Sesimicity of the Pejibaye-Matina, Costa Rica, region: a strike-slip tectonic boundary?

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Received: October 27, 2008; accepted: May 13, 2009

Resumen

Este estudio provee ubicaciones de temblores en un esfuerzo por determinar orientaciones de fallas e investigar la existencia de un límite tectónico transcurrente en la costa Caribe de Costa Rica. Un conjunto de 121 temblores de la secuencia sísmica de Pejibaye de Turrialba de 1993 fueron relocalizados usando estaciones sísmicas cercanas a la fuente. La distribución epicentral muestra una sismicidad de fondo dispersa con dos agrupamientos, uno cerca de Pejibaye y otro junto a la falla Chirripó. En Pejibaye, la distribución de temblores tiende al noreste y es paralela a varias fallas pequeñas. Este alineamiento concuerda con el plano noreste de las soluciones focales para el temblor de Pejibaye de 1993. El grupo de temblores cercano a la falla Chirripó está asociado con una falla submarina de orientación noroeste que generó el terremoto de Limón de 1991. La sismicidad, el fallamiento y la deformación cortical no son consistentes con interpretaciones previas de un límite tectónico transcurrente de orientación noreste en el área.

Palabras clave: Sismicidad, sismotectónica, tectónica, fallamiento, límite de placa, deformación cortical, temblores.

Abstract

Earthquake locations are provided in an effort to determine fault orientations and investigate the existence of a strike-slip tectonic boundary on the Caribbean coast of Costa Rica. A data set of 121 earthquakes for the 1993 Pejibaye de Turrialba seismic sequence were relocated from near-field seismic stations. The epicentral distribution shows scattered background seismicity with two clusters, one near Pejibaye and another close to the Chirripo fault. At Pejibaye, the earthquake distribution trends northeast and parallels several small faults. This alignment is in agreement with the northeast plane of focal mechanism for the 1993 Pejibaye earthquake. The group of earthquakes near the Chirripo fault is associated with a northwest-trending offshore fault that also generated the 1991 Limon earthquake. Seismicity, faulting and crustal deformation are not consistent with erlier interpretations of an east-northeast oriented strike-slip tectonic boundary in the area.

Key words: Seismicity, seismotectonics, tectonics, faulting, plate boundary, crustal deformation, earthquakes.

Introduction

The 1993 Pejibaye seismic sequence is characterized by small-magnitude events. The main events occurred on July 08 (Ml=4.8), July 10 (Ml=5.3) and July 13 (Ml=4.9). The activity intensified toward 10 July 1993, with the largest event being a shallow felt local magnitude (ML) 5.3 earthquake at 20:40 (GMT). Seismicity increased in the region following this event, with hundreds of earthquakes detectable at one or more local seismic stations in the following.months.

The sequence provided evidence for a previously unidentified seismic source region in Costa Rica. This source had probably not been previously detected because of the low rate of regional strain, that takes a long time to accumulate and release. At the beginning of the 90's Costa Rica was struck by a seismic crisis whose main earthquakes occurred on March 25th 1990 on the Pacific side, December 22th 1990 in central Costa Rica and on April 22th 1991 on the Caribbean side. During that seismic crisis tectonic stress was released in the area generating the 1993 earthquake known as the Pejibaye earthquake.

Fan *et al*. (1993), studied the 1991 Limon earthquake, the most important event of the 90´s seismic crisis. They suggested that a diffuse transcurrent fault zone trending northeast-southwest and composed of various sub parallel strike-slip faults exists in Costa Rica. They claimed that this fault zone extends from the Pacific coast to the Caribbean coast near Limon across central Costa Rica, and that it may represent a possible plate boundary for the proposed Panama Block. This idea has been mentioned in later works (Fisher *et al*., 1994; Güendel & Protti (1998); Quintero & Guendel, 2000; Marshall *et al*., 2000; Montero, 2001; Trenkamp *et al*., 2002; Linkimer, 2003), Fisher *et* *al*. (1994) proposed that the Cenozoic deformation of central Costa Rica corresponds to the western boundary of the Panama microplate. That deformation was referred to as the Central Costa Rica Deformed Belt (Marshall *et al*., 2000) and it was identified as the tectonic boundary between the Caribbean plate and the Panama Block. Montero (2001) argued that this tectonic boundary is diffuse, and Linkimer (2003) proposed a width larger than 100 km for that boundary. However, Fernández *et al*. (2007) found no evidence of this limit and suggested that the deformation and the seismic anomaly of central Costa Rica are due to the subduction of seamounts under the Caribbean plate.

This paper discusses the 1993 Pejibaye seismic sequence and the seismicity and faulting of an area that extends from the epicenter of the 1993 Pejibaye earthquake to the Caribbean coast of Costa Rica. The purpose of the study is to understand the source of the 1993 Pejibaye seismic sequence and the alleged sub parallel strike-slip faults reported by Fan *et al*. (1993).

Tectonic framework

The major regional tectonic features that define the tectonic framework of this study include the Middle American Trench (MAT), the North Panama Deformed Belt (NPDB) and the Panama Fracture Zone (PFZ). Collision of the Cocos and Caribbean plates occurs at the Middle American Trench (MAT, Fig. 1), western boundary of the Caribbean plate. The convergence rate increases from northwest to southeast along the trench from about 7.3 cm/yr off Mexico and Guatemala to 9.9 cm/yr in western Costa Rica (DeMets, 2001; Montero, 2000).

