Present-day stress orientations in the Great Sumatran Fault in North Sumatra

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Present-day stress orientations in the Great Sumatran Fault in North Sumatra

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Trench-parallel strike slip faults develop at lithospheric scale during oblique high-angle subduction. A "sliver" plate forms due to slip partitioning between the subduction plane (margin-normal slip) and the strike slip fault (margin-parallel slip). This process ultimately controls the location of volcanoes and earthquakes. The Great Sumatran Fault (GSF) is a showcase of this tectonic configuration located in the Sumatran section of the Sunda arc-trench system (e.g., Katili 1970; Fitch 1972) (Fig.1, upper panel). Kinematics of the large-scale structures of the Sumatra section of the Sunda trench are well understood (see McCaffrey 2009, for a review), and tensional and compressional domains have been identified at the regional scale. However, detailed understanding of the stress distribution is still lacking yet essential for evaluating the seismic hazard potential in order to mitigate the impact of the large, hazardous earthquakes associated with this system (e.g., Ishii et al. 2005; Moreno et al. 2010).

In this contribution, we study the present-day stress orientations of the Great Sumatran Fault at its northern section (NGSF). We deduced the state of (paleo)stress along structural features observed at two scales; (a) at meso-scale, analyzing ASTER GDEM data, and (b) at outcrop-scale, with field data measurements. We focus on the leading edge of northwestward propagating continental sliver deformation exposed on land, i.e. the northernmost tip of Sumatra (between 4,5°N and 6°N), where the NGSF bifurcates into its two major branches (Jarrard 1986; McCaffrey 1991, 1992). These two fault branches form two structural highs bounding a graben basin in the onshore, continuing into the Pulau Weh Island in the east, and the Pulau Aceh Archipelago in the west (Fig. 1). Given their location at the present day deformation front, these islands provide a unique opportunity to compare the sub-recent stress field with present day stresses, contributing to the understanding of the stress field evolution during northwestwards propagation of the Sumatran forearc continental sliver.

We performed structural analysis of the GDEM using the FaultTrace module of TerraMath WinGeol® (Reif et al. 2011). This module uses a geometrical method to identify planar attributes on the basis of a minimum of three points along the intersection between geological features and topography. With this analysis we are able to detect and characterize two different transpressional fault systems in relation to the NGSF at the regional scale (Fig. 2). We determined several fault sets with faults trends between N150 and N170° and with dips of 50° or more along the eastern branch (Fig. 2). The distribution of strike and dip of few of these fault sets suggests their development as part of conjugate faults. In the western branch we distinguished two fault sets on the basis of their dip and dip direction; faults striking between N60 and N110° with dip values of less than 40°, and faults striking between N160° and N185° with dip values higher than 60° (Fig. 2).

At outcrop scale, we acquired structural data and conducted paleostress analysis in a limited number of locations given dense vegetation and restricted accessibility. When possible, we used fault slip data to derive recent paleostress histories for the area. If kinematic indicators were not available, we used data clusters derived from geometry and/or attitude of the main structures as a proxy. Data falls generally into two distinct groups. Near the western branch of the NGSF, the faults trend parallel to the main structure (N205°) and dip 55°, with transpressive kinematics showing displacements toward the WSW. Elsewhere, kinematic indicators are unclear, but seem to indicate clustering in relation with a roughly N-S stress field, which associated deformation manifests as NNW-SSE strike-slip faults and E-W to ENE-WSW strike-to-oblique faults.

Based on a combination of field observations and DEM analysis, we interpret (a) the eastern branch of the GSF as a N160° trending Riedel system, with synthetic R and P systems, and (b) the western branch as a system of thrust splays and associated folds, diverging westwards from it. Along the western branch, the low-dipping faults are interpreted as thrusts and the steeply dipping ones as strike slip faults. Line-length balancing yields a minimum amount of shortening of 33% accommodated along this contractional system (Fig. 2).

