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Paper:

Fault Distribution, Segmentation and Earthquake Generation Potential of the Philippine Fault in Eastern Mindanao, Philippines

Jeffrey S. Perez*, **Hiroyuki Tsutsumi****, **Mabelline T. Cahulogan***, **Desiderio P. Cabanlit***, **Ma. Isabel T. Abigania***, **and Takashi Nakata*****

*Philippine Institute of Volcanology and Seismology – Department of Science and Technology (PHIVOLCS-DOST)
PHIVOLCS Bldg., C.P. Garcia Avenue, U. P. Diliman Campus, Quezon City 1101, Philippines
E-mail: jeffperez02@yahoo.com
**Department of Geophysics, Kyoto University
Kitashirakawa-oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan
***Department of Geography, Hiroshima University
Higashi-Hiroshima 739-8522, Japan
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The 1,250-km-long, NNW-trending, arc-parallel Philippine fault, one of the world's most active tectonic structures, traverses the Philippine archipelago and has been the source of surface-rupturing earthquakes during the last four centuries. In this paper, we will discuss Philippine fault distribution and segmentation in Mindanao Island by integrating detailed fault mapping together with new geological and paleoseismic data and the analysis of historical surface-rupturing earthquakes. Using geometric segmentation criteria, we have identified nine geometric segments separated by discontinuities such as en echelon steps, bends, changes in strike, gaps, steps and bifurcation in the surface trace. Fault segments ranges from 20 to 100 km in length and are capable of generating earthquakes of M_w6.6 to M_w7.4. The results of our study have important implications for earthquake generation potential and seismic hazard assessment of the Philippine fault in Mindanao Island.

Keywords: Philippine fault, fault segmentation, active tectonics, seismic hazard assessment, paleoseismology, Mindanao Island

1. Introduction

The Philippine fault – one of the world's major active faults – transects the Philippine archipelago for about 1,250 km from Luzon Island southward to Mindanao Island. This NNW-trending, arc-parallel, left-lateral strike-slip fault is a major source of large earthquakes in the country [1–5] (**Fig. 1**). The Philippine fault was formed by accommodating the trench-parallel component of the oblique convergence between the Philippine Sea plate and the archipelago along the Philippine trench [2]. The regional location and distribution of tectonic geomorphic features associated with the Philippine fault have been known since the first half of the 20th century and are clearly observable from aerial photographs, satellite and remotely sensed images such as Landsat, SPOT and radar

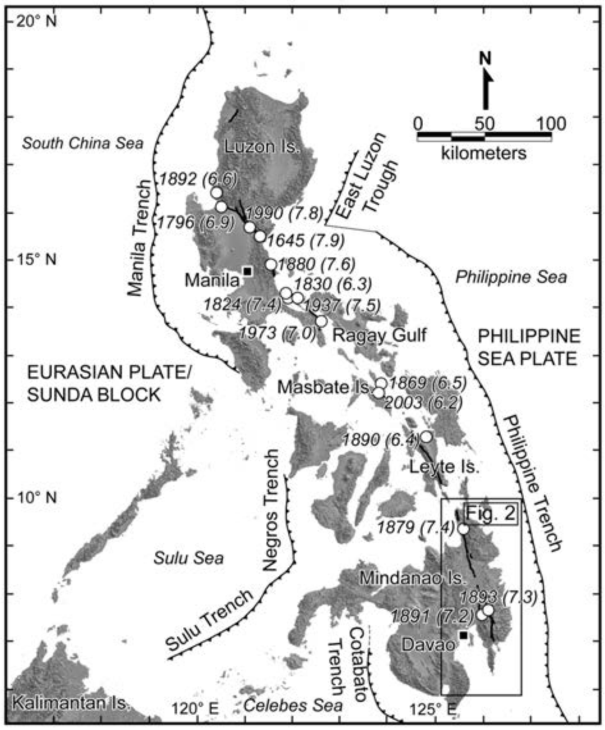

Fig. 1. Seismotectonic setting of the Philippines. Map showing the tectonic structures in the Philippine archipelago, the Philippine fault, and the epicenters (circles) of moderate to large earthquakes of $M_s > 6$ along the Philippine fault from 1700 to 2012. The Philippine fault trace (solid black line) is from Tsutsumi and Perez [5], while the epicenters are from Bautista and Oike [4] and the Philippine Institute of Volcanology and Seismology [31]. The rectangle shows the location of **Fig. 2**. The base map is from SRTM 3-arc-second elevation data.

and in the field [1, 5–11]. The tectonic geomorphic expressions of the fault include offset streams, fault scarps, elongated depressions, sag ponds and pressure and shutter ridges.