Moderate earthquakes are nearly uniformly distributed along the MAT. The northeast dipping slab goes down to a maximum depth of 200 km under western Costa Rica (Protti *et al*., 1994) but to only 70 km in southern Costa Rica (Arroyo, 2001). Shallow subduction under the southern end of MAT is due to the buoyant Cocos ridge that impinged the trench ~5 Ma (de Boer *et al*., 1995),

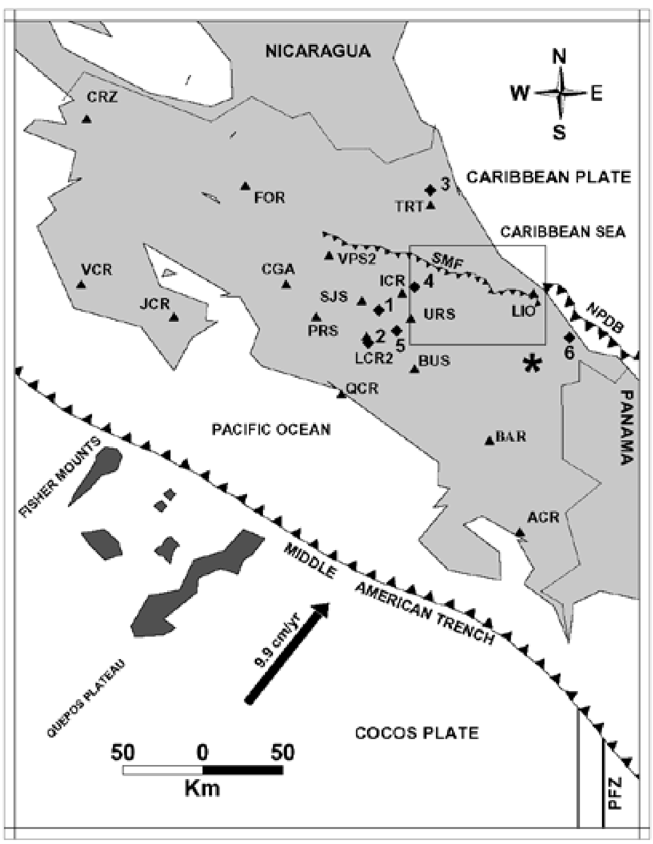

Fig. 1. Map of Costa Rica and seismic stations. Nearby tectonic features and a belt of seamounts (black areas offshore) are shown. Triangles represent seismometers of the Red Sismológica Nacional (RSN: ICE-UCR) and diamonds correspond to seismic stations of the Observatorio Vulcanologico y Sismológico de Costa Rica (OVSICORI) used in this study; 1:OCM, 2: LARO, 3: CDL, 4: VTU, 5: RMCR, 6: FICA. The asterisk shows the location of the 1991 Limon earthquake. The box indicates the studied area. PFZ: Panama Fracture Zone, SMF: Siquirres-Matina Fault and NPDB: North Panama Deformed Belt.

causing a decrease in the volcanic activity in this region. Subduction of the Cocos ridge and a of seamount belt which rises almost 2 km above the seafloor generated uplift and significant deformation of the arc.

The NPDB extends off the Caribbean coast from the Panama-Colombia border up to coast of Costa Rica northwest of Puerto Limón (seismic station LIO). This overthrust feature originated from the convergence of the Caribbean plate and the Panama block, but it is not clearly related to the subduction zone. It may be explained by a movement of blocks within the Caribbean plate (Adamek *et al*., 1988; Silver *et al*., 1990). Recent recorded seismicity in north central Panama associated with the convergence between the Caribbean plate and the Panama block shows that events in this region can reach depths of 70 km.

The Panama Fracture Zone, a dextral N-S striking oceanic transform fault, is the plate boundary between the Cocos and Nazca plates. This 150 km wide fracture zone extends from near the Equator to 6° N, where it splits into a series of parallel north-west trending dextral strike slip faults. The PFZ shows high seismic activity and has generated large (Ms > 7.0) events

Data and methodology

The seismic data of the Pejibaye sequence were obtained from the Red Sismologica Nacional (RSN: ICE-UCR) for the period July-September 1993. Waveforms from the Observatorio Vulcanológico y Sismológico (OVSICORI) of the National University for the three main events of the sequence were also used in this work. Three seismic data sets were used to infer the details of seismic activity within the study area: (1) Protti & Schwartz´s (1994) relocated events for the time period May 9 to 20,1991 with Md > 2, (2) Ponce *et al.*´s (1994) relocated events for the time period April 29 to May 3, 1991–with Ml > 2 and, (3) Linkimer´s (2003) relocated events for the time period 1992-2002 with Ml > 2. Data sets (1) and (2) provide information on the aftershock activity of the 1991 Limon earthquake, whereas the third data set provides accurate information on the location of events along most of the seismic zone. Fault information was obtained from Montero (2001), Denyer *et al*. (2003) and Linkimer (2003).

Earthquake waveforms from events in the Pejibaye seismic sequence were reviewed to determine the arrival times of the P and S waves for at least six seismograph stations (TRT, LIO, LCR2, BUS, URS and ICR, fig. 1). Each earthquake was located with 4 or more stations and at least two S phases. The average RMS of the locations is 0.20 and the average error location in longitude, latitude and depth are 2.9 km, 1.7 km and 3.9 km respectively.

SEISAN Sismological Seismic Analysis (Havskov and Ottemøller, 1999), Hypocenter program and the local one-dimensional velocity structure (Protti & Schwartz, 1994) in Table 1 were used to relocate the earthquakes.

Table 1

Local crustal model used in this work.

Layer	Vp, km/s	Vs, Km/s	Depth, km
1	5.10	2.97	0.00
2	5.90	3.43	4.00
3	6.60	3.84	16.0
4	7.73	4.49	30.0
5	8.20	4.77	80.0

Computer program FOCMEC systematically searched the focal sphere for valid solutions based on *P*-wave polarities (Snoke *et al*., 1984) for four earthquakes of the 1993 Pejibaye sequence. These inversions were carried out with a set of nearby seismic stations which included the stations of the RSN and 6 additional stations of OVSICORI (OCM, LARO, CDL, VTU, RMCR, FICA). The inversion searched the focal sphere in 5 degree increments.

Faulting

As in most of Costa Rica, the east-central area contains a number of active faults. These faults generally run in a northwest-southeast direction and are due to crustal stresses associated with movement of the Cocos and Caribbean tectonic plates. From east to west the major active faults are Rio Blanco, Siquirres-Matina, Ayil, Pacuare, Kabebeta, Atirro, Pejibaye, Navarro and Simari (Fig. 2). Often the traces of these faults are marked by river valleys and canyons as in the Turrialba area where the Atirro, Pacuare and Pejibaye faults run along the corresponding rivers.

The Rio Blanco fault has been considered active and of great importance to the tectonic pattern of eastern Costa Rica. Apparently it connects the large northwest trending reverse faults on the Caribbean side of Costa Rica. It is an oblique fault striking northeast. According to Montero (2001) this fault is a ramp connecting the Siquirres-Matina fault with the North Panama Deformed Belt.

