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Paper:

Coseismic Displacement and Recurrence Interval of the 1973 Ragay Gulf Earthquake, Southern Luzon, Philippines

Hiroyuki Tsutsumi*, **Jeffrey S. Perez****, **Jaime U. Marjes****,
Kathleen L. Papiona**, **and Noelynna T. Ramos*****

*Department of Geophysics, Kyoto University
Kitashirakawa-oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan
E-mail: tsutsumh@kugi.kyoto-u.ac.jp
**Philippine Institute of Volcanology and Seismology (PHIVOLCS)
C. P. Garcia Avenue, Quezon City 1101, Philippines
***National Institute of Geological Sciences, University of the Philippines, Diliman
C. P. Garcia Avenue, Quezon City 1101, Philippines

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The 1973 Ragay Gulf earthquake produced an onshore surface rupture approximately 30 km in length along the Guinayangan segment of the Philippine fault in southern Luzon Island. Through geologic mapping and paleoseismic trenching, we have characterized the amount of coseismic offsets, the average recurrence interval, and the slip rate of the segment. The coseismic offsets we identified in the field were fairly constant along the fault, ranging from 1 to 2 m. Paleoseismic trenching at the Capuluan Tulon site exposed stratigraphic evidence for three or possibly four surface-rupturing events after the deposition of strata dated at AD 410–535. The average recurrence interval was calculated to be 360–780 years, which is close to that for the Digdig fault, the source fault of the 1990 central Luzon earthquake. The slip rate, based on the calculated recurrence interval and offsets during the 1973 earthquake, has been calculated to be 2.1–4.4 mm/yr. This rate is significantly smaller than the geodetic slip and creep rates of 20–25 mm/yr estimated for the Philippine fault on the islands of Masbate and Leyte. The slip rate deficit may be explained by the possibilities of underestimation of the recurrence interval due to possible missing paleoseismic events within the stratigraphic records, the occurrence of larger earthquakes in the past, and the aseismic fault creep between the surface-rupturing earthquakes.

Keywords: Philippine fault, 1973 Ragay Gulf earthquake, surface rupture, trenching, recurrence interval

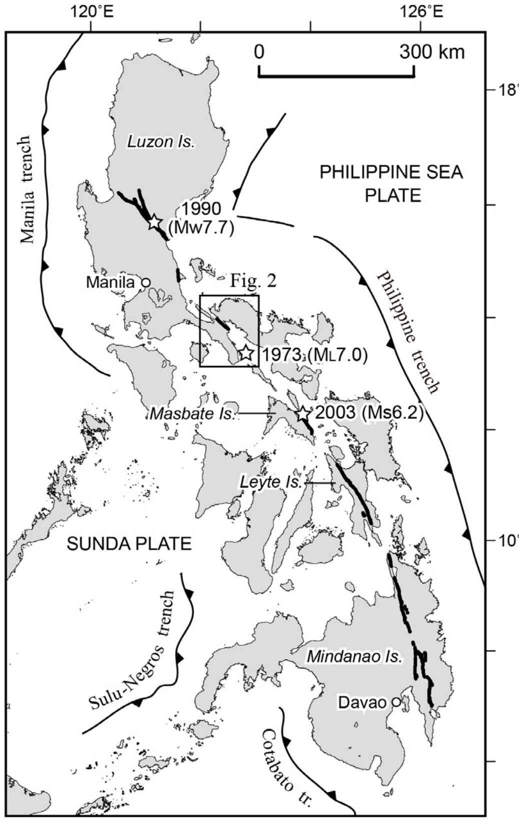

Fig. 1. Tectonic setting and epicenters of surface-rupturing earthquakes on the Philippine fault since 1970 (stars). The fault trace is from [5]. Location of **Fig. 2** is shown.

1. Introduction

Although the Philippine fault is one of the fastest-slipping faults on the earth [1], surface-rupturing earthquakes on the fault are relatively rare, with only three such events having occurred in the past 50 years, including the 1973 M_L7.0 Ragay Gulf, 1990 M_w7.7 central Luzon, and 2003 M_s6.2 Masbate earthquakes (**Fig. 1**). It is therefore important to document and analyze each surface rupture in as much detail as possible. The 1990 central Luzon earthquake was the first earthquake along the Philippine fault for which systematic and detailed surface rupture mapping was conducted [2]. Detailed surface rupture mapping was also conducted after the 2003 Masbate earthquake [3]. Although the 1973 Ragay Gulf earthquake occurred only about 40 years ago, there was no detailed description of the surface rupture. General seismological and geological characteristics of the earthquake were reported, but a detailed description of the surface rupture was not provided; coseismic displacements were reported only from three localities along the ∼30-km-long onshore surface rupture [4]. There is also no information on the history of past surface-rupturing earthquakes on the Guinayangan segment of the Philippine fault that was reactivated in 1973.