The largest, most destructive surface-rupturing earthquake along the Philippine fault in the last century was the 1990 M_w7.8 Luzon earthquake (**Fig. 1**), which was accompanied by a 120-km-long surface rupture with about 6 m maximum horizontal displacement [12]. This earthquake left over 1,600 casualties and damage exceeding 12 billion pesos (500 million US dollars). Other recent surface-rupturing earthquakes along the fault include the 1973 M_l7.0 Ragay Gulf earthquake [13, 14] and the 2003 M_s6.2 Masbate earthquake [15] (**Fig. 1**). The fault's high seismic activity is also deduced from high slip rates ranging from 20 to 30 mm/yr observed by GPS [2, 3, 16]. Tectonically, the Philippine fault has played an important role in the archipelago's complex evolution, situated as it is in a region of broad deformation, high seismicity and active volcanism.

A common global characteristic of major strike-slip faults that is also observed along the Philippine fault is the fact that these active structures are generally not continuous and do not rupture their entire length in a single earthquake, but tend to rupture individual fault segments. Surface rupture may occur along a single segment with its own surface rupture history or it may extend to multiple fault segments [17–19]. Fault segmentation may be geometric or structural and is based mainly on the physical characteristic of the fault trace, or temporal segmentation, which is in turn based on the coseismic behavior revealed in historical surface rupture and paleoseismic studies [17–19]. Temporal fault segmentation is the more reliable method but paleoseismic and historical data are either insufficient or difficult to obtain for some active faults. Recent studies of modern global surface-rupturing earthquakes, for example the 2002 M_w7.6 Denali earthquake, the 1999 M_w7.1 Izmit, Turkey earthquake and the 1990 M_w7.8 Luzon, Philippines earthquake, have revealed that mapped complexities in surface fault geometry, such as changes in strike, step overs, bifurcations and fault bends or gaps, may persist down to the seismogenic zone [19]. These fault characteristics influence the nucleation and termination of faulting processes [19–21]. Releasing steps, for example, may act as barriers to rupture propagation [22] and propagating ruptures may terminate at major steps, bends and in branches or other cross-cutting structures [23].

Fault segmentation studies have been done on other major strike-slip faults of the world such as the San Andreas fault [24], the Median Tectonic Line [25], the North Anatolian fault [26], and the Sumatran fault [27]. In this paper, we will describe the distribution, geometry, characteristics and segmentation of the Philippine fault in eastern Mindanao (**Fig. 2**), using geometric segmentation criteria and integrating paleoseismic and geological information from previous studies. Basic information of the distribution and segmentation of the Philippine fault in eastern Mindanao is crucial in evaluating its earthquake generation potential. It may be used for medium to long term earthquake risk assessments, especially in areas where major population centers exist.

2. Philippine Fault in Mindanao Island

Compared to other segments, the Philippine fault in Mindanao Island has been the subject of few geological studies. Structural analysis using remote sensing images – Landsat, SPOT, radar and aerial photographs – has shown that the Philippine fault in eastern Mindanao is restricted to a well-defined narrow deformation zone [10]. Results of radar images, drainage pattern analysis and field studies suggest that the Philippine fault is a neotectonic structure which initiated after the Eocene and bounds the eastern flank of the Agusan Marsh and Davao Basins (**Fig. 2**) [28]. The Philippine fault extends offshore, south of Mindanao, as revealed by seismic profiles and other geophysical data [29, 30]. Recent mapping using aerial photographs has also shown that the Philippine fault is consists of several segments divided by geometric discontinuities such as steps and branching (**Fig. 2**) [5].

Offshore record of earthquakes reveal subduction of the Philippine Sea plate along the Philippine trench while onshore seismicities suggests movement along segments of the Philippine fault and other nearby active faults. Written historical documents indicate possible surface-rupturing earthquakes such as: the 1891 M_s7.2 Davao earthquake and the 1893 M_s7.3 Monkayo earthquake [4, 11, 32] (**Figs. 1** and **2**). In terms of slip rate, GPS survey campaigns indicate a southward decrease in slip rate along the Philippine fault from 24 mm/yr in Surigao to about 10 mm/yr in Davao [2].

3. Fault Distribution, Characteristics and Segmentation

Building upon the works of Tsutsumi and Perez [5] and Perez et al. [11], we have conducted additional aerial photo interpretation and field investigation to better characterize the location and geometry of the Philippine fault. We used aerial photographs with a scale of 1:30,000 taken in 1979 from the National Mapping and Resource Information Authority (NAMRIA) of the Philippine government to identify tectonic geomorphic features that shows evidence of recent movements of these active faults. We transferred these features onto 1:50,000-scale topographic maps also published by NAMRIA. Additional information on fault characteristics from our most recent field mapping over the last five years have been added together with review of historical and instrumental seismicity in eastern Mindanao [5, 11, 31–34]. Fault maps presented in this paper were reduced for presentation purposes (**Figs. 2** and **3a-d**) while the original 1:50,000-scale fault maps are available at the Philippine Institute of Volcanology and Seismology – Department of Science and Technol-

