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Preliminary Tectonic Geomorphology of the Opak Fault System, Java (Indonesia)

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Introduction

Identification of active tectonic geomorphological features represents a challenge in slowly broad deforming areas that have tropical climates like Java. Faults may be buried by thick sediments or soils, land relief is low, and their geomorphic expression such as fault scarps are eroded quickly constraining it undetectable until the next earthquake (e.g. Marliyani et al., 2016).

This work focuses on the Opak Fault system, located in the central-southern part of Java, Indonesia (Figure 1) and thought to be the source of the devastating 2006 M 6.3 Yogyakarta earthquake. Here, we present a tectono-geomorphological analysis based on morphometric indices of channel steepness index and knickpoint identification in order to map the Opak fault system as well as identifying other existing faults in the vicinity that may have potential to produce large earthquakes.

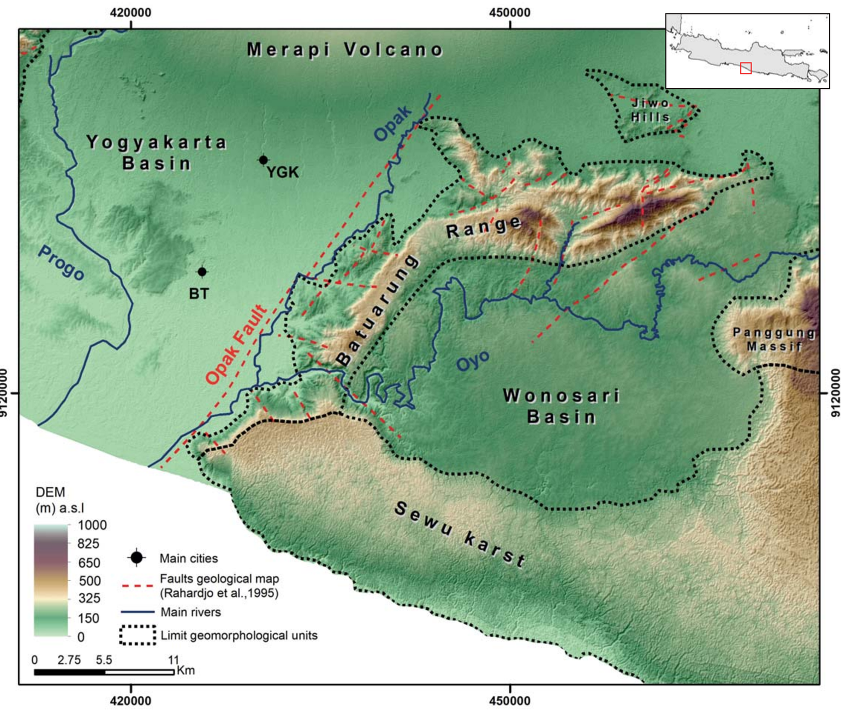

Figure 1. General geomorphological units of the study area. Hillshaded digital elevation model DEMNAS 8 m resolution (http://tides.big.go.id/DEMNAS/). Reference system UWGS_1984_UTM_Zone_49S. Abbreviations for major cities: BT: Bantul, YGK: Yogyakarta.

