Present-Day Stress Field of Southeast Asia*

Mark Tingay[1], Chris K. Morley[2], Rosalind King[1], and David Coblentz[3]

Search and Discovery Article #41111 (2012)**
Posted December 31, 2012

*Adapted from oral presentation at AAPG International Conference and Exhibition, Singapore, September 16-19, 2012

[1]Australian School of Petroleum, University Adelaide, Adelaide, SA, Australia (mark.tingay@adelaide.edu.au)
[2]PTT Exploration and Production Public Company Limited, Bangkok, Thailand
[3]Los Alamos National Laboratories, Los Alamos, NM

Abstract

Present-day stress information is particularly valuable for petroleum geomechanics applications in Southeast Asia. The region contains 31 basins, the majority of which host active petroleum producing fields, with Indonesia, Malaysia, Vietnam and Thailand having a combined production of over 2.4 million barrels of oil per day. The Cenozoic tectonic evolution of the Sunda region of Southeast Asia is usually considered to be controlled by escape tectonics associated with India-Eurasia collision. However, Southeast Asia is bounded by a poorly understood and complex range of convergent and strike-slip zones and little is known about the effect of these other plate boundaries on the intraplate stress field in the region.

We compile the first extensive stress dataset for Southeast Asia, containing 275 A-D quality (177 A-C) horizontal stress orientations, consisting of 72 stress indicators from earthquakes (located mostly on the periphery of the plate), 202 stress indicators from breakouts and drilling-induced fractures and one hydraulic fracture test within 14 provinces in the plate interior. This data reveals that a variable stress pattern exists throughout Southeast Asia that is largely inconsistent with the region's approximately ESE absolute motion direction. The present-day maximum horizontal stress in Thailand, Vietnam and the Malay Basin is predominately north-south, consistent with the radiating stress patterns arising from the eastern Himalayan syntaxis. However, the present-day maximum horizontal stress is primarily oriented NW-SE in Borneo, a direction that may reflect plate-boundary forces or topographic stresses exerted by the central Borneo highlands. Furthermore, the South and Central Sumatra basins exhibit a NE-SW maximum horizontal stress direction that is perpendicular to the Indo-Australian subduction front. Hence, the plate-scale stress field in Southeast Asia

appears to be controlled by a combination of Himalayan orogeny-related deformation, forces related to subduction (primarily trench suction and collision) and intraplate sources of stress such as topography and basin geometry.

References

Hillis, R.R., and A.F. Williams, 1993, The contemporary stress field of the Barrow-Dampier Sub-basin and its implications for horizontal drilling, *in* J.A. Odins, and R.A. Facer, (eds.), Conference papers from the ASEG 10th geophysical conference and exhibition: Exploration Geophysics Melbourne, v. 24/3-4, p. 567-575.

Hillis, R.R., and A.F. Williams, 1993, The stress field of the North West Shelf and wellbore stability: The APEA Journal, v. 33/1, p. 373-385.

Hiscott, R.N., 2001, Depositional sequences controlled by high rates of sediment supply, sea-level variations, and growth faulting; the Quaternary Baram Delta of northwestern Borneo: Marine Geology, v. 175/1-4, p. 67-102.

Tingay, M., P. Bentham, A. de Feyter, and A. Kellner, 2011, Present-day stress-field rotations associated with evaporates in the offshore Nile Delta: GSA Bulletin, v. 123/5-6, p. 1171-1180.

Tingay, M., C. Morley, R. King, R.R. Hillis, D. Coblentz, and R. Hall, 2010, Present-day stress field of Southeast Asia, *in* O. Heidbach, M. Tingay, and F. Wenzel, (eds.), Frontiers in stress research: Tectonophysics, v. 482/1-4, p. 92-104.