In order to better evaluate the seismic risk of the Philippine fault, we have been conducting tectonic geomorphic mapping and paleoseismic trenching along the different segments from Luzon to Mindanao Islands [5]. Since 2009, we have surveyed the surface rupture of the 1973 Ragay Gulf earthquake to better characterize its location and coseismic displacements. We have also excavated a paleoseismic trench across the surface rupture to obtain geologic evidence of multiple earthquakes in the past.

In this paper, we describe the results of these geological and paleoseismological studies on the surface rupture associated with the 1973 Ragay Gulf earthquake. We show the location and coseismic displacements of the surface rupture in detail, and we discuss the average recurrence interval of large earthquakes on this portion of the Philippine fault. This is a companion paper of an offshore fault mapping in the Ragay Gulf based on seismic profiling [6]. These two papers present a prototype of geological studies of the Philippine fault, about half of which is located underwater (**Fig. 1**).

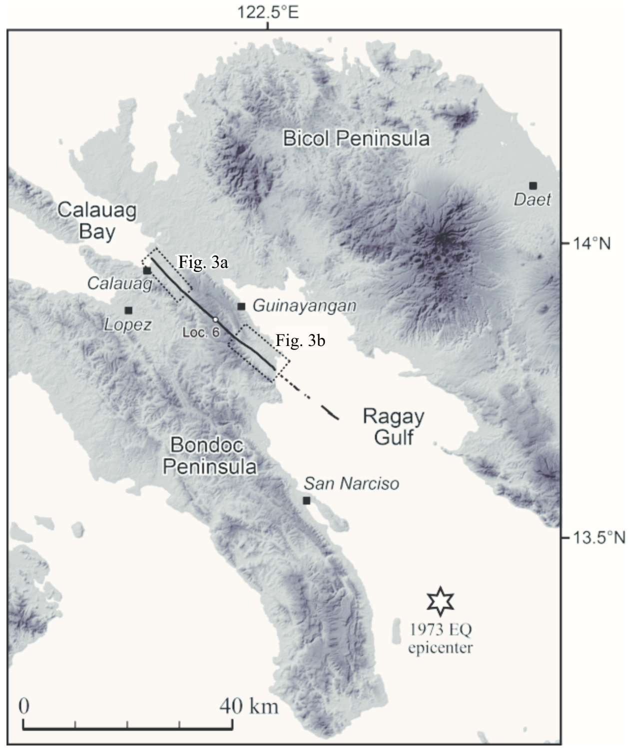

Fig. 2. Fault trace of the Guinayangan segment of the Philippine fault cutting across the Bondoc Peninsula. The fault trace in the Ragay Gulf is from [6]. The star indicates the epicenter of the 1973 earthquake [4]. The locations are shown for more detailed maps, **Figs. 3a** and **3b**.

2. 1973 Ragay Gulf Earthquake

The M_L7.0 Ragay Gulf earthquake of March 17, 1973 claimed 14 lives and caused extensive damage to southern Quezon Province on the Bondoc Peninsula (**Fig. 2**) [4]. Although the seismic stations in the Philippines were sparse at that time, the epicenter is thought to have been located at approximately 13.4°N and 122.8°E in the Ragay Gulf. The earthquake was felt on most of Luzon Island and the northern Visayas region. Intensity VIII on the Rossi-Forel scale was assigned to the municipalities of Calauag, Lopez, and Guinayangan (**Fig. 2**). The earthquake caused serious damage to houses, concrete buildings, roads, bridges, and railways [4].

A surface rupture appeared on land along the Guinayangan segment of the Philippine fault. The rupture cuts across the northeastern part of the Bondoc Peninsula from the Ragay Gulf shoreline northwestward to the Calauag Bay shoreline, a distance of ∼30 km (**Fig. 2**) [4]. For the most part, the rupture appeared along the fault trace previously identified from aerial photograph interpretations [1]. Surface faulting was predominantly left lateral without conspicuous or systematic vertical movement. The observed horizontal displacements from three localities (described in section 4) ranged from 1.1 to 3.4 m. In many places, the surface rupture exhibited moletrack features with ground fissures arranged en echelon in an E–W direction [4], which is typical for left-lateral faults and similar to the 1990 central Luzon earthquake rupture [2]. The aftershock distribution within eight days following the mainshock were elongated along a ∼250-km-long section of the Philippine fault [4].

3. Methods

From the coastline of the Calauag Bay southeastward to Mambaling (**Fig. 3a**), we were able to interpret 1:15,000-scale color aerial photographs taken in 2010 by the National Mapping and Resource Information Agency (NAMRIA) of the Philippine government. For the rest of the area, aerial photographs were not available, and we relied on 1:50,000-scale topographic maps, shaded relief maps from SRTM 3-arc-seconds data, and Google Earth images. We conducted field investigations in August 2009, July 2010, and March 2011. We identified the fault trace locations based on tectonic geomorphic features and sought eyewitness accounts on the surface rupture. At several localities, we identified rows of coconut trees that were systematically offset left-laterally. We measured the offsets using tape measures by projecting the trend of the alignment of the trees to the fault line. As the mountainous area in the central portion of the surface rupture has very few settlements, accessibility was limited. Thus, we surveyed only along the main road west of Guinayangan. In order to identify geologic evidence of past surface-rupturing earthquakes, we excavated a trench at Capuluan Tulon (Loc. 8 in **Fig. 3b**).