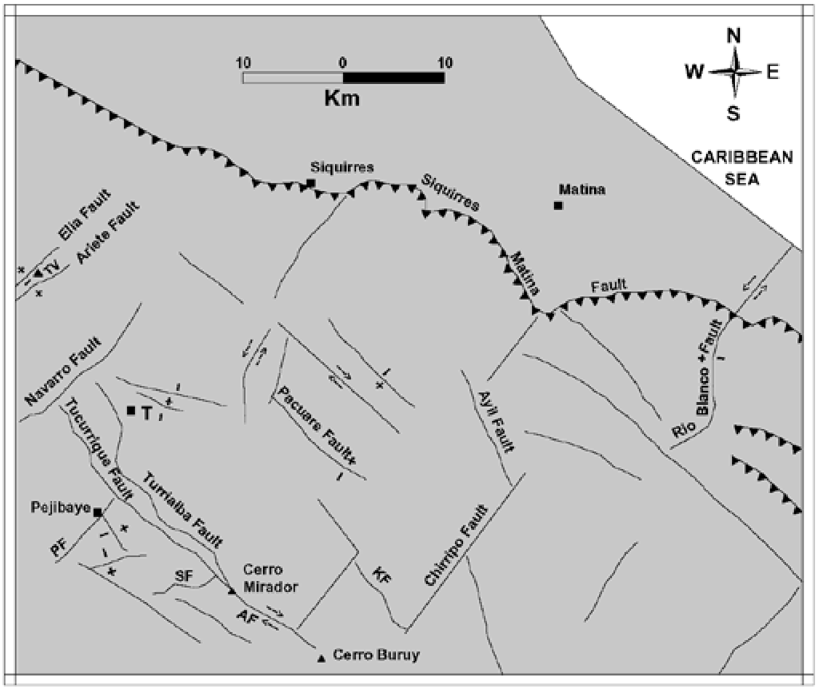

Fig. 2. Map of faults. TV: Turrialba Volcano, T: Turrialba, PF: Pejibaye fault, AF: Atirro fault, KF: Kabebeta fault, SF: Simari fault. Solid lines are mapped faults. ± : normal faults, triangles along solid lines indicate thrust faults, arrows in opposite directions indicate strike-slip faults. Squares are cities.

The Siquirres-Matina fault is characterized by high topographic relief with uplifted terraces and deep -narrow river valleys over much of its length (Soulas, 1989). It is a 80 km long reverse fault that runs almost the entire length of the study area from southeast to northwest, clearly marking the eastern boundary of the Talamanca and Central Volcanic ranges, as well as the beginning of the Caribbean plain. Linkimer (2003) extends this fault toAguas Zarcas de San Carlos (not shown) for a total distance of 150 km.

Chirripó is a northeast striking fault that runs through the Chirripo River. The fault forms a long, straight linear valley that cuts through the Talamanca Cordillera. Viewed from the air, the linear arrangement of the Chirripo River is striking. According to Denyer *et al.* (2003) it has not been active during the Quaternary.

The Ayil, Pacuare and Kabebeta faults strike northwest. The Ayil fault is a high-angle lineament characterized by linear valleys, fault saddles and a large landslide along its trace (Montero, 2001). Pacuare is a strike-slip fault with reverse component of motion defined by linear valleys, scarps of 60-100 m, triangular facets, offset rivers and abandoned meanders (Linkimer, 2003). The Kabebeta fault combines dextral and reverse slip (Montero, 2001) and is characterized by fault trenches, fault berms and displaced streams, rivers and alluvial deposits.

One of the most obvious geologic features in central eastern Costa Rica is the Atirro fault. It forms a continuous narrow break in the Earth's crust that extends for approximately 80 km from cerro Buruy to northwest Turrialba. At Cerro Mirador, the main trace splits up. The eastern branch of the fault is known as the Tucurrique fault. The western strand is known as the Turrialba fault, because of its location near that community. Both the Tucurrique fault and the Turrialba fault show evidence of surface rupture within the Holocene, so they probably accommodate a sizable fraction of the total slip of the Atirro fault zone. Triangular facets, offset rivers, uplifted terraces, anomalous patterns of river channels and staggered scarps (Montero, 2003) are some characteristic geomorphic features associated with this fault. Valdéz & Mora (1985) suggested normal slip for this fault but Montero (2000) gives evidences of dextral motion. Given its proximity to population centers and important infrastructure in the area, the fault warrants close scrutiny in terms of seismic hazard analysis of the region.

The Pejibaye fault strikes N50°E and according to Valdez & Mora (1985) it is a normal fault. The fault is evident in some places along the Pejibaye river where tilted alluvial deposits strongly suggest neotectonic movement (Mora, personal communication).

The 54 km long Navarro fault is a left-lateral strike-slip fault with a clear normal component (Montero, 2001) which extends along the Navarro River in central Costa Rica (not shown) to northern Turrialba in the study area where it appears to end. It is characterized by linear valleys, scarps, antiscarps, fault saddles and 7 sinistral displacements of river channels ranging between 150-1000 m (Linkimer, 2003). Simari is an almost east-west strike-slip complex fault (Montero, 2000)

The 1993 Pejibaye sequence

The Pejibaye sequence started with an isolated magnitude 4.9 foreshock on July 8th, 1993. Two days later, on July 10th, the 5.3 magnitude mainshock and many aftershocks occurred. The main aftershock took place on July 13th. During July and August the activity continued and it practically ended in September.

The 1993 Pejibaye earthquake was the most damaging earthquake to occur in Turrialba. It caused extensive damage in seven localities near Turrialba and remains the most destructive earthquake in the region, resulting in one fatality and several injuries. The shaking from this earthquake was the strongest ever recorded in Pejibaye and surrounding towns. It produced severe damage on masonry and wooden buildings. The event occurred near the epicentral area of the 1991 Limon earthquake; it triggered landslides and was felt as far as Limon (not shown) in the East.

In a attempt to determine the source for the Pejibaye seismic sequence, 121 events were located with nearby seismic stations and a local velocity structure (Fig. 3A). The epicenters were concentrated in a rectangular area of 8 km x 5 km to the southeast of Pejibaye. The orientation of this area coincides with the strike of small northeast faults.