THE UNIVERSITY OF ADELAIDE
AUSTRALIA

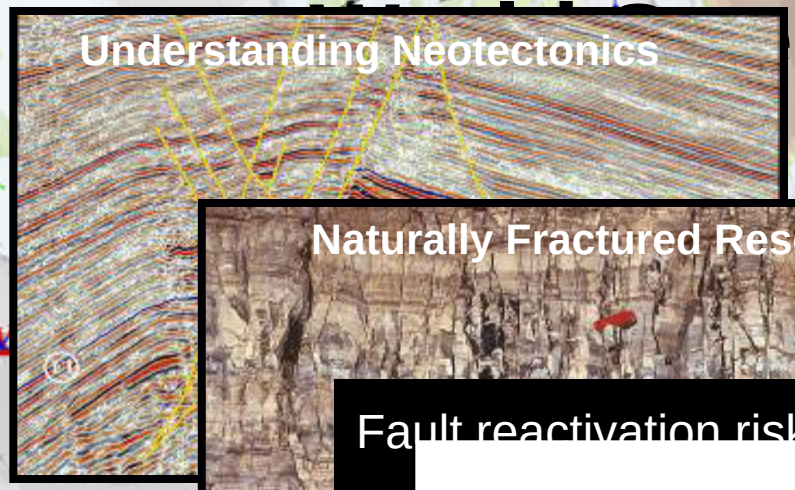
SUB CRUCE LUMEN

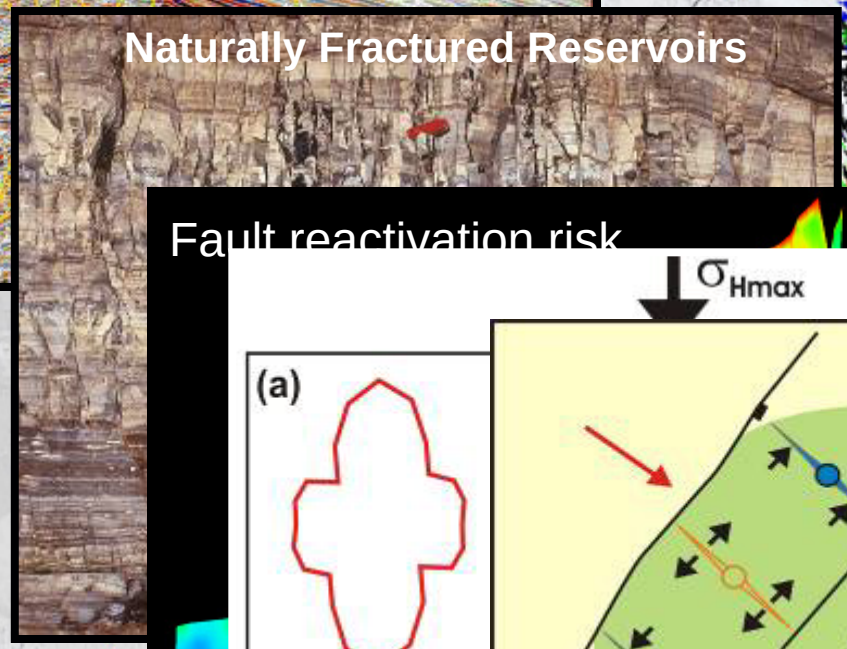
Present-day Stress Field of SE Asia

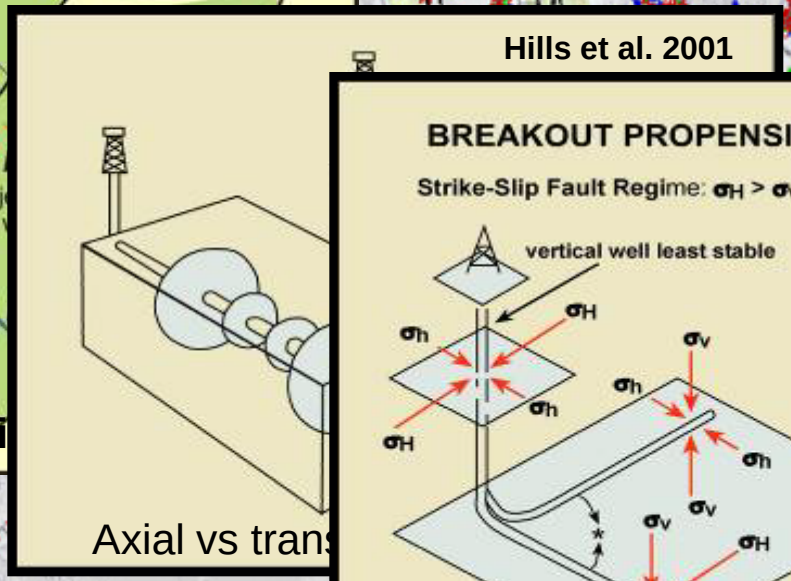
Mark Tingay[1], Chris Morley[2],
Rosalind King[1] & David Coblentz[3]

[1] University of Adelaide, Adelaide, Australia
[2] PTT Exploration and Production, Bangkok, Thailand
[3] Los Alamos National Laboratories, New Mexico, USA

