quaternary. Most of the folds are expressed at the surface in rocks of Miocene age or older and exhibit marked asymmetries that indicate dominant seaward vergence.
Recent biostratigraphic analysis of Neogene rocks has shown that the uplift of this area occurred principally during the Quaternary, possibly in response to Cocos Ridge collision beneath the arc (Collins and others, 1995).
The 1991 Costa Rica (Limon) earthquake demonstrated that active deformation is continuing and illustrated the relationship between folding and blind-thrusting (Plafker and Ward, 1992) (see PA-12A). However, the available age control for subsurface data are not sufficiently precise to justify separating individual elements for seismotectonic evaluation. Therefore the numerous local structures are grouped under this one description.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; Oct. 10, 1996

TIPO DE ESTUDIOS/TYPE OF STUDIES: Seismic-reflection surveys with local well control, supplemented by field surveys, mapping, and biostratigraphic analysis (Terry, 1956; Champlin Oil, 1958; Coates and others, 1992; Collins, 1993; Collins and others, 1995).

GEOMETRIA DEL PLIEGUE/FOLD GEOMETRY
LONGITUD DEL EJE/LENGTH OF FOLD AXIS: End-to-end 142.3 km (cumulative 339.1 km)
Comentarios/Comments: Includes length of zone and all axes in zone.
RUMBO PROMEDIO DEL EJE/AVERAGE STRIKE OF FOLD AXIS: N. 60° W. ± 15°(average of all axes)
INCLINACION DE LOS FLANCOS/DIP OF LIMBS: See comments below
Comentarios/Comments: Typically the folds have moderately long and gently to moderately dipping southwest limbs (35-60°), and short, steeply dipping (40° to vertical or overturned) northeast limbs. The northeast limbs are rarely visible in the field and in most cases are inferred to be cut by northwest-trending reverse and thrust faults. The asymmetry of folding is reported to be greater and the fold pattern more complicated to seaward (Champlin Oil, 1958), consistent with the inferred location of the main thrust front of the North Panama Deformed Belt (PA-12) (Silver and others, 1995).
INCLINACION DEL EJE/PLUNGE: Many doubly-plunging structures.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Relatively strong expression of the axial traces of anticlines in erosion resistant parts of the sedimentary sequence in the Almirante-Changuinola area.

TASA DE LEVANTAMIENTO/UPLIFT RATE: Unknown

DEFORMACIONES HISTORICAS/HISTORICAL UPLIFT (SOLO SI CORRESPONDE): Probably Historic 1916 (and 1991, but undocumented).

NOMBRE DEL TERREMOTO/NAME OF EARTHQUAKE: Bocas del Toro (see Viquez and Toral, 1987; Camacho and Viquez, 1993; Boschini and Montero, 1994).

FECHA/DATE: 26 April, 1916

MAGNITUD O INTENSIDAD/MAGNITUDE OR INTENSITY: Magnitude and location uncertain; inferred M>7 and intensity MMVIII in Almirante, Panama.

MOMENT MAGNITUDE: Unknown

LEVANTAMIENTO MAXIMO EN SUPERFICIE/MAXIMUM UPLIFT AT SURFACE: Unknown

REFERENCIAS/REFERENCES

Camacho, E., and Viquez, V., 1993, Historical seismicity of the North Panama Deformed Belt: Revista Geologia de America Central, no. 15, p.49-64.

Champlin Oil Company (Geophoto Services), 1958, Geologic evaluation Champlin Oil and Refining Company Concession, Bocas del Toro Province, Republic of Panama: Unpubl. Open-File report held at Direccion General de Hidrocarburos Panamá, Panamá City, Republic of Panamá, 60 p.

Coates, A.G., and seven others, 1992, Closure of the Isthmus of Panama—The near-shore record in Costa Rica and western Panama: Geological Society of America Bulletin, v. 104, p. 814-828.