These structural patterns developed in a transpressional setting along the two branches of the tip of the NGSF. Both the Riedel system and the fold and thrust belt are coherent with a $_{1}$ and$_{3}$ roughly trending N010°–N190° and N100–N280°, respectively. This is similar to the present day principal stress axes (e.g. McCaffrey 2009)(Fig. 3). However, the present day state of stress shows that strain is mainly accommodated along contractional structures in the Aceh Basin, located offshore, west of Sumatra along a dextral strike slip system trending parallel to the GSF (Berglar et al. 2010)(Fig. 3). Berglar et al., 2010 show that the offshore system, which propagates northwestwardly, accommodates the oblique convergence since late Miocene. Our analysis corroborates these findings. In addition we show that strain is accommodated in dissimilar manners within an overall similar stress field, resulting in apparently contrasting kinematics between the eastern and western branch of the system. We speculate that the western branch with the fold and thrust belt is a local particularity, related to early-distributed deformation of the propagating system.

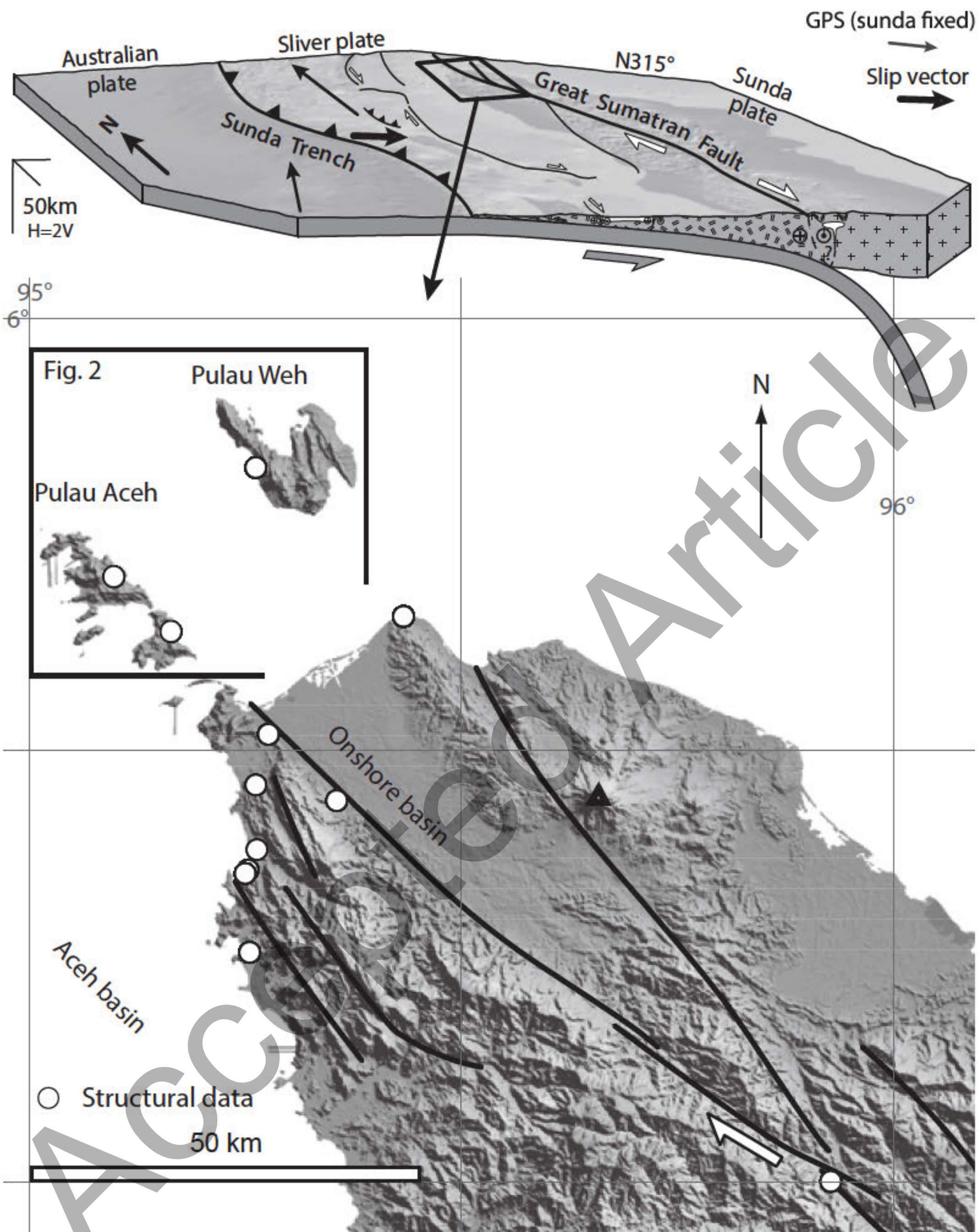
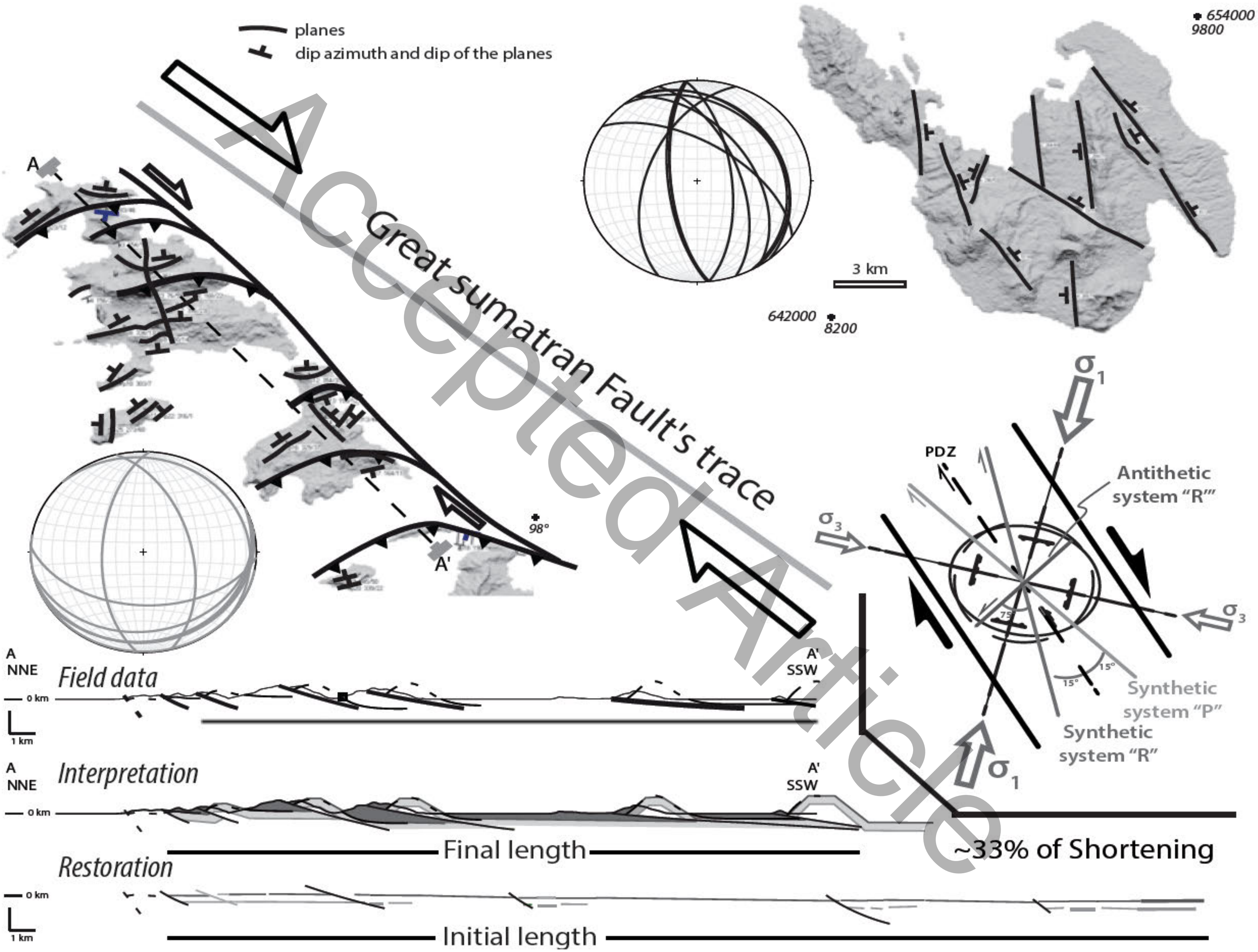


Fig. 1. 3D regional tectonic configuration in the Sumatran section of the Sunda arc-trench system (upper panel), and map-view of the GSF. White dots represent location of the data used in this contribution.