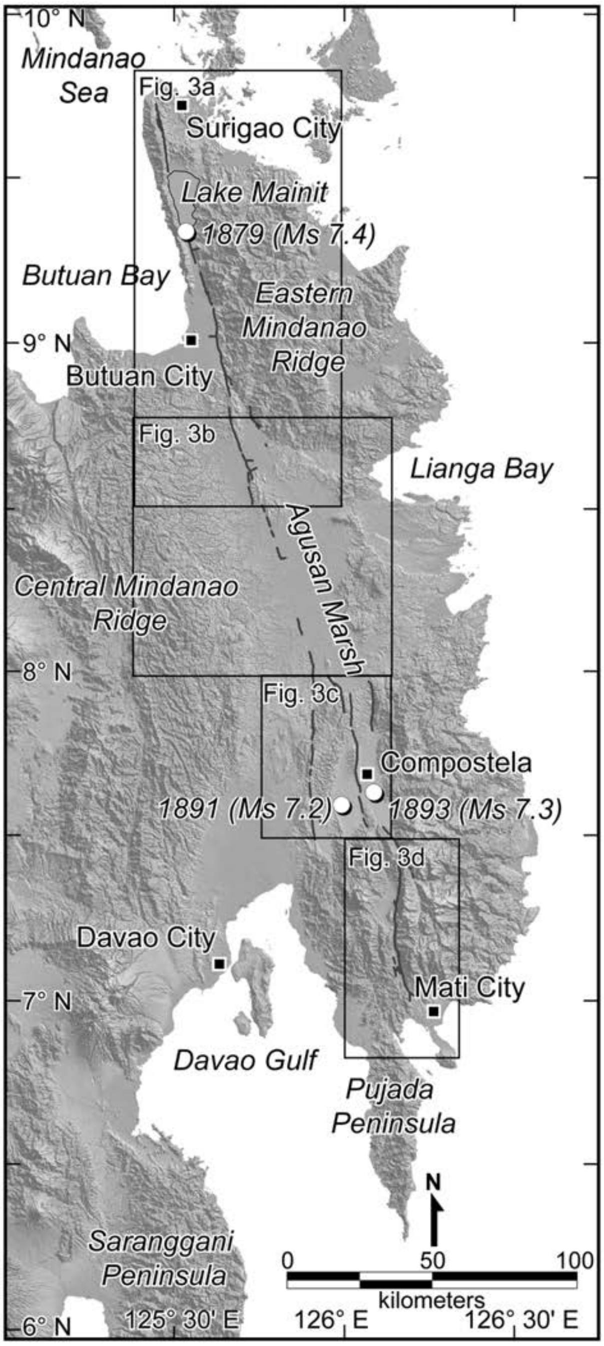

Fig. 2. The Philippine fault in eastern Mindanao and epicenters (circles) of moderate to large earthquakes of $M_s > 6$ along the Philippine fault from 1700 to 2012. The Philippine fault trace is from Tsutsumi and Perez [5] while the epicenters are from Bautista and Oike [4] and the Philippine Institute of Volcanology and Seismology [31]. Rectangles show the locations of **Figs. 3a-d**. The base map is from SRTM 3-arc-second elevation data. See **Fig. 1** for the location of the map.

ogy (PHIVOLCS-DOST) website[1] [5]. We applied the concept of geometric segmentation to identify the different fault segments. We describe here the fault segments identified from north to south.

1. www.phivolcs.dost.gov.ph

3.1. Surigao Segment

Perez et al. [11] described in detail the tectonic geomorphic features of the Surigao segment, which we summarize in this section. From Leyte Island (**Figs. 1** and **2**), the Philippine fault traverses the Mindanao Sea and enters eastern Mindanao Island west of Surigao City (**Fig. 3a**). Between the coastline and Lake Mainit, the fault traverses the eastern margin of Malimono Ridge for about 30 km. From the northern end of this segment, the fault extends to the south for about 4 km where another parallel trace $\sim$ 3-km-long is located about 500 m west of the main trace. The general strike in this area is N15°–20°W.

South of Malimono Ridge, the fault extends to Lake Mainit (**Fig. 3a**), traversing the western edge for about 20 km. South of Lake Mainit, Perez et al. [11] identified a continuous 10-km-long, fresh tectonic scarps that transect Tubay Valley (**Fig. 3a**). In this paper, fresh tectonic scarps are defined as features strongly exhibiting geomorphic evidence of surface rupture. These features are manifested in aerial photographs and in the field. These east-facing tectonic scarps strike N20°W and are 0.5–1.0 m high. At one site, a left-laterally offset stream shows a displacement of about 5.5 m. Perez et al. [11] concludes that the mapped tectonic scarps and the offset creek are related to the surface rupture of the 1879 M_w7.4 Surigao earthquake based on tectonic landforms, paleoseismic results and historical documents.

South of Tubay Valley, no continuous fault scarps are observed because of recent sedimentation along active river systems (**Fig. 3a**). South of this river, no structures are identified for about 4 km. The fault trace steps to the left for about 600 m (**Fig. 3a**) and appears along the western edge of the Eastern Mindanao Ridge, where the fault traverses recent alluvial fans. Several offset creeks are identified and most of the scarps are west-facing and strike N15°–20°W. The fault extends for about 35 km with almost the same strike.