Seismotectonic Setting

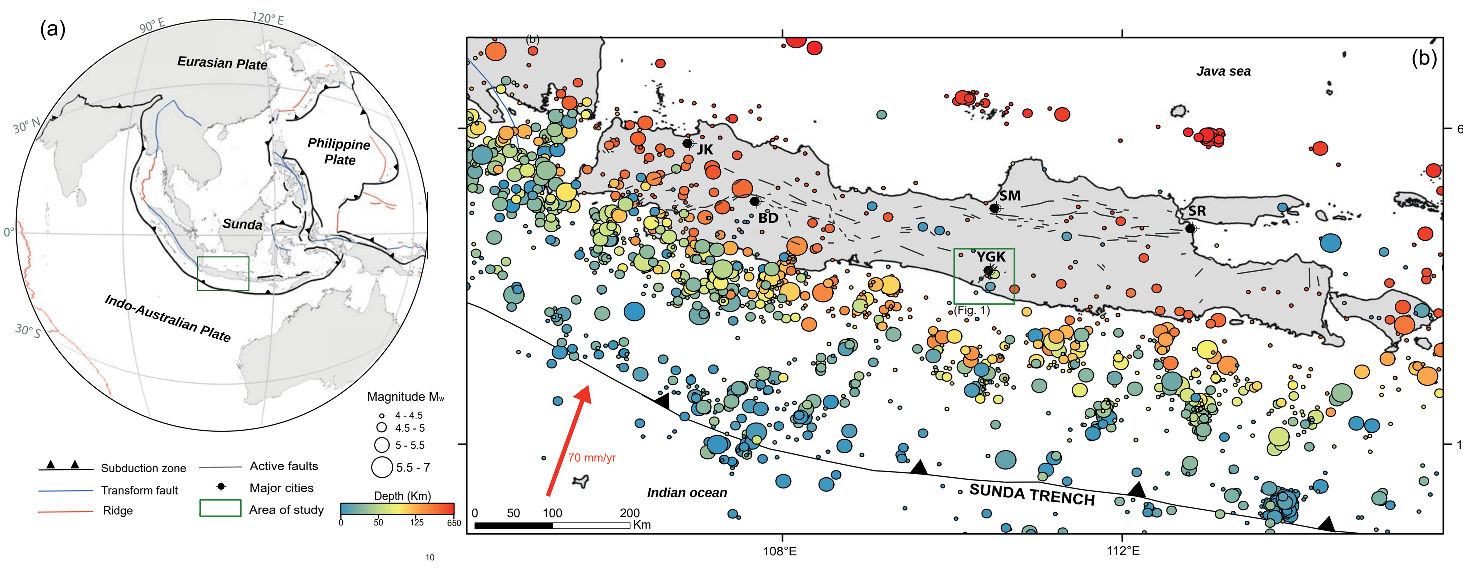

Figure 2. a) Simplified tectonic setting of the Indonesian region. (b) Instrumental seismicity of Java Island between 2008-2018 (USGS seismic catalogue, https://earthquake.usgs.gov). Motion of the Australian Plate at a rate of 70 mm/yr towards the Sunda Plate is indicated by a red arrow (Bock et al., 2003). Active faults are indicated by grey lines (Marliyani, 2016). Abbreviations for major cities: JK: Jakarta, BD: Bandul, YGK: Yogyakarta, SR: Subraya, SM: Semarang.

Java forms part of the volcanic arc in the Sunda Plate adjacent to the Java trench where the Australian Plate is subducted at a rate of 71 mm/y in a N20ºE direction according to NUVEL-1A model (Bock et al., 2003) (Figure 2).

Yogyakarta area has experienced several earthquake events during the time. On the 27th of May 2006, a M 6.3 earthquake (Figure 3) occurred in the area, causing more than 6000 fatalities and $3 billion economic loss. Opak Fault was initially thought to be the source of this earthquake, but the epicenter and aftershocks distributions were inconsistent with the extent of the fault presented at the regional geology map and the aftershock distribution.