The epicentral distribution of this sequence clearly shows that the source was a northeast oriented fault. The epicenters of 30 events whose locations included the easternmost station LIO are shown in Fig. 3B. In map view, the cluster is elongated in the SW-NE direction.

The cross section A-B (Fig. 3C), which extends from Pejibaye to the coordinates 83°36'W-9°42'N, shows the hypocenters of the earthquakes in fig. 3B. Note that the hypocenters of those 30 events are grouped in a narrow depth range, from 0 to 15 km. A fault plane intersecting the surface at p3 and dipping 76° northwest explains satisfactorily the distribution of hypocenters observed in fig. 3C. That northwest dipping fault better matchs with the hypocenter distribution of the Pejibaye earthquake. According to this, the Simari fault would be the fault plane of the seismic activity. Consequently, the Simari fault would be a high angle fault with high normal component.

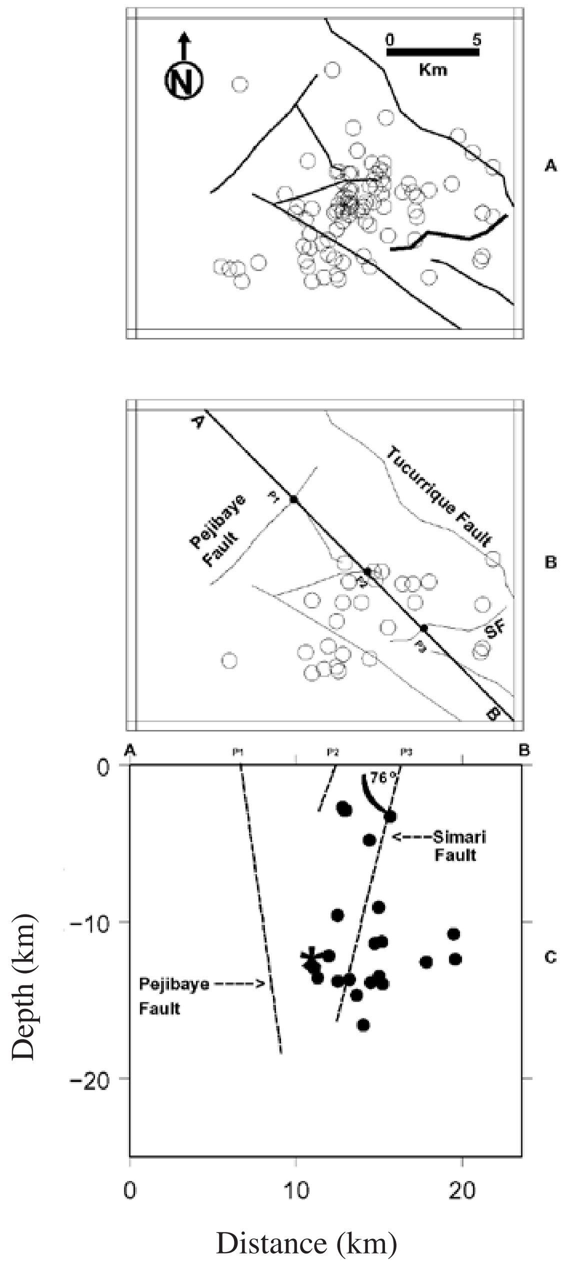

Fig. 3.A: Epicenter distribution of 121 earthquakes from the Pejibaye seismic sequence. The earthquakes form a trend from southwest to northeast. B: The best locations of the seismic sequence. AB: Cross-sectional line; p1, p2 and p3 are intersections of fault traces with the cross-sectional line. SF: Simari Fault. C: Cross-sectional view showing the locations of earthquakes beneath the epicenter of the 1993 Pejibaye earthquake. The cross-section represents a vertical slice of the crust downward from line A-B in the map view (B). The asterisk shows the main event of the sequence.

Earthquake source analysis

Fault-plane solutions have been determined for two foreshocks, for the main shock, and for the main aftershock of the Pejibaye seismic sequence (Fig. 4). The source parameters of all the 4 events are summarized in Table 2. For the main event, only two solutions were found, with a good estimation of the focal mechanism and the proper selection of the fault plane. In the case of the foreshock and the main aftershock, the inversion yielded a group of similar solutions. All the solutions are shown in the appendix.

For the main shock two fault plane solutions with NE and almost N strike azimuths, respectively, are determinable from the polarity of the P waves. The NE plane, that can be taken as the fault plane, has a strike azimut of 262 and a dip of 70/76° to the northwest. The N nodal plane is restricted by the data to have an azimut of 1.11 and a dip of 58.6 to the East. If the NE nodal plane is taken as the fault plane, the motion was predominantly dip-slip on a high-angle fault, the northwest side moving to the northwest. However, according to Angelier (1979) such solution corresponds to a strike-slip fault with a normal component. The northeast plane of the solutions fits very well with the geological arrangement of the epicentral area. On the contrary, the north-south plane is inconsistent with the set of faults located near Pejibaye.

Other focal mechanisms also show a NE nodal plane that closely resembles the NE plane of the main event. The fault-plane solutions obtained show normal faulting with a small strike-slip component.

The solution for the main event is not in close agreement with the solution reported by the USGS/NEIC, July 1993 (Fig. 4). The National Earthquake Information Center (NEIC) reported a pure strike-slip focal mechanism for the main event of the sequence which was located at 20 km depth. The fault-plane determination was poor and does not match with the geology of the area**.** In fact, the NEIC location is out of the epicentral area.

The focal mechanisms suggest that an oblique NE fault, dipping to the northwest generated the 1993 Pejibaye seismic sequence. That fault ruptured along a short length but never broke through to the surface. The maximum magnitude expected for a 10 km long normal fault is 6,5 (Ml) according to Matsuda (1977). Then, the 1993 Pejibaye earthquake was generated by a fault whose length is smaller than 10 km.

Table 2

Fault parameters for the best fault-plane solution of each event

Solution	Strike MP	Dip MP	Rake MP	Strike AP	Dip AP	Rake AP
1 MF	263.14	63.94	-44.31	16.36	51.13	-145.64
2 F	239.58	68.53	-57.5	359.45	38.29	-143.8
3 ME	262.37	75.97	-32.40	1.11	58.68	-163.52
4 MA	240.48	43.96	-22.18	346.83	74.81	-131.76

Note. MP: Main Plane, AP: Auxiliary Plane, MF: Main foreshock, F: Foreshock, ME: Main event, MA: Main aftershock.