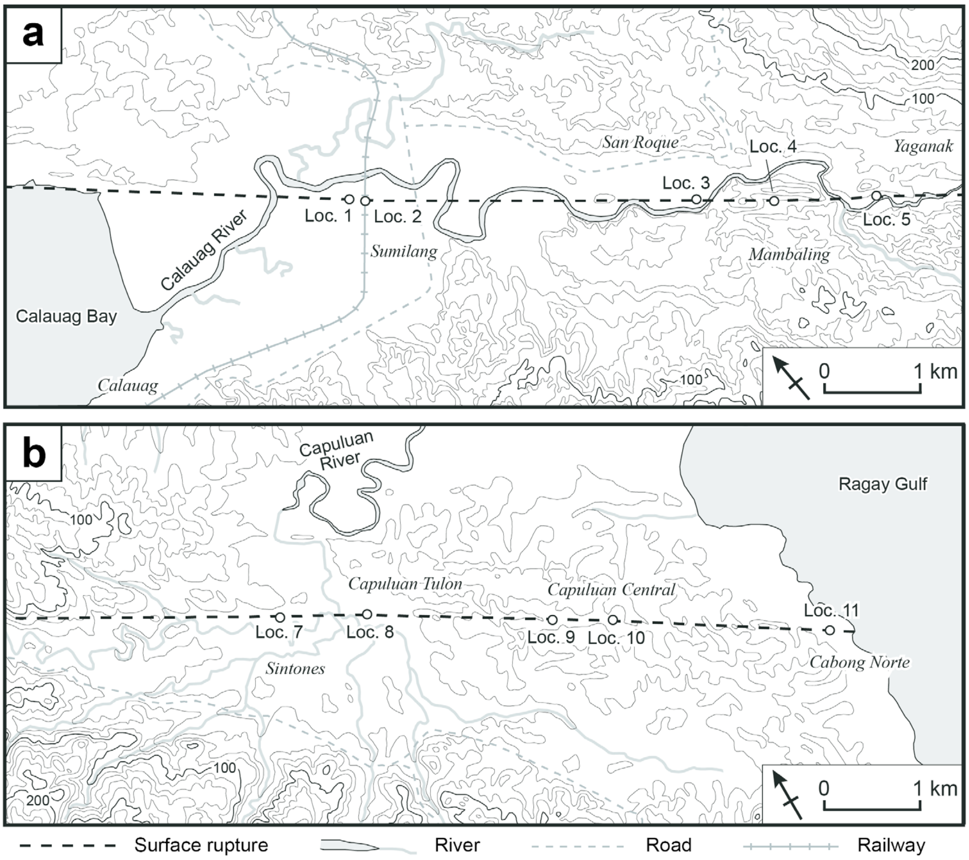

Fig. 3. Locations of the surface rupture associated with the 1973 Ragay Gulf earthquake and field observation points. Base map is 1:50,000-scale topographic map sheets "Lopez" and "Liboro" published by the National Mapping and Resource Information Agency of the Philippine government. The contour interval is 20 m.

4. Location and Displacements of Surface Rupture

We will describe the location and coseismic displacements identified in the field from north to south. Near its northwestern end, the surface rupture extends across the alluvial lowland along the Calauag River (**Fig. 3a**). Here, it is difficult to identify the exact fault trace location based on tectonic geomorphic features due to rapid fluvial sedimentation and erosion. At Sumilang, the surface rupture offset the railway tracks of the Philippine National Railways by 1.85 m left-laterally (Loc. 2 in **Fig. 3a**) [4]. Although the tracks have been repaired, Pileno Romero (born in 1939) showed us the exact location of the surface rupture. About 100 m northwest of the offset railway, we identified a systematic offset of aligned coconut trees across a shallow and less than 5-m-wide depression trending N50°W (Loc. 1). Ruben Labhawan has learned from the former settlers of the area that the depression follows the location of the open cracks that appeared during the 1973 earthquake. Four rows of coconut trees that are almost perpendicular to the depression are offset left-laterally at 0.8 m, 0.8 m, 0.9 m, and 0.9 m (**Fig. 4a**). At Loc. 3 in San Roque, there is a N55°W-trending, ~200-m-long, northeast-facing scarp less than 3 m high. This scarp faces away from the modern northwest-flowing Calauag River, suggesting that it is tectonic in origin. Gregorio Oserin (born in 1931), who has lived next to the scarp, identified open cracks along the scarp immediately after the earthquake. There are pressure ridges northeast of the fault trace at Mambaling and Yaganak (**Fig. 3a**). At the southwestern base of the ridge at Mambaling, Domingo Lobioso (born in 1959) showed us an approximately 30-cm-high, west-facing scarp that appeared during the earthquake (Loc. 4). At the western base of the ridge at Yaganak (Loc. 5), local people documented that ~1-m-wide open cracks appeared during the earthquake. Left-lateral displacements of 1.1 m were reported at two localities in Yaganak [4]. For a distance of about 15 km between Yaganak and Sintones, the fault traverses a mountainous terrain. Near the main road west of Guinayangan, local people at Dungawan Paalyunan took us to a locality where open cracks appeared during the earthquake (Loc. 6 in **Fig. 2**, N13°52′23.6″, E122°24′46.6″).