ss Map Project: 2008

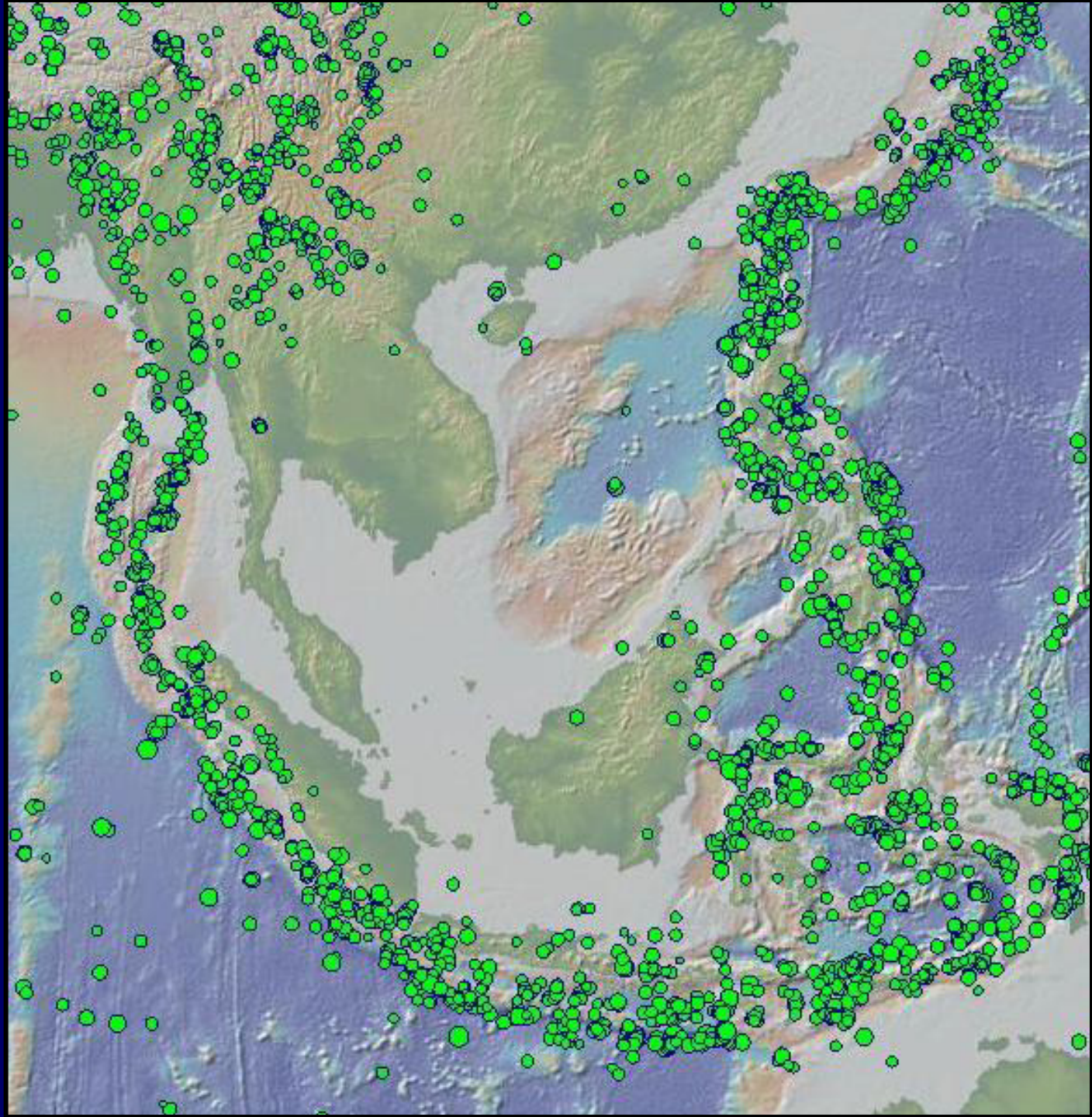






SE Asia (Sunda)

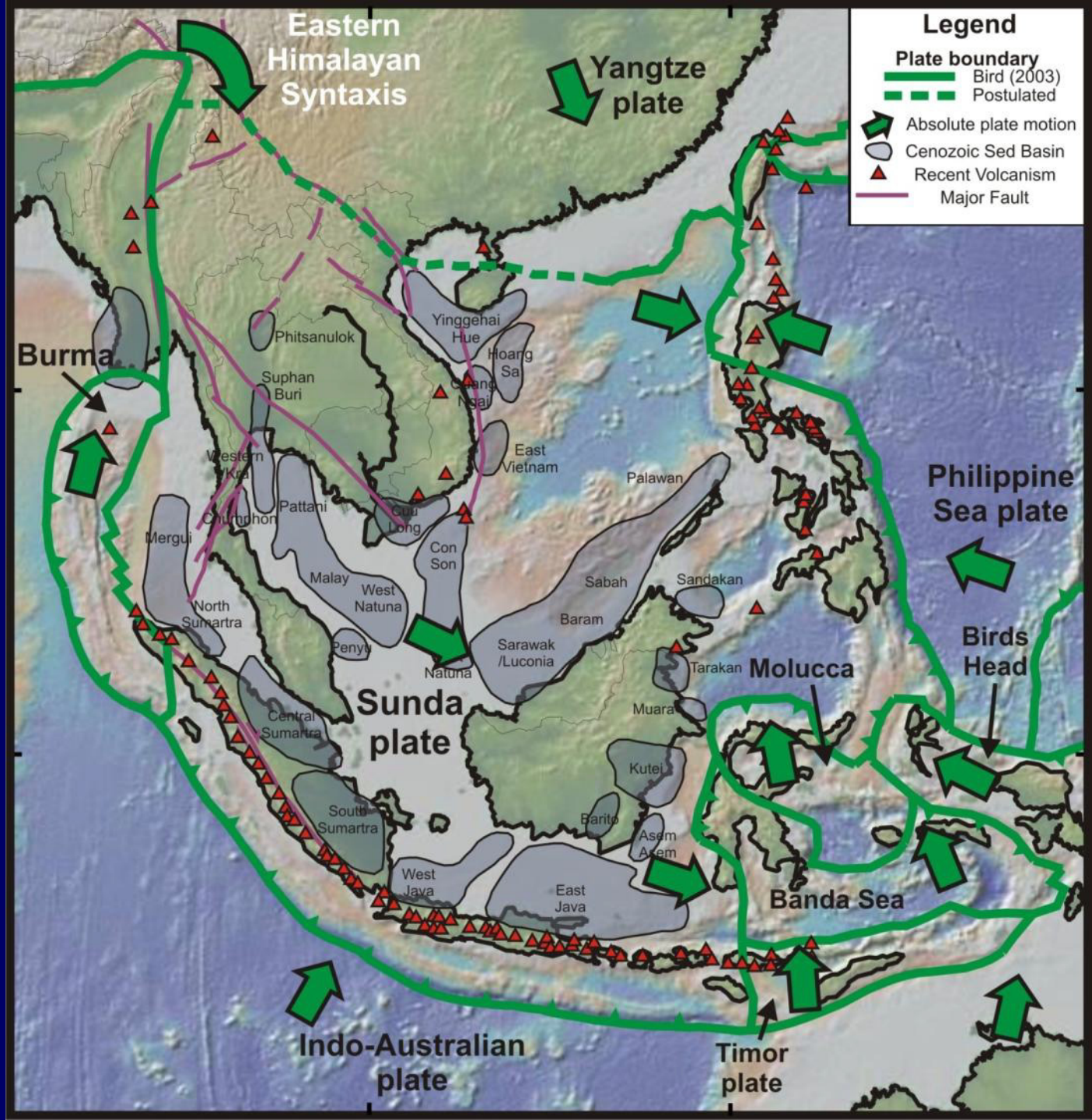
- Intense seismicity at edges.
- Stable interior.
- Sometimes termed Sunda ‘craton’.