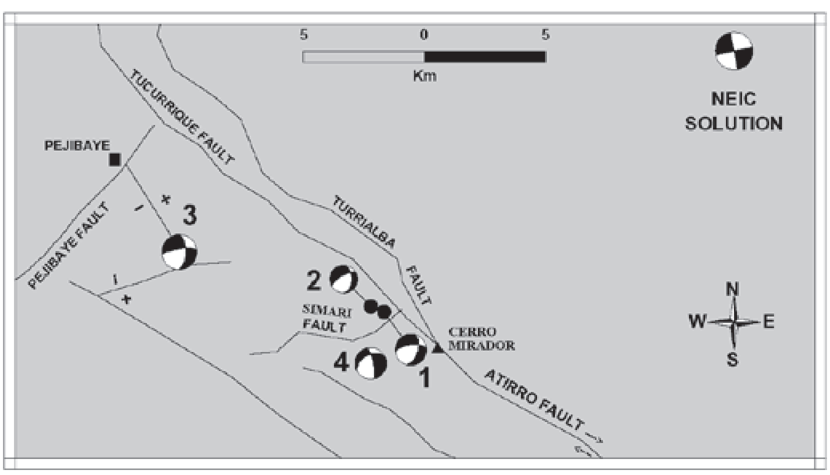

Fig. 4. Best fit focal mechanisms determined from P wave modelling for 4 events of the1993 Pejibaye seismic sequence. 1: Main foreshock, 2: Foreshock, 3: Main event, 4: Main aftershock The solution reported by NEIC to the right.

Is the area cut by a NE strike-slip tectonic boundary?

Güendel & Protti (1998), in their regional-scale study about seismicity and seismotectonic of Central America, proposed a shear zone along central Costa Rica as follows:

1-It crosses the country along an east-west axis.

2-It extends from Puerto Limon in the Caribbean to the Gulf of Nicoya in the Pacific.

3-It crosses the tectonic trough of the Central Valley of Costa Rica.

4-It connects the North Panama Deformed Belt to the Middle American Trench.

5-It is due to the propagation of the NPDB.

6-It consists of northeast shallow left-lateral strike-slip faults.

7-It is a narrow and almost linear structure in the Caribbean side of Costa Rica.

8-It is a strike-slip tectonic boundary.

If this strike-slip tectonic boundary exists, clear evidence of the NE sub parallel strike-slip set of faults proposed by Fan *et al*. (1993) and Güendel & Protti (1998) should be present within the studied area. According to Güendel & Protti (1998) and Marshall *et al*. (2000), the strike-slip boundary is a narrow linear structure on the Caribbean side of Costa Rica, and the sub parallel NE strike-slip faults of Fan *et al*. (1993) and Güendel & Protti (1998) must be active and must have associated seismicity along a NE trend. Faulting and seismicity should reflect a narrow NE band of deformation with a strike-slip structural style. The next sections discuss the faulting pattern and the seismicity of the area, as related to the tectonic deformation of central Costa Rica.

Faulting pattern

By observing the fault pattern (Fig. 5), we may conclude that northwest-striking faults dominate in the area. Among the most important and better known northwest faults are Atirro, Pacuare, Ayil and Siquirres-Matina. The last one is the largest of the studied area and it is a reverse fault considered as the inland prolongation of the North Panama Deformed Belt (Soulas, 1989). According to this consideration, the possible tectonic boundary within Costa Rica would be compressive and located in the back arc of the country. The Siquirres-Matina fault is more realistic than the proposed strike-slip structure along central Costa Rica, and therefore, a possible tectonic boundary should be looked for in the back arc not within the inner arc. It is quite improbable that both the strike-slip and the compressive boundary coexist in the narrow territory of Costa Rica.

Northeast trending conjugate faults are also present. The northeast faults are shorter than the northwest ones and show a different sense of motion. For instance, the Navarro fault, a strike-slip fault, is located between Elia,

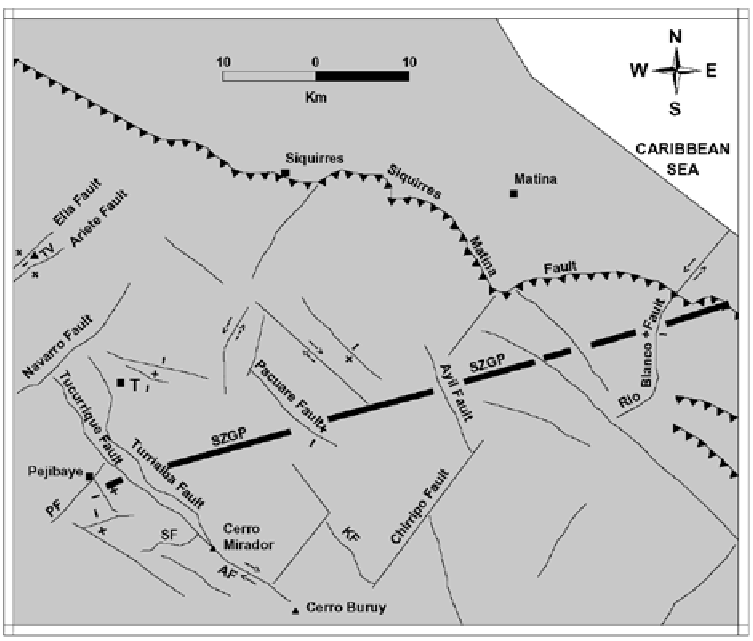

Fig. 5. Faulting and the linear shear zone (SZGP) proposed by Güendel & Protti (1998).

Ariete and Pejibaye faults, three recognized normal faults. The parallelism of northeast faults exists but it is not evidence of a strike-slip tectonic boundary because the parallel faults have very different motion. The Chirripó Fault, an important northeast fault was not actived by the Limón earthquake and is considered inactive (Denyer *et al*., 2003).