Near the southern end of the Surigao segment, east of Butuan City, the fault strike changes significantly from N15°–20°W to N20°–30°W and the fault branches as it traverses the Eastern Mindanao Ridge (**Fig. 3a**). The main trace continues for about 10 km. West of this main trace is a continuous fault across a 500-m-wide, restraining step (**Fig. 3a**). The changes in the strike, the presence of a restraining step and the branching of the fault to the south characterize the southern end of the Surigao segment.

3.2. Esperanza Segment

South of the Surigao segment is the Esperanza segment (**Figs. 3a** and **b**), which is fairly continuous for about 50 km with a general strike of N15°–20°W. The northern part of this segment traverses the western side of the Eastern Mindanao Ridge. Here, the fault is difficult to access because of the dense mountain vegetation. As it exits the ridge and enters the Agusan Marsh, the fault bends to the right and extends with little change along the fault strike. From this point, we have identified an 8-km-long, east-facing, continuous tectonic scarp located in the munici-

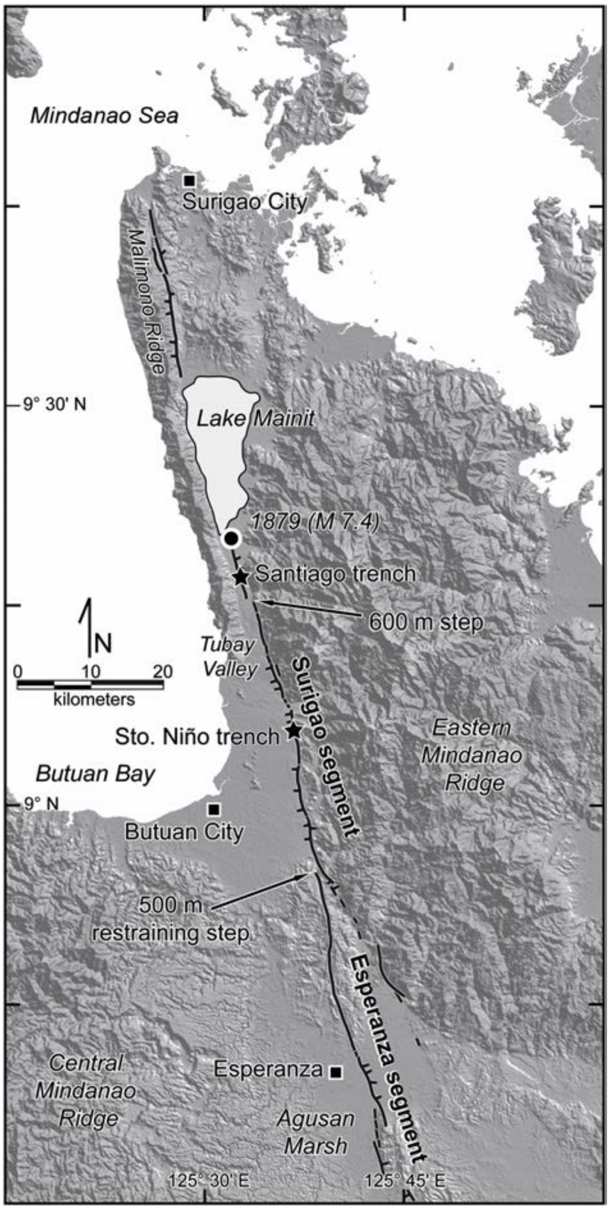

Fig. 3a. Surigao and Esperanza segments. Map showing Philippine fault segments in eastern Mindanao. Black solid lines represent the active fault, hachures indicate the direction of the downthrown side, stars indicate locations of trench sites, circles represent epicenters of historical surface-rupturing earthquakes [4], and black squares represent key cities and municipalities. The base map is from SRTM 3-arcsecond elevation data. See **Fig. 2** for the location of the map.

pality of Esperanza (**Fig. 3b**). This fault strikes N20°W with a scarp height of about 1 m and traverses the wide alluvial plain of the Agusan River and the northern part of the Agusan Marsh. A review of historical seismicity for the last 400 years shows no surface-rupturing earthquakes attributable to this Philippine fault segment. At the southern end of this continuous trace, the fault continues and steps to the left for about 1 km (restraining step) and steps to the right for about 3 km (releasing step) north of Talacogon (**Figs. 3a** and **b**).