Seismicity in SE Asia (M_w>4.0)

SE Asia (Sunda)

- Intense intraplate deformation during Cenozoic.
- Recent volcanism.
- Major faulting
- Widespread uplift.
- Rapid deep basins

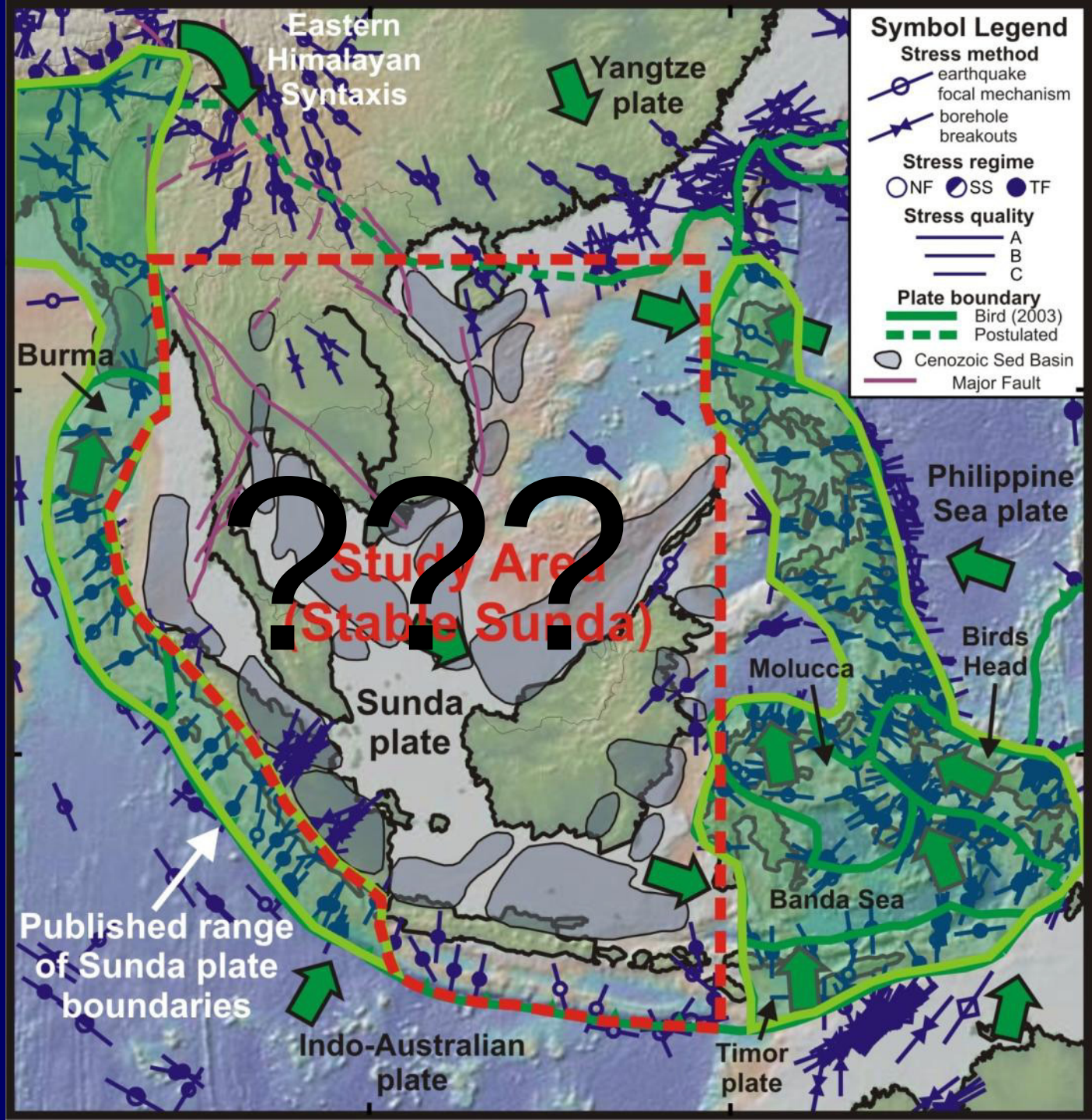


Major tectonic features of SE Asia

SE Asia (Sunda)