From Sintones southeastward to the Ragay Gulf coast, the fault trace follows a linear depression [4]. At Sintones, the fault trace is marked by a linear topographic boundary between elongated hills on the northeast and the alluvial plain of the Capuluan River. Several local residents documented that open cracks about 30 cm wide appeared along the base of the hills. At Loc. 7, aligned coconut trees are offset left-laterally at 1.3 m, 1.3 m, 1.6 m, and 1.6 m (**Fig. 4b**). At Capuluan Tulon, Emanuel Orbe (born in 1962) took us where he observed open cracks after the

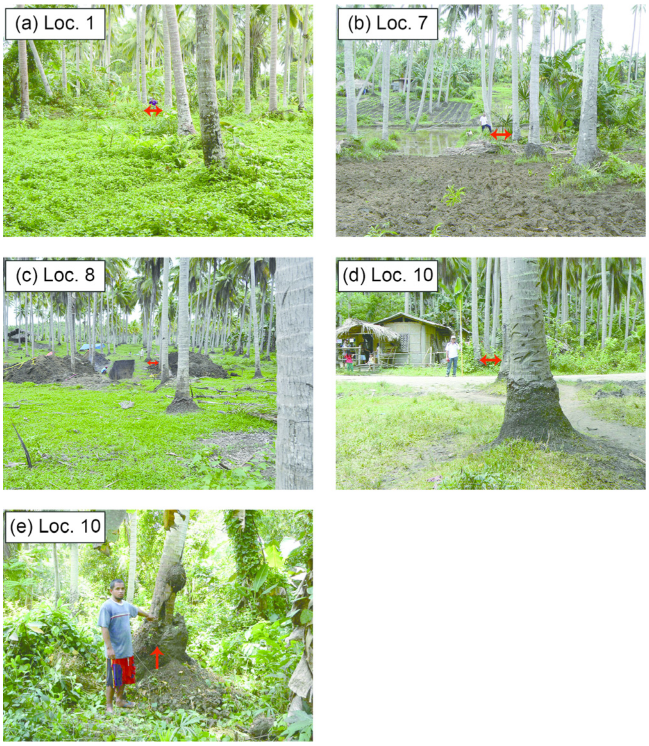

Fig. 4. Field photographs of offset features related to the 1973 Ragay Gulf earthquake. Red horizontal arrows indicate left-lateral offsets of rows of coconut trees. The red vertical arrow in (e) indicates the splitting of a coconut tree by the coseismic rupture.

earthquake (Loc. 8). In this area, rows of coconut trees are systematically offset left-laterally at 1.4 m, 1.5 m, and 1.2 m. Open cracks trending N55°W with widths of ∼30 cm are still present on the ground. At Capuluan Central, there is a ∼50-m-wide linear depression, and its northeastern side is bounded by the fault (Loc. 9). At Loc. 10, the surface rupture cuts across the settlements of Capuluan Central. The surface rupture location is marked by a narrow linear valley trending N55°W. Coconut tree lines are displaced left-laterally at 1.8 m, 1.7 m, 1.6 m, and 1.5 m (**Fig. 4d**). There is also a coconut tree that was split by the rupture (**Fig. 4e**).

Near the coastline of the Ragay Gulf at Cabong Norte (Loc. 11), there were several eyewitness accounts of the occurrence of a surface break along a small creek. A 3.4-m left-lateral offset of beach line and seaward continuation of the rupture on the shallow sea floor were reported after the earthquake [4]. The offshore extension of the Guinayangan segment in the Ragay Gulf was mapped by seismic profiling [6]. They identified NW-trending submarine faults that cut probable Holocene sediments for a distance of ∼15 km from the shoreline (**Fig. 2**). Distinct truncation of submarine strata and near-vertical faults suggest that these are predominantly strike-slip faults [6].

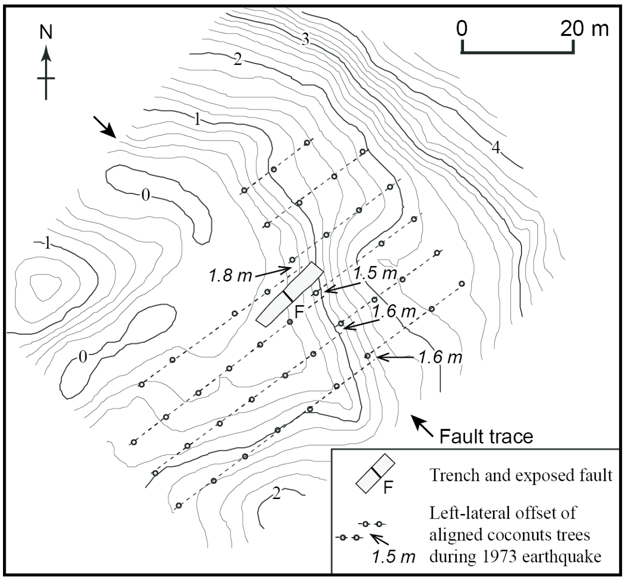

Fig. 5. Topographic map of the Capuluan Tulon trench site constructed using a total station. The contour interval is 20 cm, and the elevation is relative to the lowest point within the surveyed area. The trench site and offset coconut tree lines are also shown.