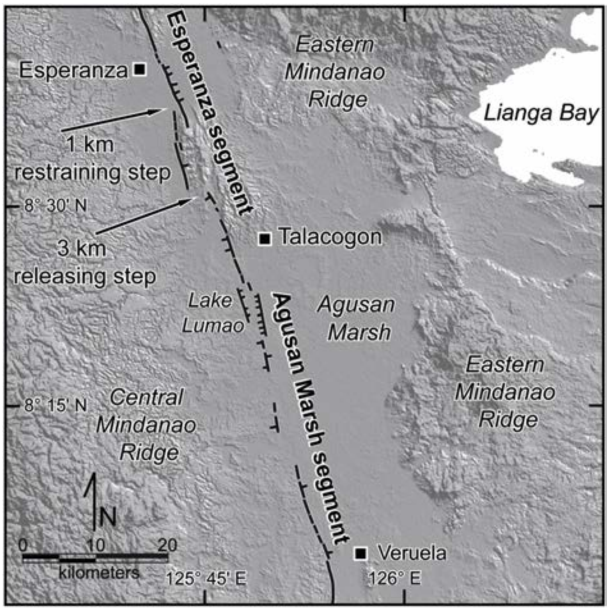

Fig. 3b. Esperanza and Agusan Marsh segments.

3.3. Agusan Marsh Segment

South of the Esperanza segment is the Agusan Marsh segment that traverses the Agusan Marsh, which is wide and bounded in the east by the Eastern Mindanao Ridge and in the west by the Central Mindanao Ridge (**Fig. 3b**). Most of the trace along this segment was delineated from aerial photographs. This portion of the fault was difficult to map continuously in the field because most traces are submerged under water. This segment strikes N10°-15°W and extends for about 65 km from Talacogon to south of Veruela. No systematic direction for the downthrown side was identified but in some areas, parallel fault traces and steps resulted in tectonic depressions manifested by lakes (e.g., Lake Lumao) (**Fig. 3b**). Historical and instrumental seismicity in this area also indicates that no surface-rupturing earthquake had occurred along this segment in the last 400 years. The fault may extend at the edge of Mount Olagusan but the left-stepping en echelon faults with at least 5 km steps may indicate the southern termination of the Agusan Marsh segment (**Figs. 3b** and **c**). South of this segment are several N-trending left-stepping fault strands.

3.4. Compostela Valley Segments

The 20-km-wide Compostela Valley bounded in the east by the Eastern Mindanao Ridge and in the west by the Central Mindanao Ridge, which includes the Olagusan and Jaguimitan Mountains (**Fig. 3c**). Here, the Philippine fault is manifested by several N-S trending left-stepping en echelon fault strands. The westernmost strand, the West Compostela Valley (WCV) segment, extends from the eastern edge of northern Mount Olagusan to the eastern edge of the Central Mindanao Ridge near the municipality of Mawab (**Fig. 3c**). This segment strikes almost N-S to N5°W. It is manifested by linear tectonic scarps cutting across the mountain range with offset creeks, as observed from aerial photographs. This segment extends for about 55 km. Several small left steps and branching were mapped in the north and the segment terminates abruptly in the south without steps or branching. Near the southern end of the trace, east of Mawab, a 5-km fault strand was also identified trending N30°–35°W (**Fig. 3c**).

East of the WCV are several left-stepping en echelon faults (5–10 km in length) that bound the northern part of Mount Jaguimitan. One prominent fault strand is the Central Compostela Valley (CCV) segment that bounds the eastern edge of Mount Jaguimitan and traverses the Compostela Valley (**Fig. 3c**). This segment, which trends almost N-S and extends for about 60 km, is where a 10-km east-facing fresh tectonic scarp about 1 m high was mapped. Offset creeks were also mapped in the northern part. In the southern part of this segment, the strike changes from N-S to N15°W. From this point, three right-stepping en echelon faults with lengths of less than 5 km and one left-stepping fault (∼5-km-wide restraining step) indicates the termination of this segment to the south. This left-stepping fault extends to the south and traverses the Eastern Mindanao Ridge up to the Tagub Mountains (**Fig. 3d**).

In the middle of the CCV segment, the fault branches to the west, marking another Philippine fault segment in the Compostela Valley, – called the Nabuntaran segment – that bounds the eastern edge of Mount Jaguimitan and the Central Mindanao Ridge (**Fig. 3c**). This segment generally strikes N5°–15°E, compared to the other segments in Compostela Valley where the fault strikes almost N-S. Most scarps are west-facing and this segment extends for about 25 km.

The shortest Philippine fault segment in the Compostela Valley is the East Compostela Valley (ECV) segment (**Fig. 3c**). This segment bounds the western edge of the Eastern Mindanao Ridge and strikes almost N-S. The mapped trace for this segment is about 20-km-long. There is a continuous lineament to the south identified from satellite images (SRTM) but careful analysis of aerial photographs indicates no tectonic geomorphic features that suggest recent faulting.