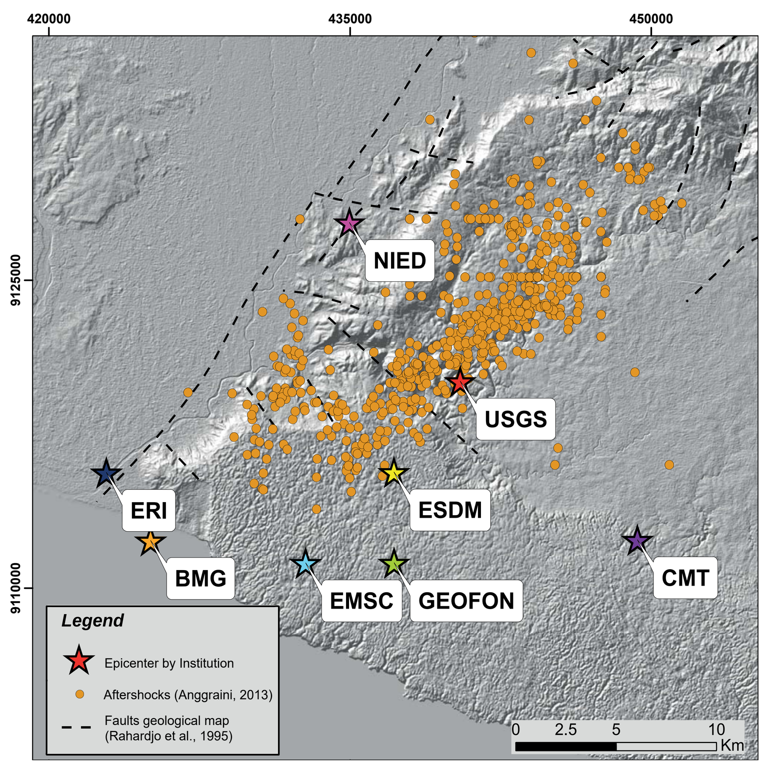

Figure 3. Distribution of the aftershocks sequence and source parameters of the 2006 Yogyakarta Earthquake. Hillshaded digital elevation model DEMNAS 8 m resolution (http://tides.big.go.id/DEMNAS/). Reference system UWGS_1984_UTM_Zone_49S. Aftershock catalogue from Anggraini (2013). Source parameters from USGS seismic catalogue (https://earthquake.usgs.gov).

Methods

We have calculated two morphometric indices: normalized channel steepness index (Ksn) and spatial distribution of knickpoints, in order to integrate them with the geomorphology and geology of the study area in order to map the Opak fault system. Our input data is the 8 m resolution DEMNAS digital elevation model (http://tides.big.go.id/DEMNAS/). The analysis is perfomed using LSDTopoTools software (Mudd et al., 2018) which is able to extract knickpoints from river profiles (Figure 4).