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Collins, L.S., Coates, A.G., Jackson, J.B.C., and J. Obando, 1995, Timing and rates of emergence of the Limon and Bocas del Toro basins—Caribbean effects of Cocos Ridge subduction, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 263-289.

Boschini, I., and W. Montero, 1994, Sismicidad historica e instrumental del Caribe de Costa Rica: Revista Geologia de America Central, Vol. Especial Terremoto de Limon, p. 65-72.

Plafker, G., and Ward, S.N., 1992, Thrust faulting and tectonic uplift along the Caribbean Sea coast during the April 22, 1991, Costa Rica earthquake: Tectonics, v. 11, p. 709-718.

Silver, E.A., Galewsky, J., and McIntosh, K.D., 1995, Variation in structure, style, and driving mechanism of adjoining segments of the North Panama deformed belt, *in* Mann, P. (ed.) Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 225-233.

Viquez, V., and Toral, J., 1987, Sismicidad historica sentida en el Istmo de Panamá: Revista Geofisica, v. 27, p. 135-152.

PA-21, SOUTHERN PANAMA FAULT ZONE (SPFZ)

NUMERO DE LA FALLA/FAULT NUMBER: PA-21

NOMBRE DE LA FALLA/FAULT NAME: Southern Panama (zone)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: Left-lateral strike-slip margin of the Nazca Plate (offshore), southeast of Azuero Peninsula and in Gulf of Panama. The Southern Panama fault zone (SPFZ) strikes ENE, accommodating relative motion between the Nazca Plate and Panama. The SPFZ extends from the South Panama Deformed Belt (PA-09) at 80.5° W. long., eastward to 78.5° W. long., then turns southeast parallel to the trench offshore of northern Colombia.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; March 30, 1997.

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Marine geophysical studies and seismology.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end 470 km (cumulative 516 km)
RUMBO PROMEDIO/AVERAGE STRIKE: N. 88° W. ± 14°
INCLINACION PROMEDIO/AVERAGE DIP: Sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Left-lateral strike slip.

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Well expressed in the bathymetry, southeast offshore of the Azuero Peninsula.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown
Comentarios/Comments: Unknown, but several historical events M>6.

TASA DE MOVIMIENTO/SLIP RATE: Probably >5 mm/yr.
Comentarios/Comments: Based on GPS geodesy and closures of plate-motion circuits.

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Probably historic.
Comentarios/Comments: Historic movement based on location of several historical M> 6 events, including estimated M_S 7.0 event of October 1, 1913 (MacDonald and Johnson, 1913). Entire fault zone is shown as <15 k.y. based on assigned slip rate.

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown

REFERENCIAS/REFERENCES

Kellogg, J.N., and Vega, V., 1995, Tectonic development of Panama, Costa Rica and the Colombian Andes—Constraints from global positioning system geodetic studies and gravity, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p. 75-90.

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Westbrook, G.K., Hardy, N.C., and Heath, R.P., 1995, Structure and tectonics of the Panama-Nazca plate boundary, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p., 91-109.

PA-22, COLOMBIAN ACCRETIONARY COMPLEX (DEFORMATION ZONE)

NUMERO DE LA FALLA/FAULT NUMBER: PA-22

NOMBRE DE LA FALLA/FAULT NAME: Colombian Accretionary Complex (deformation zone)

SINOPSIS Y AMBIENTE GEOLOGICO/SYNOPSIS AND GEOLOGIC SETTING: A broad deformation zone of westward- and eastward-verging, folded thrust slices located at the eastern end of the South Panama fault zone (PA-21) between 78° W. and 79° W. long.). The Colombian Accretionary Complex is developed in pelagic and turbidite sediments, overlying oceanic crust of the Nazca Plate and represents the shallowest part of the Colombian subduction zone, where Nazca Plate is actively subducting beneath northwestern Colombia.

COMPILADOR, AFILIACION Y FECHA DE COMPILACION/COMPILER, AFFILIATION, & DATE OF COMPILATION: Hugh Cowan, Instituto de Geociencias, Universidad de Panamá, Panamá City, Panamá; July 26, 1997.