A review of historical and instrumental seismicity indicates two historical surface-rupturing earthquakes in the Compostela Valley area (**Figs. 1**, **2** and **3c**) [4, 32]. The 1893 M_s7.3 Monkayo earthquake produced long and wide cracks that may indicate a surface rupture near the town of Monkayo as described in historical documents [4, 32] (**Figs. 2** and **3c**). In our field mapping and from aerial photographs, we identified a fresh-looking, east-facing, continuous scarp south of Monkayo that traverses the Compostela Valley (CCV segment) (**Fig. 3c**). A paleoseismic trench excavated across this scarp showed evidence of a recent surface-rupturing earthquake most probably the 1893 Monkayo earthquake [34]. We therefore suggest that the 1893 Monkayo earthquake ruptured the CCV segment.

The 1891 M_s7.2 Davao earthquake is another possible surface-rupturing earthquake in this area (**Figs. 2** and **3c**). Historical documents mention long and wide fissures

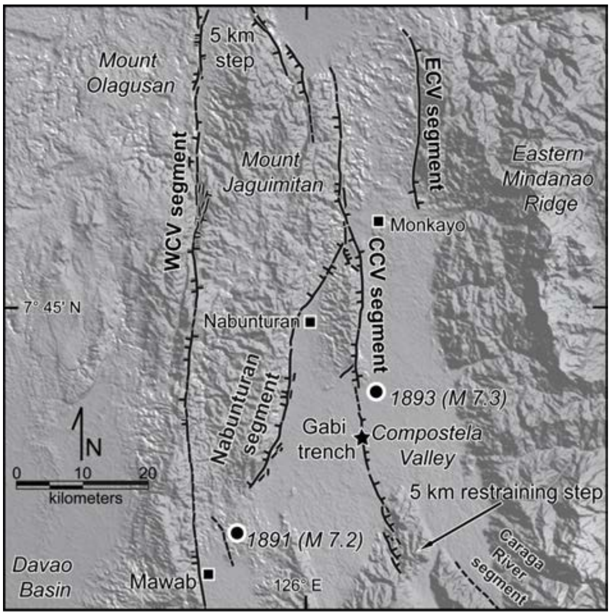

Fig. 3c. Compostela Valley segments.

in the hills, most probably along the Central Mindanao Ridge [4, 32]. Bautista and Oike [4] suggested that the epicenter of this earthquake was in the Central Mindanao Ridge (north of Davao). Compared to the other two historical surface-rupturing earthquakes – the 1879 Surigao and the 1893 Monkayo earthquakes – it is difficult to conclude whether the 1891 Davao earthquake was accompanied by a surface rupture because the long and wide fissures may also indicate landslides in the mountains. The proposed epicenter suggests that the most plausible source of this earthquake is the WCV segment. Although it is possible that a surface rupture occurred during this earthquake, it would have been difficult for the people of that time to recognize and document because the fault traverses a highly vegetated mountain range [4, 32].

3.5. Caraga River Segment

From the southern end of the CCV segment, a 5-km-wide restraining step indicates the northern termination of the Caraga River segment (**Figs. 3c** and **d**). The Caraga River segment is marked by a continuous fault scarp that bounds the eastern edge of a ridge and almost coincides with the fault, controlling the course of the Caraga River, before it traverses again the Eastern Mindanao Ridge. This segment is fairly continuous for about 25 km, with a general strike of N30°–40°W. Offset creeks were mapped from aerial photographs. At the southern end of the segment is a series of en echelon steps (right and left steps) that ranges from 0.5 to 2 km wide. No historical surface-rupturing earthquake could be attributed to this segment [4, 32].

3.6. Mati Segment

Branching off to the right from the middle of the Caraga River segment is the Mati segment (**Fig. 3d**), which traverses the Eastern Mindanao Ridge for about 15 km before bounding the eastern edge of an inter-valley mountain, the Maragusan Valley. The fault strikes N10°–15°W along the valley's eastern edge and transects young alluvial fans. South of this valley, we have identified a continuous, upslope-facing scarp for about 3 km. The fault continues further south for about 55 km, traversing the Eastern Mindanao Ridge. Fault branches, steps, and gaps were identified in the middle of the segment's southern end. We mapped offset creeks, sag ponds, pressure ridges, and springs during our field surveys. This segment terminates to the south toward Mati City, marked by the branching of the fault and changes in the strike (**Fig. 3d**). Based on our review of the area's historical and instrumental seismicity and paleoseismic studies this segment has not ruptured during the last 400 years [4, 32–34].