5. Paleoseismic Trenching

In order to determine the recurrence interval of surface-rupturing earthquakes on the Guinayangan segment of the Philippine fault, we excavated a trench at Capuluan Tulon (Loc. 8) in March 2011. The trench was excavated by a backhoe across a gentle southwest-facing scarp with a direction of N40°E, almost perpendicular to the fault trace (**Fig. 5**). The trench was 13 m long with the maximum depth of 2.5 m. The slopes of the trench walls were greater than 80°. During the observation period, the southern wall collapsed and we had to abandon the wall. At the final stage of the logging, we dug further around the fault zone to examine the deeper deformational structures (**Fig. 6**). We collected shell fragments and bulk humic soil samples for radiocarbon dating. As is true with many cases of paleoseismic trenching in humid tropical countries, we were not able to find charcoals at this site. The samples were dated using the AMS method at Paleo Labo Co., Ltd., Japan (**Table 1**). At the trench site, rows of coconut trees were systematically offset left-laterally at 1.8 m, 1.5 m, 1.6 m, and 1.6 m (**Figs. 4c** and **5**).

5.1. Stratigraphy

We divided the strata exposed on the trench wall into 10 stratigraphic units (unit 10 to unit 90 in descending order) based on lithology, color, and texture (**Fig. 6**). The base of our stratigraphic sequence is massive yellowish light-brown clay, unit 90. This unit is exposed only on the upthrown side of the fault zone and contains numerous near-vertical dark-brown stripes, which are probably due to bioturbation. Shell fragments less than 1 cm in diameter are scattered throughout this unit. A shell frag-

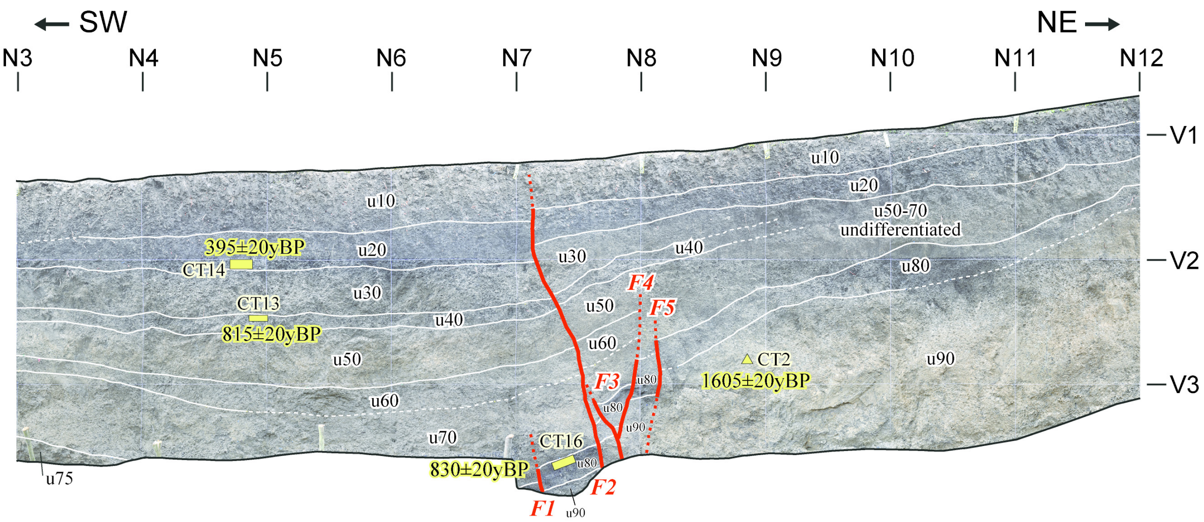

Fig. 6. Log of part of the north wall of the trench at the Capuluan Tulon site. The triangle indicates the location of a shell sample as projected from the south wall. Rectangles indicate where bulk soil samples were taken. Grid interval is 1 m.

Table 1. Radiocarbon ages for the Capuluan Tulon site trench.