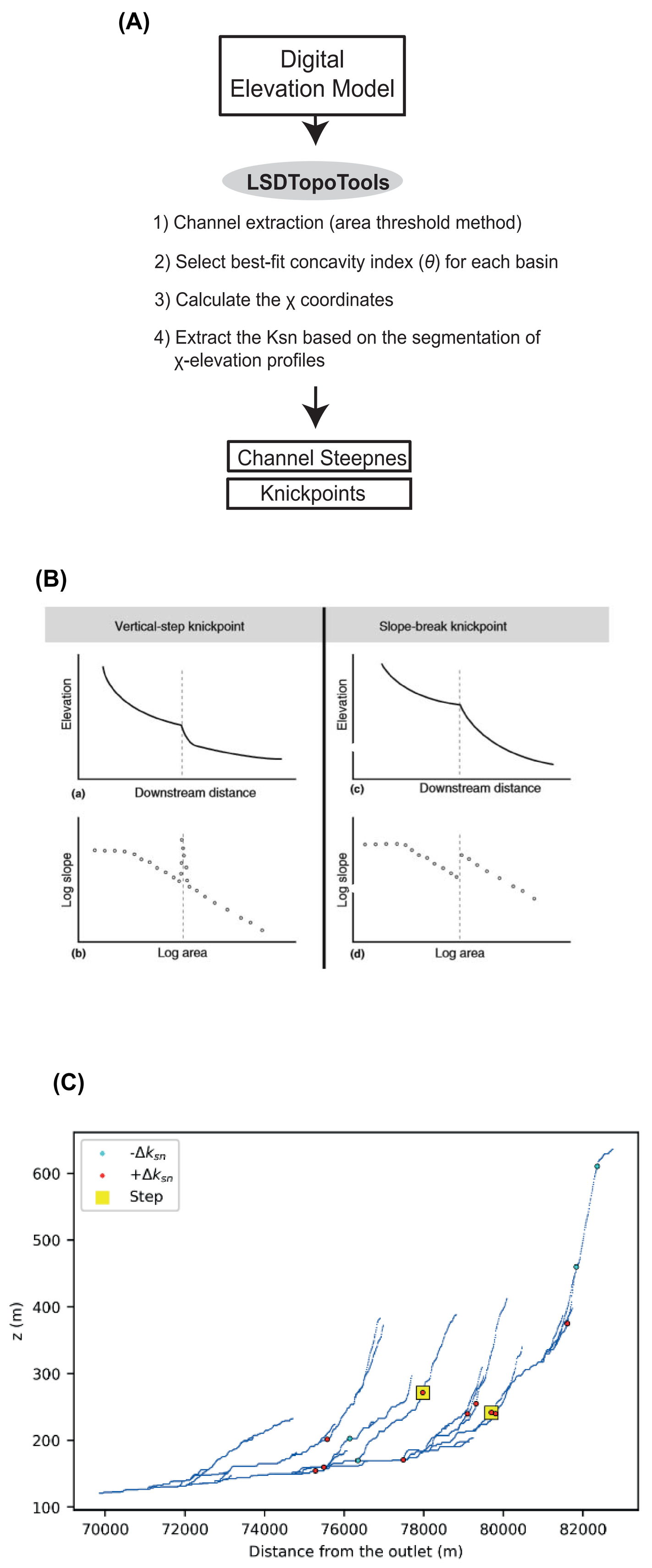

Figure 4. A) Flowchart of the LSDTopoTools knickpoint detection algorithm. Simplified from Gailleton et al. (2018). B) Type of Knickpoints: vertical-step knickpoints and slope-break knickpoints, here illustrated both in terms of channel profile form (upper) and slope-area relations (bottom) (Whipple et al., 2013). C) Example of knickpoint extraction for a basin of the study area shown for the channel long profiles.

Results

Channel Steepness

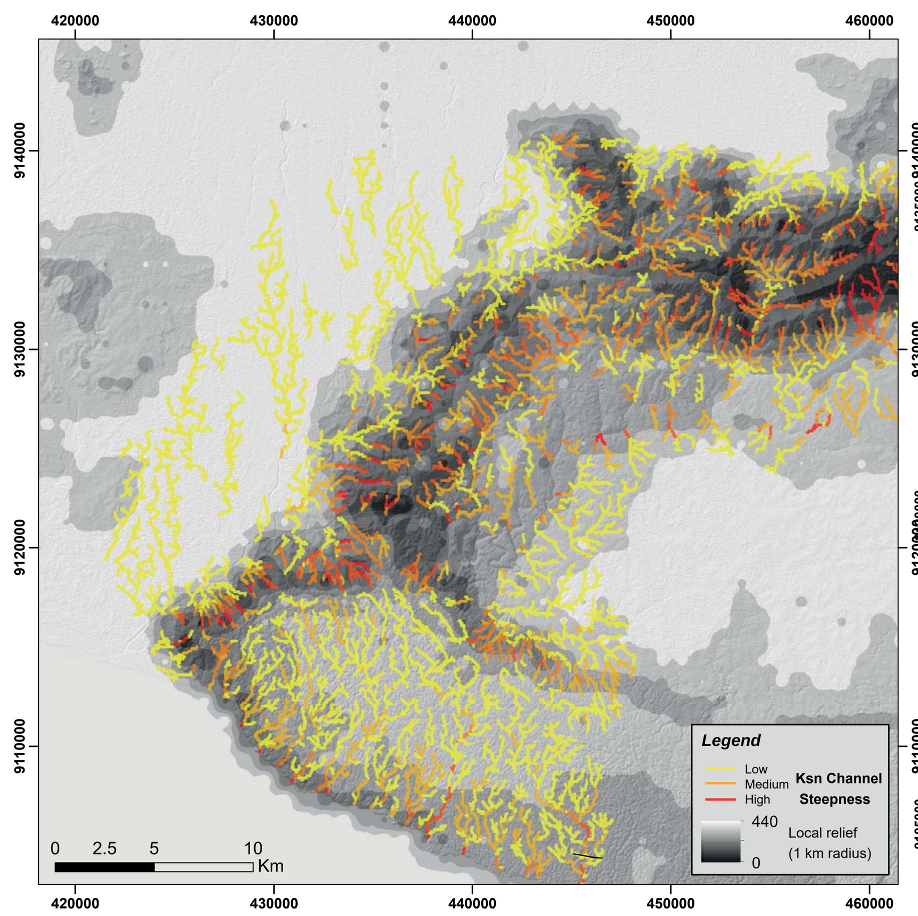

Figure 5. Map of spatial distribution of Ksn (channel steepness) obtained with LSDTopoTools (Mudd et al., 2018). High Ksn values are indicated in red while low in yellow. This areas are in agreement with the zone of high hillslope gradients and local relief.