Contrary to the proposal of Güendel & Protti (1998) the faulting of this work does not suggests any linear northeast shear zone in the Caribbean side of Costa Rica. Neither the set of sub parallel NE strike-slip faults suggested by Fan *et al*. (1993) nor the shallow sinistral strike-slip faults proposed by Güendel & Protti (1998) are represented by the faults of this study. Even more, the shear zone proposed by Güendel & Protti (1998) cuts 5 northwest faults and 1 northeast fault (Río Blanco) and there is no parallelism between the proposed shear zone and the NE faults.

Another important difference of this work with respect to Güendel & Protti (1998) is the prolongation of the NPDB within the territory of Costa Rica. For Güendel & Protti (1998) that prolongation is an east-west trending shear zone cutting across central Costa Rica. In this work, the reverse northwest Siquirres-Matina fault system is the propagation of the NPDB in the continental area of Costa Rica (Soulas, 1989). This northwest striking fault system runs parallel to the flanks of the Central Volcanic and Talamanca Ridges and marks the limit between the inner arc and the back arc of Costa Rica.

Seismicity of the Pejibaye-Matina region

The earthquake activity in the studied area reveals a pattern of low background seismicity with no significant historic earthquakes. Scattered seismicity has been recorded along some faults. With the exception of the energetic 1993 ML 5.3 Pejibaye earthquake, rates of microseismicity have been low since digital waveform data became available in 1992.

Fig. 6 shows the microseismicity of the study area between 1991 and 2003. Two notable clusters constitute the most relevant features of the seismicity, a) the aftershock activity of the 1991, $M_S = 7.6$, Limon and b) the 1993, M_S $=5.3$ Pejibaye earthquakes. The cluster associated with the Limon earthquake occurred 40 km east of Pejibaye at depths of 10–20 km. This cluster is near the Chirripo fault as mapped by Denyer *et al*. (2003). In map view the events are roughly aligned in a pattern consistent with a northwest-striking active fault, that of the North Panama Deformed Belt which also generated the large earthquake. As shown in Fig. 6, the events of Pejibaye align along a northeast-southwest trend which is about 15 km long, and the seismicity is concentrated along a narrow belt (Fig. 6), suggesting a narrow and well-defined fault zone.

In recent years there have been several earthquakes recorded around Turrialba city. The epicenter distribution shows two groups of seismicity. One group locates north of Turrialba and may reflect deformation and movement along the Navarro fault. The other seismicity group

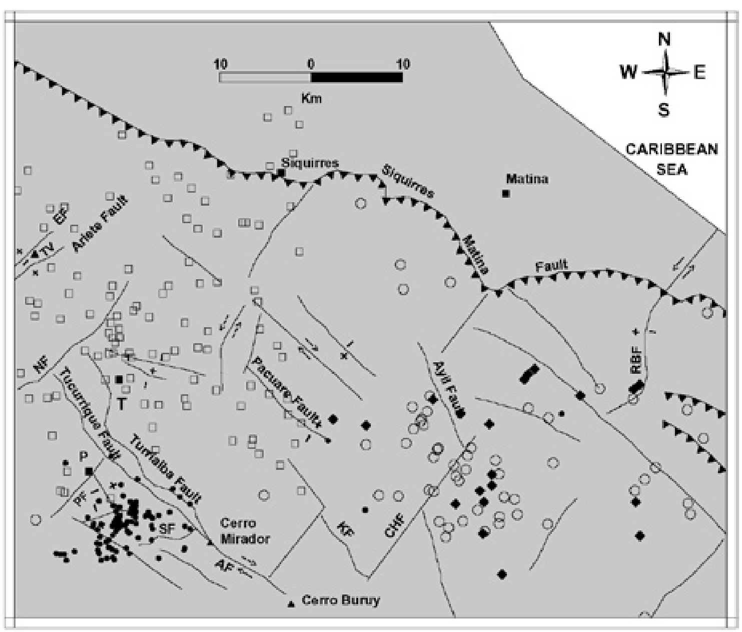

Fig. 6. Seismicity of the Pejibaye-Matina area. Ponce et al.´s (1994) locations are indicated as diamonds, Protti & Schwartz´s (1994) locations correspond to open circles and Linkimer´s (2003) epicenters are represented as open squares. Black circles are locations obtained in this work. T: Turrialba, P: Pejibaye, EF: Elia Fault, ARF: Ariete Fault, NF: Navarro Fault, PF: Pejibaye Fault, SF: Simari Fault, , AF: Atirro Fault, KF: Kabebeta Fault, CHF: Chirripó Fault, RBF: Río Blanco Fault.

locates east of Turrialba city and can be associated to a normal fault located in that sector. The shallow-focus, small-magnitude earthquakes occur sporadically without damage to the structures or infrastructure.

The seismicity along the Siquirres-Matina fault shows two distinct and very different characteristics. The southeastern segment is characterized by the absence of shallow events, while the northwestern segment seems more active and capable of generating seismic activity. Felt earthquakes and small-magnitude shallow events near Siquirres suggest activity along this segment of the Siquirres-Matina fault. The absence of seismicity in the alluvial plane emphasizes the relative seismic quiescence of the neighboring Siquirres-Matina fault to the southeast. Hence, the paucity of earthquakes between the Siquirres and Río Blanco fault could mark an important seismic gap in the zone (Soulas, 1989).

A seismic surveillance by the RSN reveals few earthquakes along the Atirro fault. The lack of earthquakes is thought to be related to very long recurrence time for large earthquakes, or to ductile aseismic slip on the interface between the faulted blocks.

Near the central segment of the fault there are some earthquakes aligned parallel to the fault suggesting an association with this fault. However, it is difficult to confirm this hypothesis because Pejibaye and other faults are also close to the seismicity and the number of earthquakes is small.

The sparse seismicity provides some information on the origin of the stress affecting the area. In map view we observe that earthquakes are more common in the west on the flanks of the cordilleras. To the east, the seismicity is less frequent, implying lower strain rates. This suggests that most deformation stress is related to the Cocos-Caribbean collision to the southwest. As it is expected, the stresses generated along this margin propagate into the inner arc and become weaker in the back arc. The large and sporadic seismic episodes of the Caribbean side of Costa Rica appear to be related to Cocos-Caribbean compression or large tectonic earthquakes in the Pacific side such as the 1990 Cobano event.