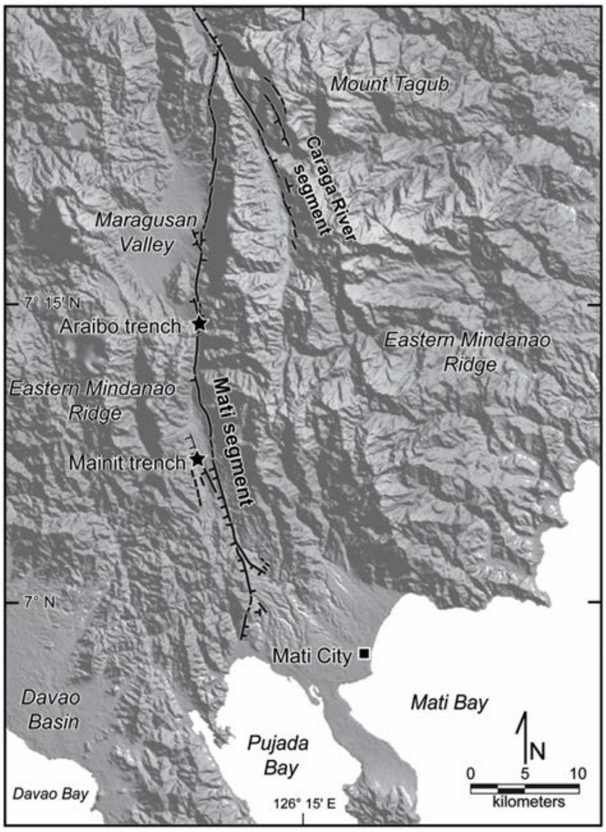

Fig. 3d. Caraga River and Mati segments.

4. Paleoseismology in Eastern Mindanao

In this section we briefly describe the results of paleoseismic trenches along the different segments of the Philippine fault in Mindanao conducted by Perez et al. [11, 33] and Perez and Tsutsumi [34]. The location of the paleoseismic trenches presented in this section is shown in **Figs. 3a-d**.

Two paleoseismic trenches 30 km apart – the Santiago and Sto. Niño trenches – were excavated along the Surigao segment (**Fig. 3a**) [11]. The Santiago trench was excavated across the surface rupture of the 1879 Surigao earthquake. We identified evidence for at least four surface-rupturing events that occurred within the last 1,300 years, including the 1879 Surigao earthquake. The Sto. Niño trench was excavated along a young alluvial fan, west of the Eastern Mindanao Ridge (**Fig. 3a**). This trench exposed several fault strands that showed evidence of at least two surface-rupturing events within the last 1,100 years, including the 1879 Surigao earthquake. Combining the results for the two paleoseismic trenches, Perez et al. [11] suggested that the recurrence interval along the Surigao segment was 400–1,000 years. Based on the review of historical earthquakes, geomorphic mapping, and paleoseismic studies conducted by Perez et al. [11], they concluded that the 1879 Surigao earthquake ruptured the entire length of the Surigao segment.

Three trenches were excavated in southern Mindanao [33, 34]. The Gabi trench in Compostela Valley was excavated across a fresh east-facing scarp, which is part of the CCV segment (**Fig. 3c**). Several fault strands exposed on trench walls formed a 10-m-wide fault zone. Perez et al. [33, 34] identified evidence of at least two and probably three surface-rupturing earthquakes within the last 1,700 years, including the 1893 Monkayo earthquake.

Two trenches – the Araibo and the Mainit trenches – were excavated across the Mati segment [33, 34]. The Araibo trench was excavated across an upslope-facing scarp (**Fig. 3d**). In this trench, Perez et al. [33, 34] found evidence of at least three and probably four surface-rupturing events within the last 3,000 years. The timing of the last event was between 670 and 1685 AD, agreeing with historical documents that no surface-rupturing events had occurred along this segment in the last 400 years. The Mainit trench near the southern end of the Mati segment shows the timing of the last event to be more than 1,000 years ago [33, 34]. These two trenches thus show that the Mati segment did not rupture during the 1893 Monkayo earthquake.

5. Earthquake Generation Potential of the Philippine Fault in Eastern Mindanao

We identified nine geometric segments that may rupture independently during large earthquakes along the Philippine fault in eastern Mindanao. These segments, which are separated by discontinuities in the trace, are listed in **Table 1** together with probable surface rupture lengths of individual segments we have identified in previous sections. **Table 1** also shows termination features for individual segments and the historical earthquakes that ruptured these segments. Using the empirical relationship between surface rupture length and magnitude [35], we calculated the moment magnitude of the maximum credible earthquake for each segment (**Table 1**).

Most segments in eastern Mindanao are capable of generating large earthquakes of $M_w > 7$, except for the ECV segment (M_w6.6), the Nabunturan segment (M_w6.7), and the Caraga River segment (M_w6.9). The largest magni-

Table 1. Summary of segment lengths, magnitudes of maximum credible earthquakes, historical earthquakes [4, 11, 32–34], and termination features for different Philippine fault segments in eastern Mindanao.