Sample No.	Lab. No. (PLD*)	Unit	Material	δ^{13}C (‰)	^{14}C (yBP±1σ)	Calendar age (2σ)
CT 2	18239	90	Shell	−8.4	1605±20	AD 410-535
CT 13	18240	40	Paleosol	−13.0	815±20	AD 1185-1265
CT 14	18241	20	Paleosol	−11.0	395±20	AD 1445-1500, 1505-1510, 1600-1615
CT 16	18242	80	Paleosol	−10.9	830±20	AD 1170-1260

*PLD: Paleo Labo Co., Ltd., Japan

ment sampled from the south wall yielded a ^{14}C age of 1605±20 yBP (AD 410–535) (**Fig. 6**, **Table 1**). Overlying unit 90 is dark-brown clay, unit 80. This is a key horizon to identify southwestward warping of strata on the upthrown side. This unit is also exposed only on the upthrown side of the fault and becomes darker or more humic towards the southwest. The upper boundary of this unit is distinct throughout the trench wall, but its lower boundary against unit 90 is gradual and less distinct. We interpret that unit 80 is paleosol developed from unit 90. A bulk soil sample from the uppermost part of unit 80 yielded a ^{14}C age of 830±20 yBP (AD 1170–1260). Exposed at the base of the trench wall on the downthrown side is ∼90-cm-thick yellowish pale-brown clay, unit 70. Near the southwestern edge of the trench, yellowish-brown well-sorted coarse sand, unit 75, is exposed. Overlying unit 70 is ∼20-cm-thick brown clay, unit 60. The upper boundary of this unit is fairly distinct, but its lower boundary against unit 70 is less distinct. We interpret that unit 60 is paleosol developed from unit 70. The upper boundary of unit 60 can be traced northeast to N8, where it seems to be truncated by a fault strand (F4). Unit 50 is yellowish light-brown clay, and its facies are almost the same as those of unit 70. Unit 50 contains thin lenses of yellowish-white clay. Northeast of the fault zone, units 50, 60, and 70 cannot be differentiated (**Fig. 6**). Overlying unit 50 is dark-brown clay, unit 40, which we interpret as paleosol developed from unit 50. Unit 40 can be confidently traced across the fault zone as far northeast as around N8.5. The upper and lower boundaries of unit 40 are irregular, but the thickness of the unit, ∼15 cm, is almost constant. A bulk soil sample from the topmost part of unit 40 yielded a ^{14}C age of 815±20 yBP (AD 1185–1265). Unit 30 is light-brown silt to clay with patchy black soil from the upper units probably due to bioturbation. This unit occasionally contains modern coconut tree roots. Southwest of the fault zone, unit 30 is almost horizontal and 30–40 cm thick. Across the fault zone, this unit thins out northeastward. Unit 20 is well-developed paleosol composed of black to blackish-gray silt to clay characterized by a blocky texture. Coconut tree roots are abundant down to this unit. This unit exhibits a uniform thickness of ∼30 cm throughout the trench wall. A bulk soil sample from the lowermost part of unit 20 yielded a ^{14}C age of 395±20 yBP (AD 1445–1500, 1505–1510, 1600–1615). Immediately below the ground surface is modern soil composed of brown silt to clay characterized by a blocky texture, unit 10. It is ∼50 cm thick at the southwestern edge of the trench and gradually thins to the northeast.

5.2. Deformational Features

A distinct shear zone appeared between N7.1 and 8.1 with five fault strands, named F1 to F5 (**Fig. 6**). In addition to stratigraphic offsets by the fault strands, the strata are warped into a monocline down to the southwest. These fault strands dip greater than 70°.

The westernmost fault, F1, clearly offsets the top of unit 80 with 16 cm of stratigraphic separation measured along the fault. The extension of F1 within unit 70 is invisible. F1 does not cut the top of unit 70 and is interpreted to terminate upward within unit 70. F2 cuts all the stratigraphic horizons exposed on the trench wall. The stratigraphic offsets by F2 are 16 cm (top of unit 80), 10 cm (top of unit 60), 5 cm (top of unit 50), 5 cm (top of unit 40), 13 cm (top of unit 30), and 13 cm (top of unit 20). The fault is invisible within unit 10, and the ground surface is flat across the fault. F3 is identified based on a ~10 cm offset of both the top and base of unit 80. Although invisible within unit 70, F3 may merge upward into F2. F4 branches upward from F3 near the trench bottom and dips steeply to the southwest. Unit 80 is sharply offset ~20 cm by F4. Neither the top nor the base of unit 60 can be traced across the possible upward extension of F4, suggesting that the unit is truncated by F4. However, unit 40 is not cut by F4, suggesting that F4 terminates upward within unit 50. F5 is the easternmost fault strand. The fault is clearly identified by the offset of unit 80; the lower boundary of unit 80 is offset 20 cm. The thickness of unit 80 changes from 40 cm (southwest) to 30 cm (northeast) across the fault, suggesting horizontal displacement. This strand is also invisible within the overlying strata, and unit 40 is not offset by the fault.

In addition to the discernible stratigraphic offsets by the fault strands, the strata are warped into a west-facing monocline. West of the fault zone, all the strata are almost flat whereas the strata on the northeast block increase their dip towards the fault zone (**Fig. 6**).

5.3. Paleoseismic Events

Because of the massive sediments and poor preservation of datable material, the stratigraphy at the Capuluan Tulon site is far from ideal to identify paleoseismic events and determine their ages. Nevertheless, we can point out geologic evidence of past surface-rupturing earthquakes and estimate their average recurrence interval.