Deformation

The basic argument of Fisher *et al*. (1994), Marshall *et al*. (2000), Montero (2001) and Linkimer (2003) in favor of a strike-slip tectonic boundary through central and eastern Costa Rica, which includes the study area, is the observed deformation. This argument requires that the deformation is constrained to the continental area between the shore and the inner arc. But that is improbable because the entire trench-inner arc space is highly deformed (Fig. 7), and therefore, it is not appropriate to restrict such deformation to just the continental area of central and eastern Costa Rica, and neither is it appropriate to consider the entire trench-inner arc space as a tectonic boundary.

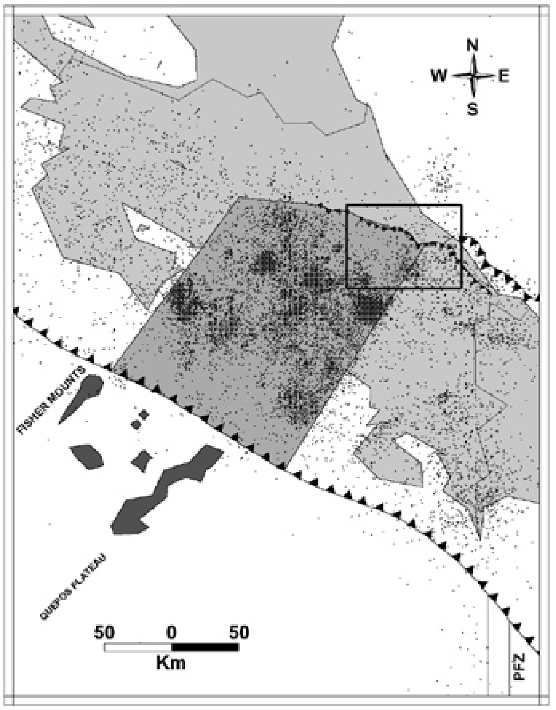

Fig. 7. Deformation in central Costa Rica. The shaded area is a highly-deformed trench-backarc zone in central Costa Rica. That zone is in front of the seamount belt and contains a seismic anomaly. The box is the studied area. PFZ: Panama Fracture Zone.

Faulting and underwater landslides scars (Fernández *et al*, 1997; Ranero & von Huene, 2000) within the trench-inner arc space in central and eastern Costa Rica indicate that it has undergone internal deformation in the past in response to the Cocos-Caribbean compression, and current seismicity within the Caribbean plate confirms that this deformation continues to the present. The 1990 Nicoya Gulf, 1999 Quepos (Rojas & Redondo, 2002; Bilek *et al.*, 2003) and 2004 Parrita (Rojas, Personal communication) events are good examples of the deformation occurring in and near the continental platform. High offshore seismicity demonstrates that the trench-shore space of central and eastern Costa Rica is highly deformed as well as the shore-inner arc space.

The clear fact is the deformation of the trench-inner arc space in front of the seamount belt of the Cocos plate which suggests that subducted seamounts are playing an important role in deforming the Caribbean plate in front of them.

In conclusion, there is no compelling evidence for a strike-slip tectonic boundary within the study area. This area is part of the trench - inner arc space, a highly deformed zone that is probably a consequence of the collision of the seamount belt with the Caribbean plate.

Conclusions

Earthquake epicenters of the 1993 Pejibaye earthquake sequence reveal a dominant alignment parallel to SW-NE trending faults south of Pejibaye. Earthquakes were located to the southeast of Pejibaye at depths of 0 to 15 km. Fault plane solutions for the Pejibaye earthquake provides evidence that a northeast oblique fault dipping 70 – 76° northwest generated the 1993 Pejibaye Earthquake. The alignment of earthquakes and the fault plane solutions strongly suggest that Simari was the main fault involved in the generation of the 1993 Pejibaye Seismic Sequence.

The background seismicity of the Pejibaye-Matina area is relatively low due to a weakly stressed crust and only seems to increase after large nearby earthquakes. Epicenters indicate that the northwestern and northeastern oriented faults generate earthquake seismicity. The most conspicuous sources of earthquakes are in the mountain belt, within the inner arc. Earthquakes occurring along northeast trending faults are expected to be less frequent.

The dominant trend of faulting in the study area is northwest. Neither the set of sub parallel strike-slip faults which comprises a transcurrent fault zone trending northeast-southwest proposed by Fan *et al*. (1993) nor the linear shear zone of Güendel & Protti (1998) are supported by the faulting of the studied area. Therefore, any larger geologic trend such as the tectonic boundary previously proposed is not evident and can not be inferred from the observed surface faults and earthquake activity.

Acknowlegments

Earthquake data were provided from the Red Sismológica Nacional data management Center. This work was possible through research grant No. 805-99-259 from the Vicerrectoría de Investigación of the Universidad de Costa Rica to the Center for Geophysical Research. The author is grateful to the Consejo Nacional de investigaciones Científicas y Tecnológicas (CONICIT) of Costa Rica for additional financial support. My gratitude to Diane Doser for her comments and suggestions. Special thanks to Conrad Lindholm and an anonymous reviewer for their comments and recommendations which improved the manuscript.