planes
dip azimuth and dip of the planes
Great sumatran Fault's trace
A
A'
98°
3 km
654000
9800
642000
8200
σ1
σ3
PDZ
Antithetic system "R'"
Synthetic system "P"
Synthetic system "R"
15°
75°
A NNE
Field data
A' SSW
0 km
1 km
Interpretation
Final length
~33% of Shortening
Restoration
Initial length

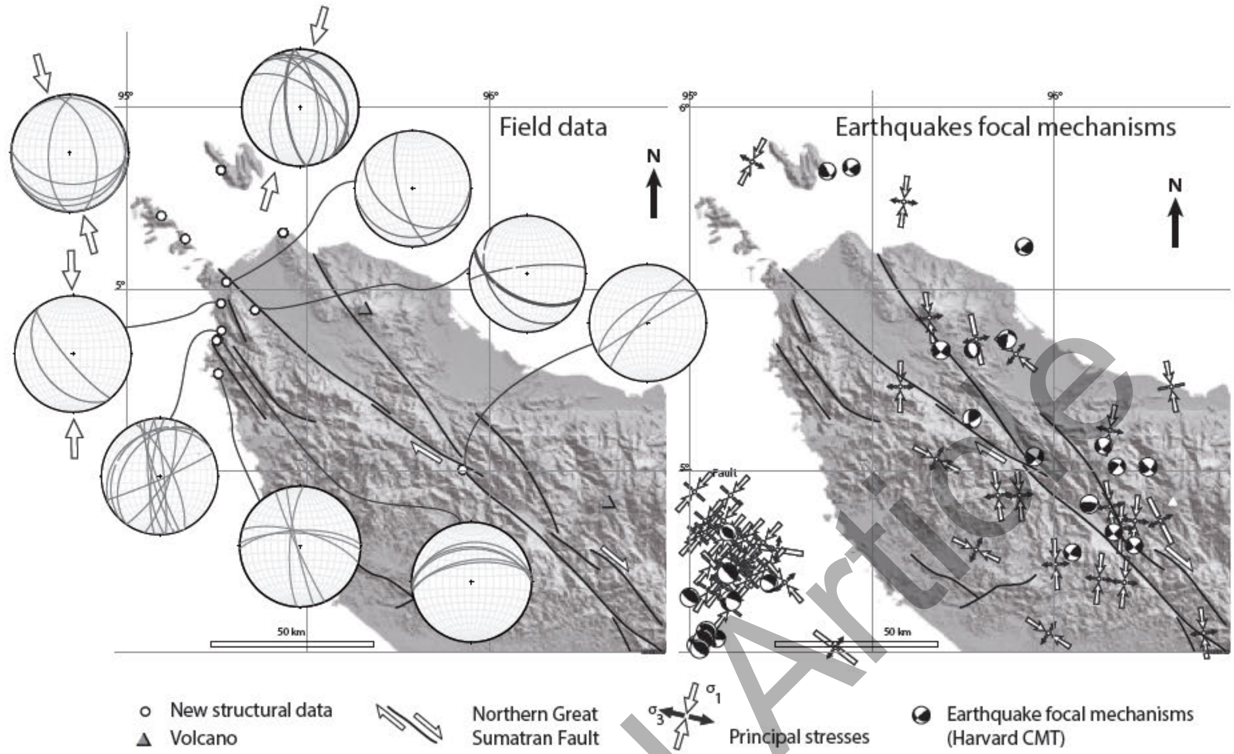


Fig. 3. Analysis of the GDEM data for the Pulau Weh island (upper-right), and the Pulau Aceh archipelago (bottom-left). Planar structures are marked in red, and used to derive the regional tectonic interpretation, shown in black. Stereplots for each island show the attitudes of planar features that interpreted as faults (in blue for Pulau Weh and in green for Pulau Aceh).

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Fig. 2. Analysis of the GDEM data for the Pulau Weh island (upper-right), and the Pulau Aceh archipelago (bottom-left). Planar structures are marked in red, and used to derive the regional tectonic interpretation, shown in black. Stereplots for each island show the attitudes of planar features that interepreted as faults (in blue for Pulau Weh and in green for Pulau Aceh).

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