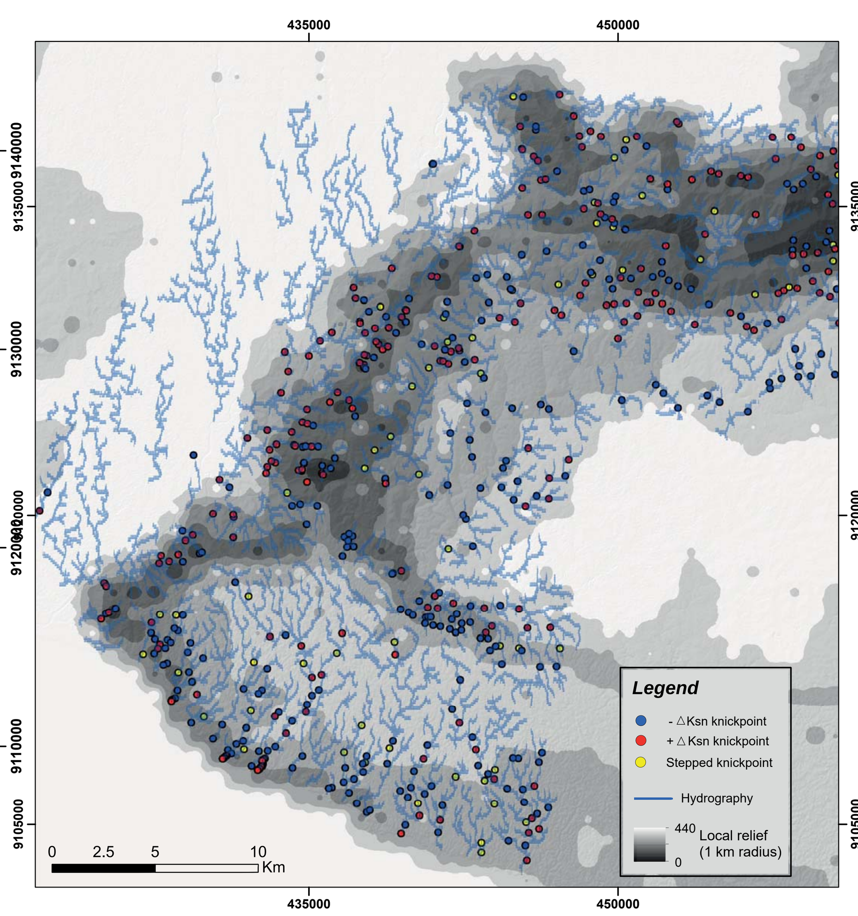

Figure 6. Map of spatial distribution of knickpoints overlain on local relief map. Vertical-step knickpoints are shown by yellow dots while slope-break knickpoints in blue (when negative value) and red (when positive value).