TIPOS DE ESTUDIOS/TYPE OF STUDIES: Marine geophysical studies and seismology.

GEOMETRIA DE LA FALLA/FAULT GEOMETRY
LONGITUD/LENGTH: End-to-end >181 km (cumulative>251 km), continues beyond map area
RUMBO PROMEDIO/AVERAGE STRIKE: N. 32° W. ± 14°, continues beyond map area
INCLINACION PROMEDIO/AVERAGE DIP: Shallow to sub-vertical
SENTIDO DE MOVIMIENTO/SENSE OF MOVEMENT: Left-lateral strike slip and east-west thrusting

EXPRESION GEOMORFOLOGICA/GEOMORPHIC EXPRESSION: Well expressed in the bathymetry offshore of the border region of Panama and Colombia.

INTERVALO DE RECURRENCIA/RECURRENCE INTERVAL: Unknown
Comentarios/Comments: Unknown, but several historical events M > 7.0

TASA DE MOVIMIENTO/SLIP RATE: >5 mm/yr
Comentarios/Comments: Based on GPS geodesy and plate-circuit closures (Kellogg and Vega, 1995).

EDAD DEL ULTIMO MOVIMIENTO/TIME OF MOST RECENT OF MOVEMENT: Probably Historic.
Comentarios/Comments: May be associated with M~7.0 earthquake of July 11, 1976 (Pennington, 1981; Viquez and Toral, 1987). Entire fault zone is shown as <15 k.y. based on assigned slip rate.

FALLAMIENTO HISTORICO EN SUPERFICIE/HISTORICAL SURFACE FAULTING: Unknown (offshore).

REFERENCIAS/REFERENCES

Adamek, S., Frohlich, C., and Pennington, W.D., 1988, Seismicity of the Caribbean Nazca Boundary—Constraints on microplate tectonics of the Panama Region: Journal of Geophysical Research, v. 93, p. 2053-2075.

Kellogg, J.N., and Vega, V., 1995, Tectonic development of Panama, Costa Rica, and the Colombian Andes—Constraints from global positioning system geodetic studies and gravity, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean Plate boundary in Southern Central America: Geological Society of America Special Paper 295, p.75-90.

Pennington, W.D., 1981, Subduction of the eastern Panama basin and the seismotectonics of northwestern South America: Journal of Geophysical Research, v. 86, p. 10753-10770.

Viquez, V., and Toral, J., 1987, Sismicidad historical sentida en el Istmo de Panamá: Revista Geofisica, v. 27, p. 26-70.

Westbrook, G.K., Hardy, N.C., and Heath, R.P., 1995, Structure and tectonics of the Panama-Nazca plate boundary, *in* Mann, P. (ed.), Geologic and tectonic development of the Caribbean plate boundary in southern Central America: Geological Society of America Special Paper 295, p., 91-109.