- Bounded by collisional zones.
- No oceanic ridge.
- Influence of Himalayan syntaxis
- Other boundaries often ignored.
- 2003 WSM: 37 A-C (61 A-D) intraplate stress indicators

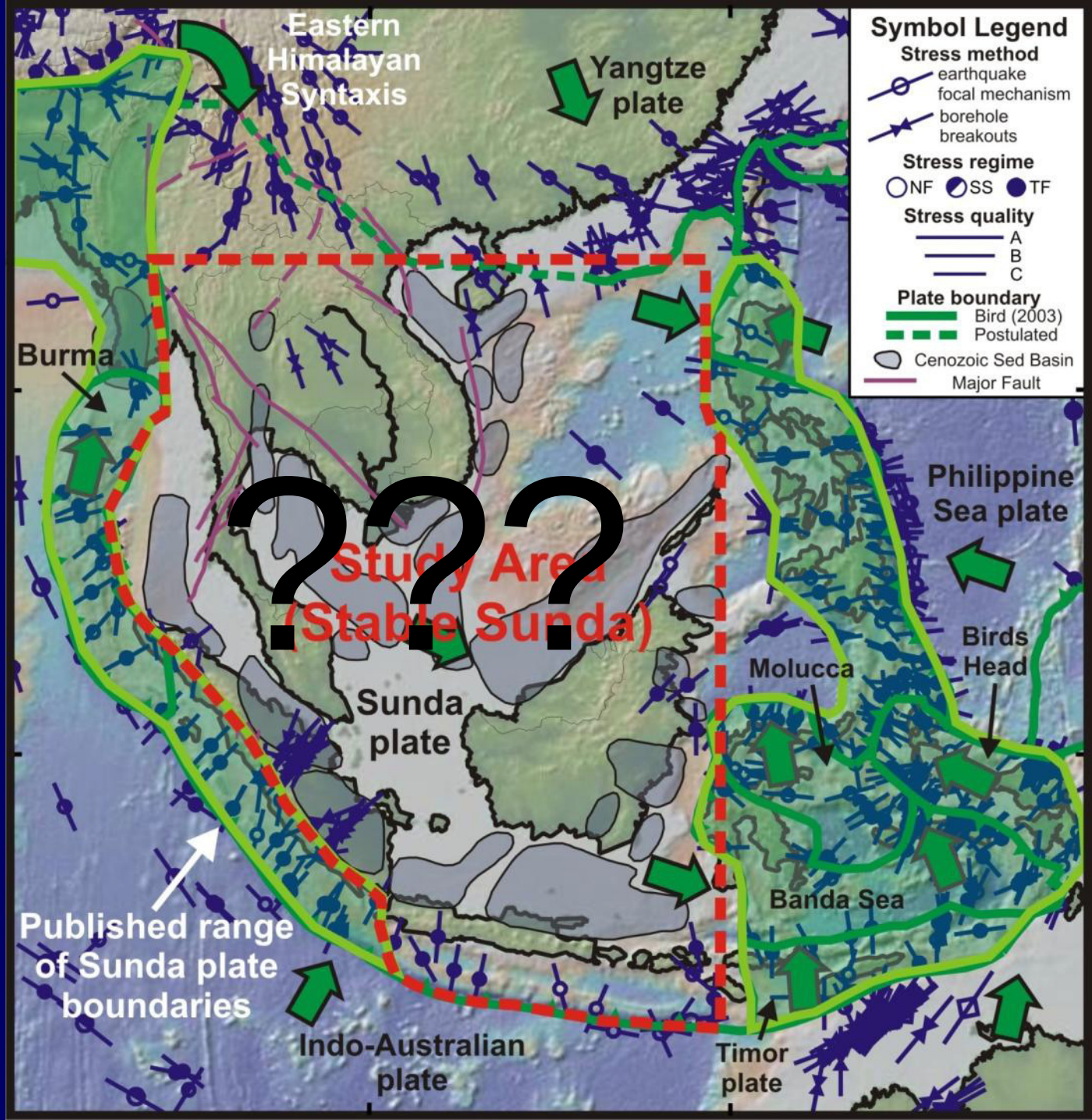
2003 WSM database for SE Asia



SE Asia Stress Map Project:

- Compile stress orientation data in SE Asia.
- Establish controls on stress field.
- Compare with Cenozoic tectonics
- Database for industry and natural hazards

2003 WSM database for SE Asia



Present-day Stress Field of SE Asia

- INTRODUCTION
- PRESENT-DAY STRESS FIELD OF SE ASIA
- DISCUSSION: PLATE-SCALE STRESS FIELD
- DISCUSSION: LOCAL CONTROLS ON STRESS
- SUMMARY

Present-day Stress Field of SE Asia

- INTRODUCTION
- **PRESENT-DAY STRESS FIELD OF SE ASIA**
- DISCUSSION: PLATE-SCALE STRESS FIELD
- DISCUSSION: LOCAL CONTROLS ON STRESS
- SUMMARY

The SE Asia Stress Map

- 275 A-D (177 A-C) quality indicators.
- Authors examined ~230 wells in Thailand, Brunei, Malaysia and Indonesia.
- 80 wells in Indonesia, Malaysia & Vietnam from other studies.

SE Asia Stress Map

(Tingay et al., 2011)

The SE Asia Stress Map

- Data collected in 18 distinct provinces.
- Average stress orientations obtained for each region
- Regions quality ranked 1-5 for reliability

Stress provinces defined from SE Asia stress database

Present-day Stress Field of SE Asia

- INTRODUCTION
- PRESENT-DAY STRESS FIELD OF SE ASIA
- **DISCUSSION: PLATE-SCALE STRESS FIELD**
- DISCUSSION: LOCAL CONTROLS ON STRESS
- SUMMARY

Stress Pattern in SE Asia

- S_{Hmax} primarily N-S in Indochina.
- S_{Hmax} primarily NW-SE in Borneo.
- S_{Hmax} primarily NE-SW in Sumatra and N-S in East Java (orthogonal to subduction zone).
- S_{Hmax} not parallel to plate motion

Average S_{Hmax} for SE Asia stress provinces

Plate-Scale Stress Modelling

- Thin Shell (100km) 2D Finite Element Modelling.

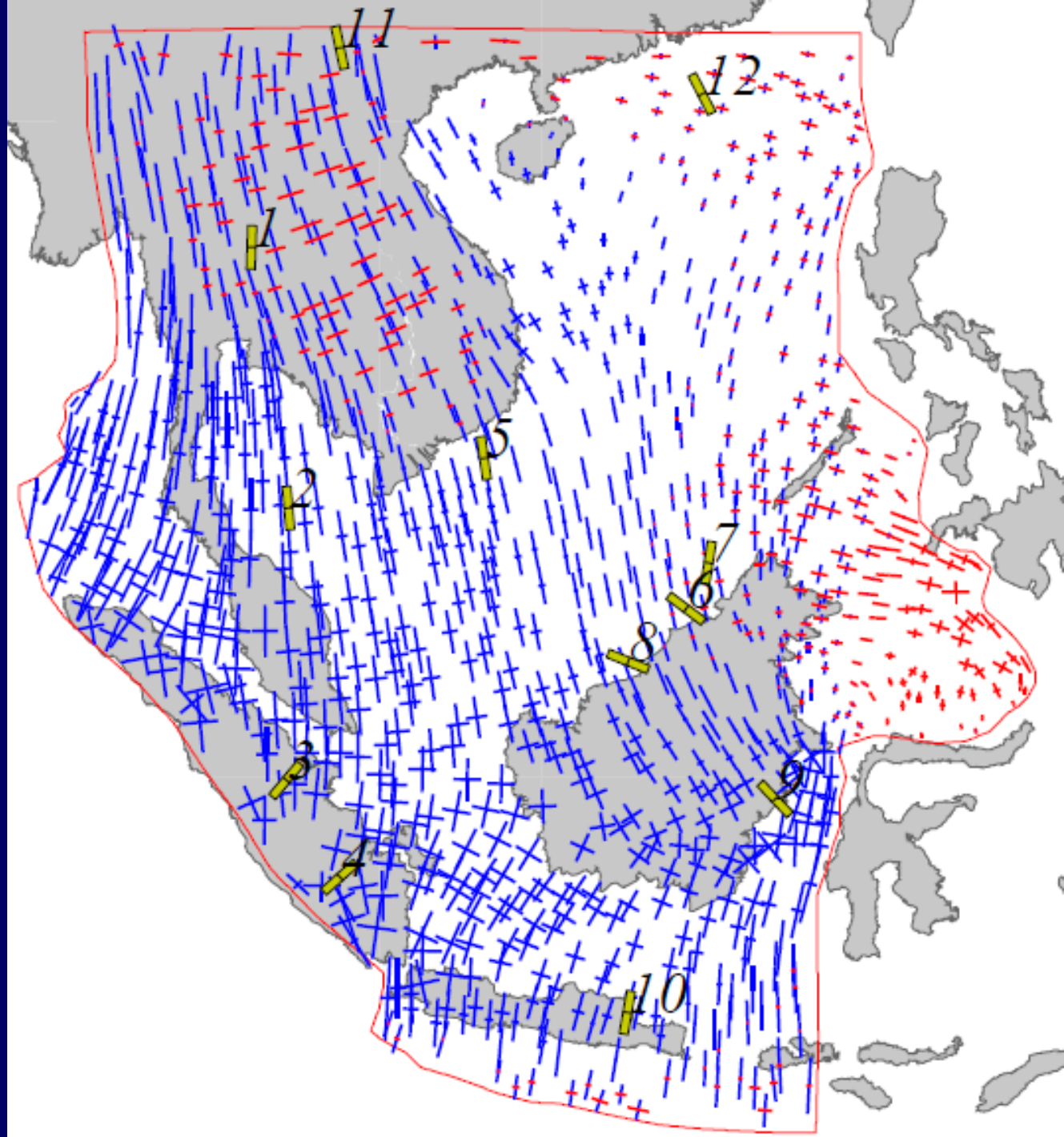
- Model (‘plate’) boundary divided into 12 segments, each with a boundary condition and orientation predicted from geology.