Event 1: The stratigraphic boundary between units 10 and 20 is offset 13 cm up-on-the-northeast by F2, indicating that a surface-rupturing earthquake occurred during (or after) the deposition of modern soil, unit 10. We cannot directly date unit 10, but a bulk soil sample from unit 20 was dated at AD 1445–1615. In the past 400 years for which a written historical earthquake catalogue is available [7], the 1973 Ragay Gulf earthquake has been the only large earthquake on the Guinayangan segment of the Philippine fault. We therefore interpret that the faulting event marked by the offset of unit 10 corresponds to the 1973 earthquake.

Event 2: East of F2, paleosol of unit 40 dips more steeply than paleosol of unit 20, and unit 30 in between the two paleosol horizons thins out to the northeast. Unlike the other paleosol horizons, unit 20 developed on top of units 30, 40, and undifferentiated units 50–70 (**Fig. 6**). This suggests that unit 30 and the underlying units dipped to the west more steeply than the topographic slope when the paleosol of unit 20 developed. These observations suggest that there was a faulting event that warped unit 30 and the underlying units southwestward. The monoclinal scarp was subsequently eroded to form a gentler topographic slope, and the paleosol of unit 20 developed. The timing of this event is after the deposition of unit 30 and before the formation of unit 20 paleosol. The evidence for this event is weaker than that of the other events because there is no fault strand that terminates upward at the proposed event horizon.

Event 3: F4 appears to truncate units 60 and 70 but does not offset the base of unit 40, suggesting that F4 terminates within unit 50. This observation suggests an older event during the deposition of unit 50. During this event, F5 may have also moved since it terminates upward within undifferentiated units 50–70.

Event 4: Unit 80 is deformed significantly more than the overlying units; the unit is offset by all five of the fault strands, with ~70 cm of total stratigraphic separation, and it is warped more steeply than unit 40. F1 clearly offsets unit 80 and terminates upward within unit 70. These observations suggest that there was a faulting event during the deposition of unit 70.

5.4. Recurrence Interval and Slip Rate

We identified evidence for three (Events 1, 3, and 4) and possibly four (Events 1–4) faulting events, including the 1973 earthquake, occurring since the deposition of unit 80. A bulk soil sample from unit 80 was dated at AD 1170–1260. However, a bulk soil sample from unit 40 yielded an almost similar age (AD 1185–1265), raising a question as to the reliability of ages from bulk soil samples. Therefore, we used the age of a shell sample from unit 90 (AD 410–535) to calculate the average recurrence interval of the three and possibly four seismic events (**Fig. 7**). The shortest possible average recurrence interval (assuming four paleoseismic events) would be

$$\frac{(1973-535)}{4} \approx 360 \text{ years}$$

and the longest possible interval (assuming three paleoseismic events) would be

$$\frac{(1973-410)}{2} \approx 780 \text{ years}$$

These recurrence intervals determined for the Guinayangan segment are close to that of the Digdig fault (i.e., 500–600 years, determined by trenching), which ruptured during the 1990 earthquake [8]. The Guinayangan segment may have ruptured with a shorter recurrence interval than those we calculated, because we used the age of unit 90, not unit 80, for the calculation of the average recurrence intervals.

We can estimate the slip rate of the Guinayangan segment of the Philippine fault based on coseismic offset during the 1973 earthquake and calculated recurrence intervals. The mean of the four offset measurements of rows of coconut trees at the trench site is ~1.6 m (**Fig. 5**). Using the shortest and longest average recurrence intervals above, we estimate the slip rate of 2.1–4.4 mm/yr based on the assumption of characteristic slip. This rate

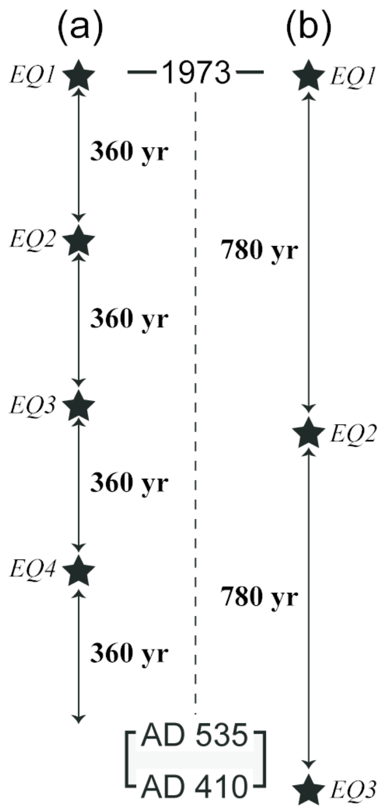

Fig. 7. Schematic diagram illustrating calculations for (a) the shortest possible average recurrence interval (assuming four paleoseismic events) and (b) the longest possible recurrence interval (assuming three paleoseismic events) after the deposition of unit 90, dated at AD 410–535.

is significantly smaller than the GPS-derived slip rate of 22±2 mm/yr on Masbate Island [9] or the ∼20 mm/yr creep rate derived from offset cultural features on Leyte Island. The slip rate deficit may be caused by one or a combination of the following: 1) we underestimated the recurrence interval due to possible missing paleoseismic events within the stratigraphic record at the Capuluan Tulon site, 2) earthquakes with larger coseismic displacements have occurred in the past, 3) the fault creeps aseismically in addition to rupturing moderate- to large-earthquakes, similar to what we recently identified on the Masbate segment.