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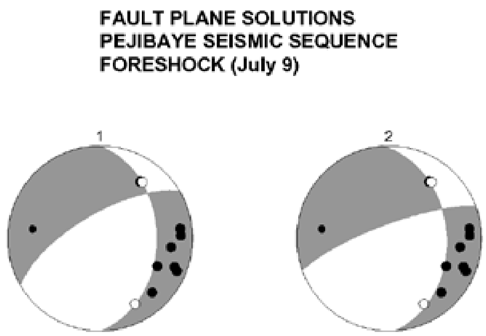
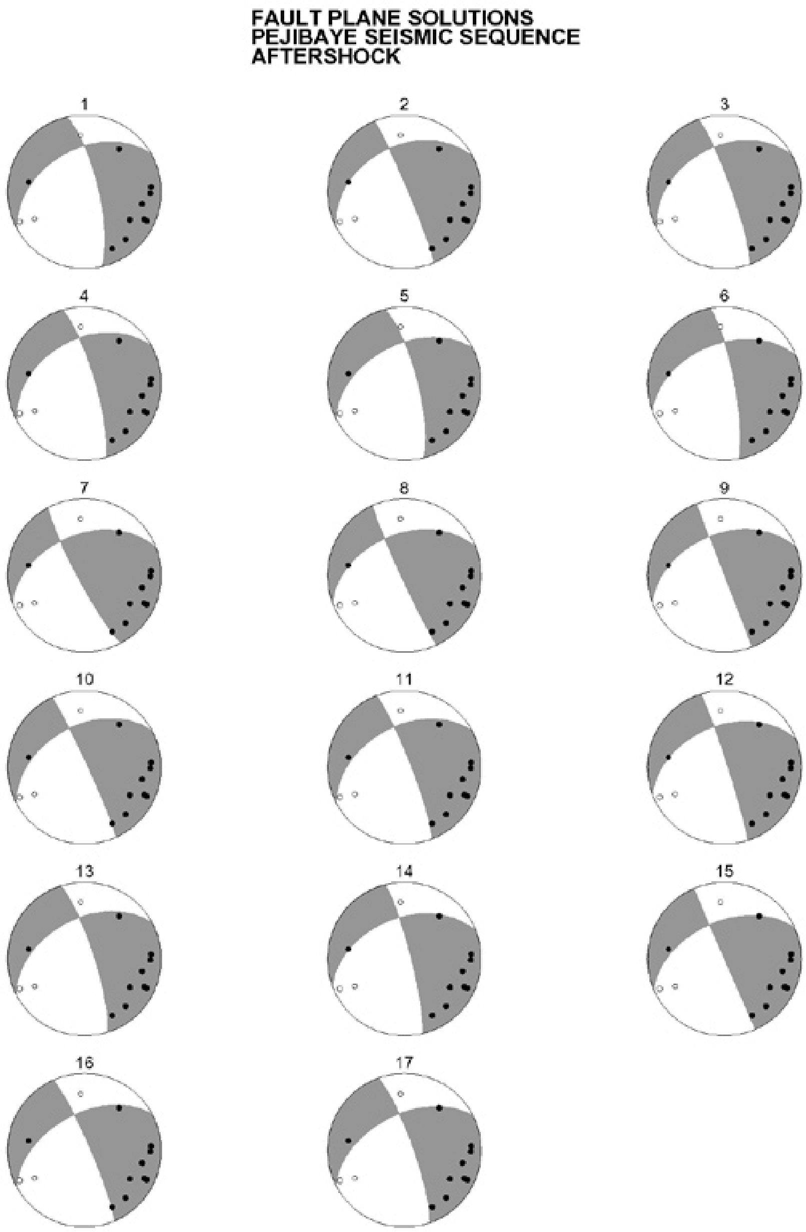
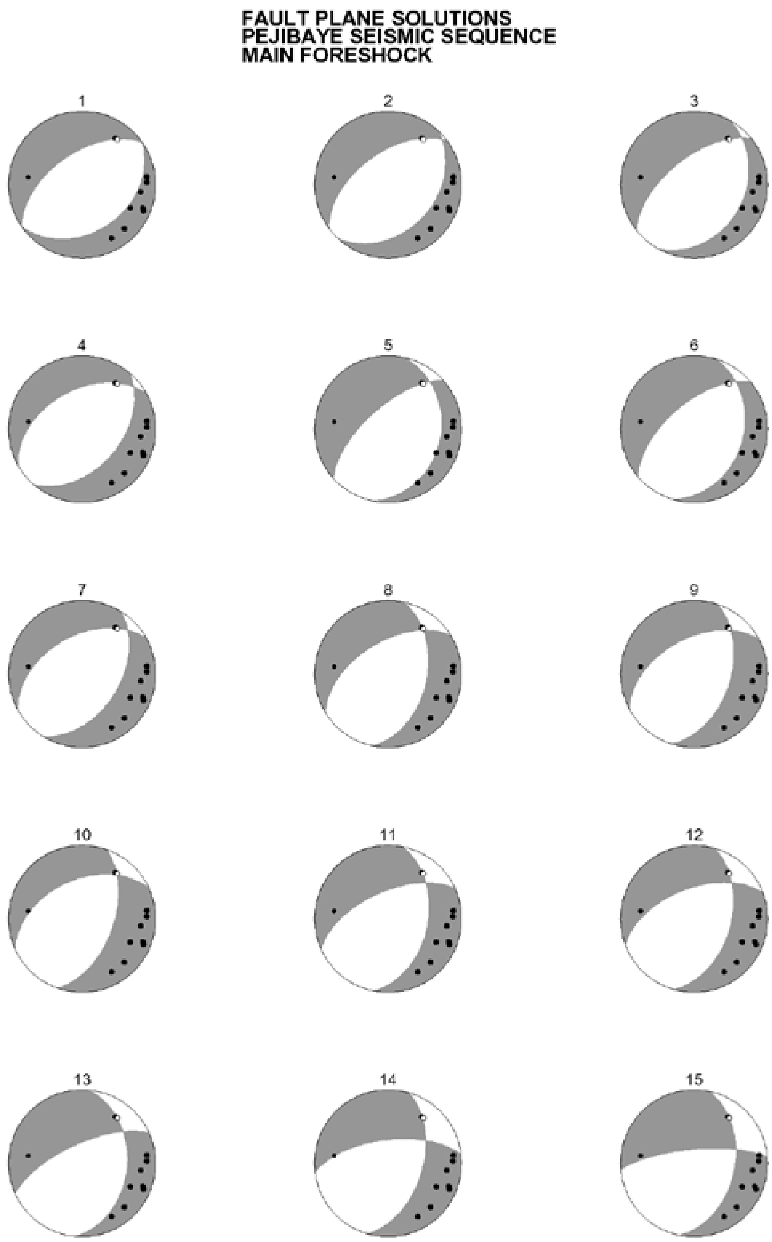
Appendix

Fault plane solutions



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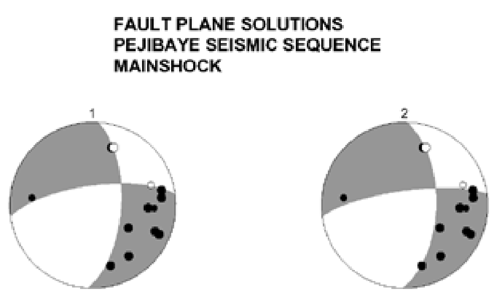
FAULT PLANE SOLUTIONS
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