- Orientation of boundary force kept constant, magnitude varied.

- Forward model >850000 of permutations to identify common boundary forces used in ‘best fit’ models (e.g. best 5% of models).

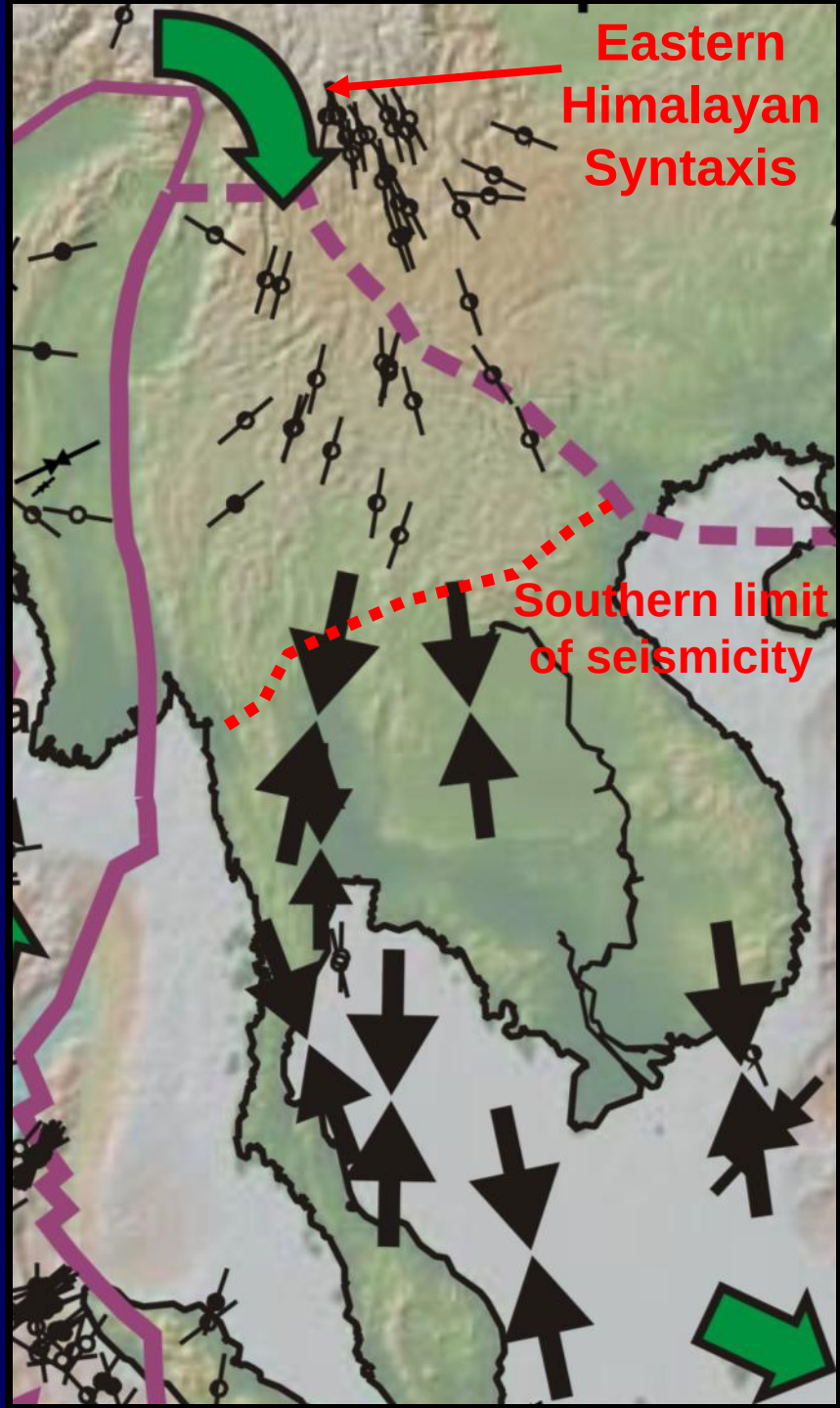
Stress Modelling Results:

- 865000 Models run – compare traits of best 5%.
- Suggests SE Asia stress field primarily controlled by forces from:
  - ➢ Himalayan syntaxis
  - ➢ Subduction in Indonesia
  - ➢ Collision in Sulawesi.
- Predicted stresses in Borneo and Sumatra are oblique to observed.
- Discrepancies due to local sources of stress (e.g. topography effects).