Knickpoints

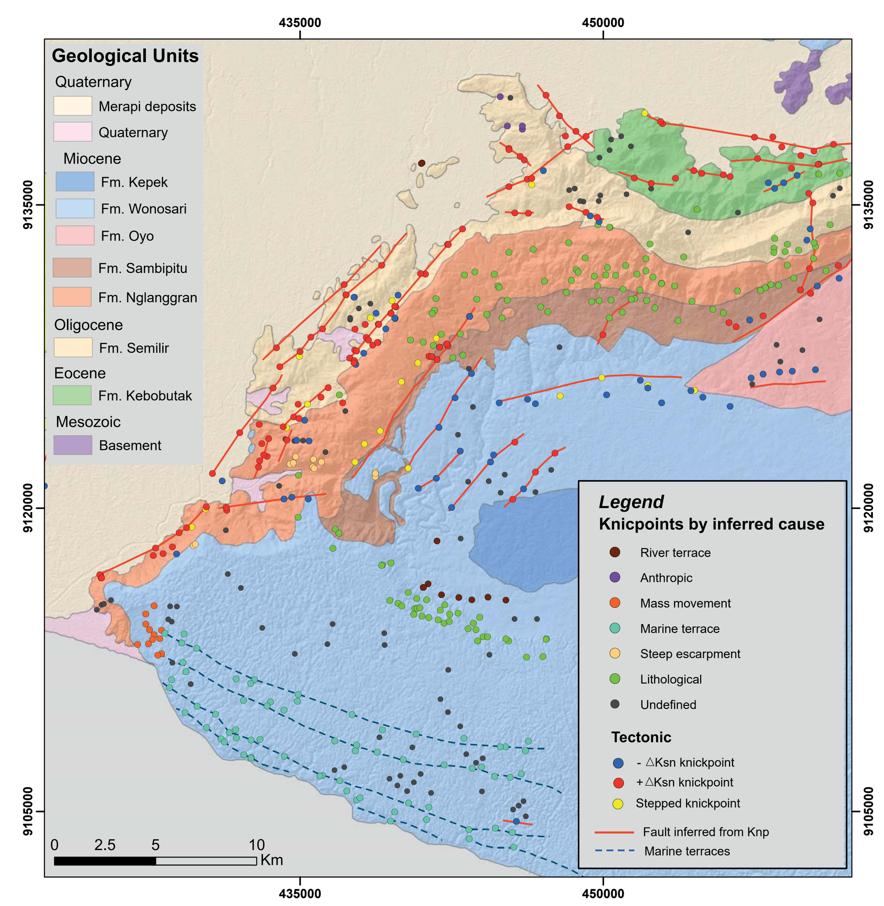

Figure 7. Location of knickpoints in the study area categorized by their inferred cause; obtained with LSDTopoTools (Mudd et al., 2018). Faults and marine terraces deduced from them are displayed. Geological map compiled from Rahardjo et al (1995). The western part of the area is mainly covered by recent volcanic deposits (Merapi deposits) and alluvium filling the Yogyakarta basin. The eastern part consists of Eocene-Miocene fluvial, volcanic and shallow marine sedimentary rocks. Fm. Kepek: tuff and limestones. Fm. Wonosari: limestones. Fm. Oyo: tuffaceous sandstone and limestone. Fm. Sambipitu: calcareous sandstones. Fm. Nglanggran, Semilir and Kebo-Butak (volcanic deposits): andesitic breccias, lapilli, ruff, sandstones, shales. Basements is composed of metamorphic rocks.

Discussion: Causative fault of Yogyakarta earthquake?