Name of segment	Segment length (km)	Magnitude of maximum credible earthquake (M_w)	Historical earthquake	Segment termination feature
1. Surigao	100	7.4	1879 M_w7.4 Surigao earthquake	changes in strike; bifurcation; 500-m-wide restraining step
2. Esperanza	50	7.1		1-km-wide restraining step and 3-wide-km releasing step
3. Agusan Marsh	65	7.2		en echelon left stepping faults (at least 5-km-wide step
4. West Compostela Valley (WCV)	55	7.1	1891 M_s7.3 Davao earthquake	steps; branching; abrupt termination of the fault to the south
5. Central Compostela Valley (CCV)	60	7.1	1893 M_s7.2 Monkayo earthquake	5-km-wide restraining step; en echelon steps; changes of strike; branching
6. Nabuntaran	25	6.7		branching
7. East Compostela Valley (ECV)	20	6.6		left steps; abrupt termination of fault
8. Caraga River	35	6.9		branching; en echelon steps and gaps (0.5 to 2 km steps)
9. Mati	60	7.1		branching of fault; changes in strike; steps

tude, M_w7.4, is assigned to the Surigao segment that ruptured during the 1879 Surigao earthquake [4, 11, 32], followed by the Agusan Marsh segment at M_w7.2. The magnitudes of the two other historical earthquakes – the1891 M_s7.2 Davao and the 1893 M_s7.3 Monkayo earthquakes – roughly coincide with our proposed magnitudes of maximum credible earthquake at possible source faults (M_w 7.1 for the WCV and CCV segments). In terms of paleoseismicity derived from paleoseismic trenches but with no written historical documentation of surface-rupturing earthquakes, the two Mati segment trenches – Araibo and Mainit trenches – showed a longer recurrence interval than the Surigao and CCV segments [33, 34]. The magnitude of the maximum credible earthquake along this segment is about M_w7.1, almost the same as the 1891 Davao and 1893 Monkayo earthquakes. The Esperanza segment had no known historical surface-rupturing earthquakes but is capable of generating M_w7.1 earthquakes.

In terms of the probability of large earthquake occurrence, six segments – the Esperanza, Agusan Marsh, Nabunturan, ECV, Caraga River, and Mati segments – have not ruptured during historical times, which may indicate probable seismic gaps along the Philippine fault in eastern Mindanao. Results of paleoseismic studies along the Mati segment also show a longer recurrence interval than the Surigao and CCV segments [11, 31–34]. Given these assumptions, no historical surface-rupturing earthquakes, and longer recurrence intervals, the probability is high that these six segments could generate surface-rupturing earthquakes in the future that may result in very strong ground shaking and could greatly adversely affect Mindanao Island. The Surigao, CCV, and WCV segments are not likely, however, to generate surface-rupturing earthquakes in the next centuries based on the most recent rupture in the last 200 years and paleoseismic study results [11, 31–34].

Our suggested earthquake magnitude potential may only be applicable if our identified individual segments move separately. In a magnitude range of M_w6.6 to M_w7.4, these segments may still generate strong ground shaking that could significantly damage eastern Mindanao. As discussed in previous sections, multiple segments may move together to generate much larger earthquakes compared to our proposed magnitudes, with greater ground shaking and a larger impact on the area. These scenarios could conceivably occur in eastern Mindanao, so we suggest that more paleoseismic trenches be excavated to determine the history of surface-rupturing earthquakes and to identify segments that have moved together.

6. Conclusions

We have conducted detailed segmentation studies to determine the earthquake generation potential of the Philippine fault in eastern Mindanao. To identify individual segments, we have used geometric segmentation criteria integrating the results of new geological and paleoseismic studies and the analysis of historical documents mentioning surface-rupturing earthquakes. We identified nine geometric segments from 20 to 100 km long in eastern Mindanao that may generate earthquakes of M_w6.6 to M_w7.4. These geometric segments are separated by discontinuities such as en echelon steps, bends, changes in strike, gaps, steps, and bifurcation in the surface trace. Integrating the results of recent geological and paleoseismic studies, we have shown that three segments – Surigao, CCV, and WCV – have moved independently during historical times. We have also identified segments having a higher probability of rupturing in the future. The information in this study serves as a significant input for future active fault research in the Philippines and should prove useful in assessing seismic hazards in Mindanao Island.

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Name:
Jeffrey S. Perez

Affiliation:
Supervising Science Research Specialist, Philippine Institute of Volcanology and Seismology – Department of Science and Technology (PHIVOLCS-DOST)

Address:
PHIVOLCS Bldg., C. P. Garcia Avenue, U.P. Diliman Campus, Quezon City 1101, Philippines

Brief Career:
1999 Joined PHIVOLCS-DOST as Science Research Specialist (Seismological Observation and Earthquake Prediction Division and Geology and Geophysics Research and Development Division)
2012- Supervising Science Research Specialist, Geologic Disaster Awareness and Preparedness Division – PHIVOLCS-DOST

Selected Publications:
- J. S. Perez, et al., "Tectonic geomorphology and paleoseismology of the Surigao segment of the Philippine fault, northeastern Mindanao, Philippines," Journal of Asian Earth Sciences (submitted).
- H. Tsutsumi and J. S. Perez, "Large-scale digital mapping of the Philippine fault zone based on aerial photograph interpretation," Active Faults Research, Vol.39, pp. 29-37, 2013.

Academic Societies & Scientific Organizations:
- Geological Society of the Philippines (GSP)

*Profiles of co-authors are omitted in this special issue.