TABLE 1. QUATERNARY FAULTS IN PANAMA AND ITS OFFSHORE REGIONS

Number	Name of structure	†Primary topographic map sheet (no.)	Time of most recent faulting	Slip rate (mm/yr)
PA-01	Longitudinal fault zone			
PA-01A	Unnamed section	David (2)	Probably <1.6 m.y.	Probably <1
PA-01B	Unnamed section	David (2)	Probably <1.6 m.y.	Probably <1
PA-02	Madre Vieja Anticline	David (2)	Possibly historic (1934), <15 k.y.	Probably >1 (uplift rate)
PA-03	Medial fault zone	David (2)	Probably <15 k.y.	Probably >10
PA-04	Panama fracture zone	Isla de Coiba (3) and offshore	Historic (1934), <15 k.y. for zone	Probably >50
PA-05	Unnamed series of faults			
PA-05A	Unnamed section	David (2)	Probably <15 k.y.	Unknown
PA-05B	Unnamed section	David (2)	Probably <1.6 m.y.	Unknown
PA-05C	Unnamed section	David (2)	Probably <1.6 m.y.	Unknown
PA-06	Unnamed faults			
PA-06A	Unnamed section	Isla de Coiba (3)	<1.6 m.y.	Unknown
PA-06B	Unnamed section	Isla de Coiba (3)	<1.6 m.y.	Unknown
PA-06C	Unnamed section	Isla de Coiba (3)	<1.6 m.y.	Unknown
PA-07	Central and South Coiba fault zones			
PA-07A	Central Coiba fault zone	Isla de Coiba (3)	Probably <1.6 m.y.	Unknown
PA-07B	South Coiba fault zone	Isla de Coiba (3)	Probably <1.6 m.y.	Unknown
PA-08	Balboa fracture zone	Isla de Coiba (3) and offshore	<15 k.y. for entire zone	Probably >5
PA-09	South Panama deformed belt	Isla de Coiba (3) and offshore	Probably <15 k.y. for entire belt	Probably 1-5
PA-10	Unnamed fault system			
PA-10A	Rio Flores fault zone	Chitre (6)	<1.6 m.y.	Unknown
PA-10B	Unnamed fault	Chitre (6)	<1.6 m.y.	Unknown
PA-10C	Unnamed fault	Chitre (6)	< 1.6 m.y.	Unknown
PA-10D	Unnamed fault	Chitre (6)	< 1.6 m.y.	Unknown
PA-11	Azuero-Sona fault zone			
PA-11A	Azuero-Sona fault	Chitre (6)	Probably <1.6 m.y.	Unknown
PA-11B	Unnamed fault	Chitre (6)	<1.6 m.y.	Unknown
PA-12	North Panama deformed belt			
PA-12A	Limón fault	Bocas del Toro (1)	Historic (1991)	Unknown
PA-12B	Western section	Bocas del Toro (1), Donoso (4) and offshore)	<15 k.y.	Unknown
PA-12C	Eastern section	Ustupo (10) and offshore	Historic (1882), <15 k.y. for section	Probably 1-5

TABLE 1—CONTINUED. QUATERNARY FAULTS IN PANAMA AND OFFSHORE PANAMA

Number	Name of structure	†Primary topographic map sheet (no.)	Time of most recent faulting	Slip rate (mm/yr)
PA-13	Unnamed fault system			
PA-13A	Unnamed fault south of Palmas Bellas	Donoso (4)	<1.6 m.y.	Unknown
PA-13B	Rio Gatun fault	Panamá Norte (7)	<1.6 m.y.	Probably <1
PA-14	Unnamed fault system	Panamá Norte (7)	<1.6 m.y.	Unknown
PA-15	Unnamed faults of the East Panama deformed belt	Panamá Sur (8) and offshore	Probably <15 k.y. for entire belt	Unknown
PA-16	Sanson Hills fault zone	La Palma (11)	Probably <1.6 m.y.	Unknown
PA-17	Pirre Hills fault zone	Jaqué (12)	Possibly historic (1974), <15 k.y. for zone	Unknown
PA-18	Sambu fault zone	La Palma (11)	Probably <1.6 m.y.	Unknown
PA-19	Jaque River fault zone	Jaqué (12)	Probably <1.6 m.y.	Unknown
PA-20	Unnamed series of folds	Bocas del Toro (1)	Historic (1991), <15 k.y. for series	Unknown
PA-21	Southern Panama fault zone	Offshore	Probably historic, <15 k.y. for zone	Probably >5
PA-22	Colombian accretionary complex (deformation zone)	Offshore	Probably historic, <15 k.y. for zone	>5

† From special series of 12 topographic maps at 1:250,000 scale entitled “Mapa General de la Republica de Panamá” (edtion 10) by the Instituto Geografico Nacional “Tommy Guardia” (IGNTG), Ministerio de Obras Publicas, Panamá.