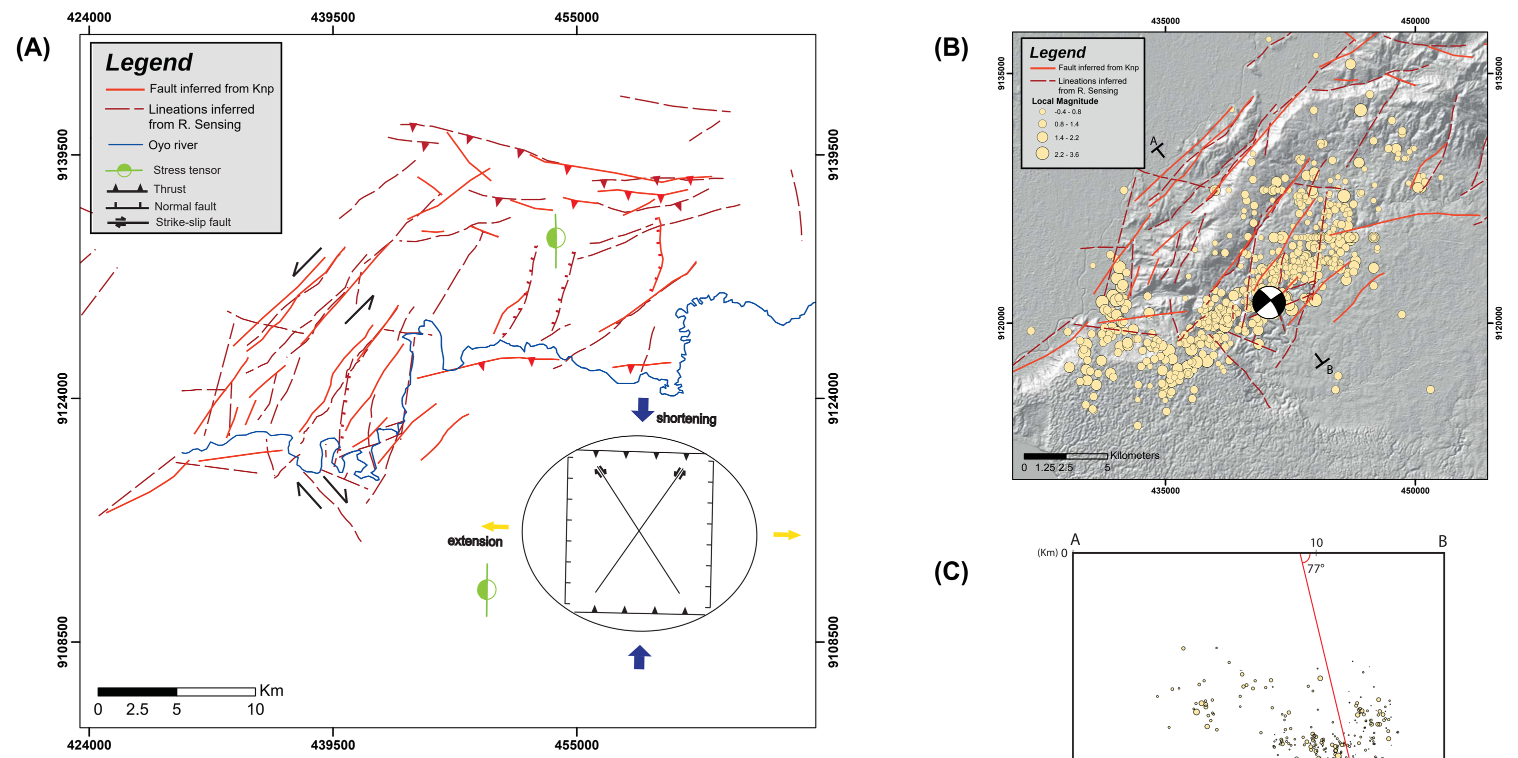

Figure 8. A) Map illustrating the fault system and the stress regime of the area derived from earthquake focal mechanism from the World Stress Map (Heidbach et al., 2018). We interpretate the slip tendency of the mapped faults if reactivated according to the stress regime. Note that the area experiencing more uplift is the north-east part of the Batuarung Range (thrust with nord direction) which may be correlated by the pattern of the Oyo river flowing in this area north to south. B) Distribution of the aftershock sequence (Anggraini, 2013) in the context of the mapped faults. C) Vertical section perpendicular on strike of major fault (NE-SW) of the aftershocks and main shock (in red).

Conclusions

The topography expressed as the Baturagung Range represent recent faulting. It is unclear which of these structures are active as short-term (Quaternary to Holocene) tectonic evidence in the landforms is lacking or not yet observed, partly because the Batuarung Range and Sewu karst region consists of an insignificant amount of Quaternary deposits. Other interesting feature is the Oyo river, its drainage pattern changes along its course northwards and southwards at various locations suggesting that several NE-SW to N-S trending faults may have controlled the drainage evolution.

We are planning to conduct a field work campaign in June 2019 to solve the current uncertainities. A detailed geological map will be carried out in order to find indices of active faulting and suitable sites for a paleoseismological studies, as well as to corroborate the obtained knickpoints. To obtain better resolution data to do our surface and subsurface analysis we will perform some geophysics: GPR, ERT and drone flying.

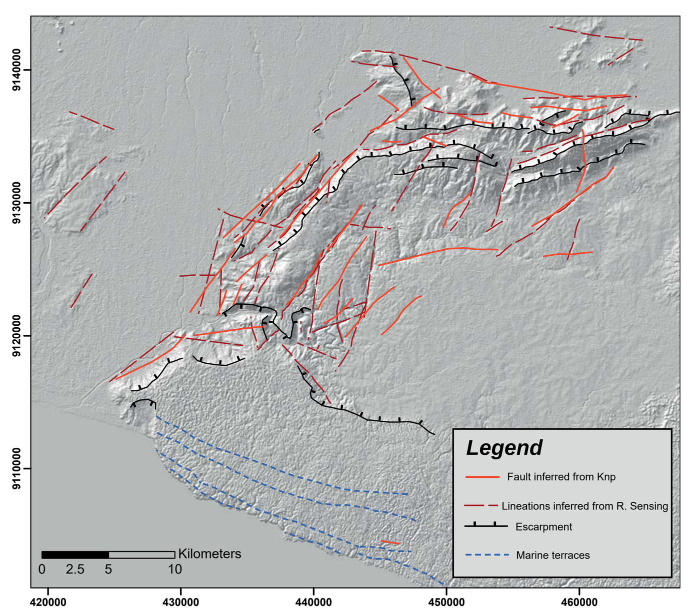

Figure 9. Summary map compiling the mapped features. Faults inferred from the knickpoint distribution and lineations by remote sensing lineament analysis. Note that not all high ksn values obtained are considered as a fault since other processes (difference in rock resistance, etc.) have to be taken into account. Hillshaded digital elevation model DEMNAS 8 m resolution (http://tides.big.go.id/DEMNAS/).

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