6. Conclusion

In order to better characterize the coseismic and long-term behavior of the Guinayangan segment of the Philippine fault on southern Luzon Island, we conducted geological and paleoseismological studies of the surface rupture associated with the 1973 Ragay Gulf earthquake. The earthquake produced a ∼30-km-long surface rupture on land along the fault trace marked by pronounced tectonic geomorphic features. The coseismic slip was predominantly left lateral, and displacements we identified in the field were fairly constant (1–2 m) along the strike of the fault. Paleoseismic trenching at the Capuluan Tulon site exposed stratigraphic evidence for three or possibly four surface-rupturing events after the deposition of unit 80. The average recurrence interval was calculated to be between 360 and 780 years, which was close to that for the Digdig fault, the source fault of the 1990 central Luzon earthquake. Based on the calculated recurrence interval and coseismic offsets during the 1973 earthquake, we estimated the slip rate of the Guinayangan segment to be 2.1–4.4 mm/yr. This geologic slip rate was significantly lower than the geodetic slip and creep rates estimated for the Philippine fault on Masbate and Leyte Islands. Our paleoseismic data were derived from only one site, so additional trenching is necessary to document the complete faulting history of the Guinayangan segment.

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References:

[1] C. R. Allen, "Circum-Pacific faulting in the Philippines-Taiwan region," Journal of Geophysical Research, Vol.67, pp. 4795-4812, 1962.

[2] T. Nakata, H. Tsutsumi, R. S. Punongbayan, R. E. Rimando, J. A. Daligdig, A. S. Daag, and G. M. Besana, "Surface fault ruptures of the 1990 Luzon earthquake, Philippines," Research Center for Regional Geography, Hiroshima University, Special Publication No.25, p. 86, 1996.

[3] PHIVOLCS Quick Response Team, "The 15 February 2003 Masbate Earthquake," PHILVOCS Special Report No.5, p. 30, 2003.

[4] E. M. Morante, "The Ragay Gulf earthquake of March 17, 1973, southern Luzon, Philippines," Journal of the Geological Society of the Philippines, Vol.28, No.2, pp. 1-31, 1974.

[5] H. Tsutsumi and J. S. Perez, "Large-scale active fault map of the Philippine fault based on aerial photograph interpretation," Active Fault Research, No.39, pp. 29-37, 2013.

[6] H. Yasuda, T. Bacolcol, A. Daag, M. Cahulogan, E. Bariso, E. Mitiam, J. Marjes, T. Ueki, T. Kobayashi, and T. Nakata, "Geometry and structure of the Philippine Fault in Ragay Gulf, southern Luzon," Journal of Disaster Research, Vol.10, No.1, 2015 (this issue).

[7] M. L. P. Bautista and K. Oike, "Estimation of the magnitudes and epicenters of Philippine historical earthquakes," Tectonophysics, Vol.317, pp. 137-169, 2000.

[8] H. Tsutsumi, J. A. Daligdig, H. Goto, N. M. Tungol, H. Kondo, T. Nakata, M. Okuno, and N. Sugito, "Timing of surface-rupturing earthquakes on the Philippine fault zone in central Luzon Island, Philippines," EOS Transactions AGU, Vol.87, p. 52, 2006.

[9] T. Bacolcol, E. Barrier, T. Duquesnoy, A. Aguilar, R. Jorgio, R. de la Cruz, and M. Lasala, "GPS constraints on Philippine fault slip rate in Masbate Island, central Philippines," Journal of the Geological Society of the Philippines, Vol.60, No.1-2, pp. 1-7, 2005.

Name:
Hiroyuki Tsutsumi

Affiliation:
Department of Geophysics, Graduate School of Science, Kyoto University

Address:
Kitashirakawa-oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan

Brief Career:
1996 Assistant Professor, Department of Geology, Kochi University
1997 Assistant Professor, Department of Geophysics, Kyoto University
2003- Associate Professor, Department of Geophysics, Kyoto University

Selected Publications:
- H. Tsutsumi, K. Sato, and A. Yamaji, "Stability of the regional stress field in central Japan during the late Quaternary inferred from the stress inversion of the active fault data," Geophysical Research Letters, Vol.39, L23303, doi: 10.1029/2012GL054094, 2012.
- H. Tsutsumi and J. S. Perez, "Large-scale active fault map of the Philippine fault based on aerial photograph interpretation," Active Fault Research, Vol.39, pp. 29-37, 2013.

Academic Societies & Scientific Organizations:
- Japan Geoscience Union (JGU)
- American Geophysical Union (AGU)

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