Primary Control on Indochina Stress Field

- S_{Hmax} primarily N-S in Indochina (orthogonal to absolute plate motion).
- Consistent with radial S_{Hmax} pattern from eastern Himalayan syntaxis.
- Suggests stresses controlled by forces exerted at syntaxis (e.g. Himalayan escape tectonics, extrusion of thickened lithosphere, topographic forces).
- But NOT dominant control on stress throughout SE Asia.



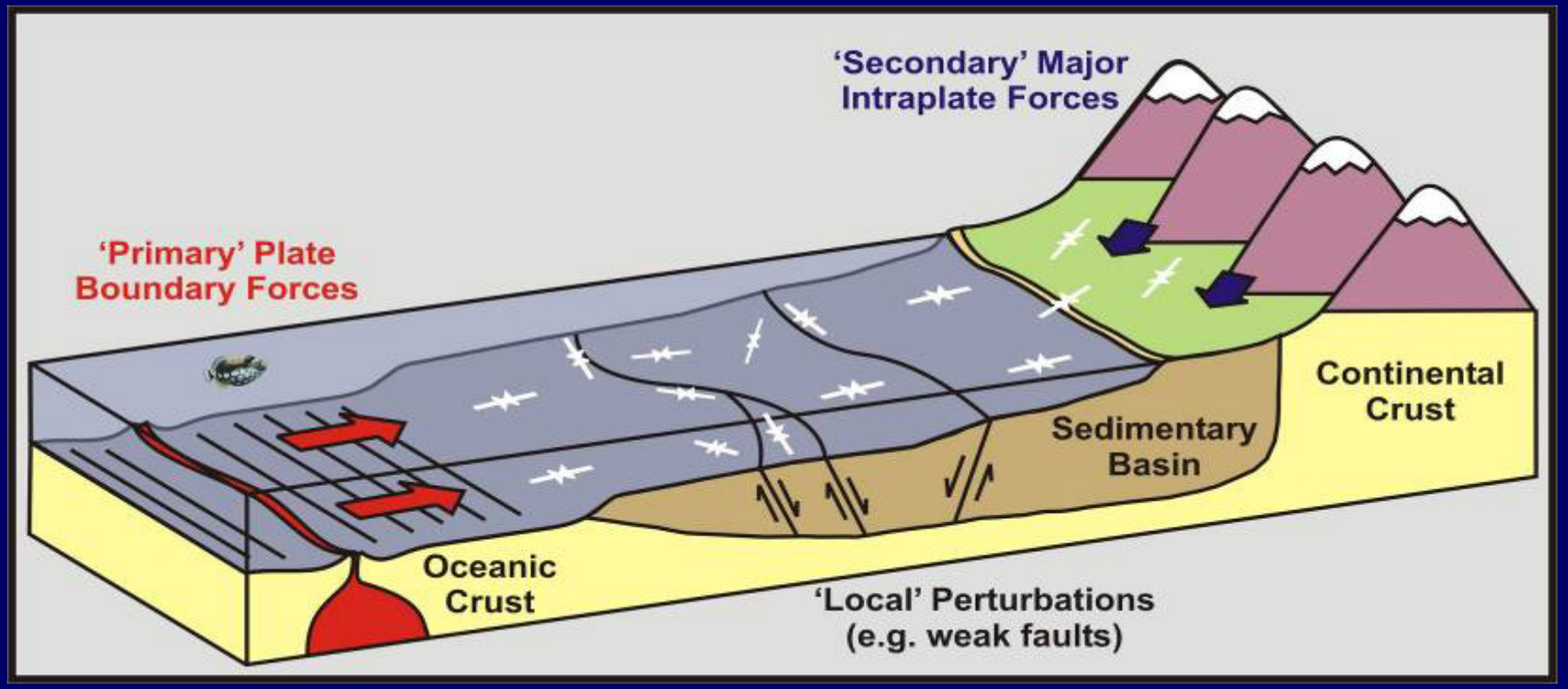
Stress field in Indochina and near the eastern Himalayan syntaxis

Present-day Stress Field of SE Asia

- INTRODUCTION
- PRESENT-DAY STRESS FIELD OF SE ASIA
- DISCUSSION: PLATE-SCALE STRESS FIELD
- **DISCUSSION: LOCAL CONTROLS ON STRESS**
- SUMMARY

Present-Day Stress Fields – Smaller Scales

Observed stress at any point results from the combination of *ALL* forces acting from the plate to local scale.



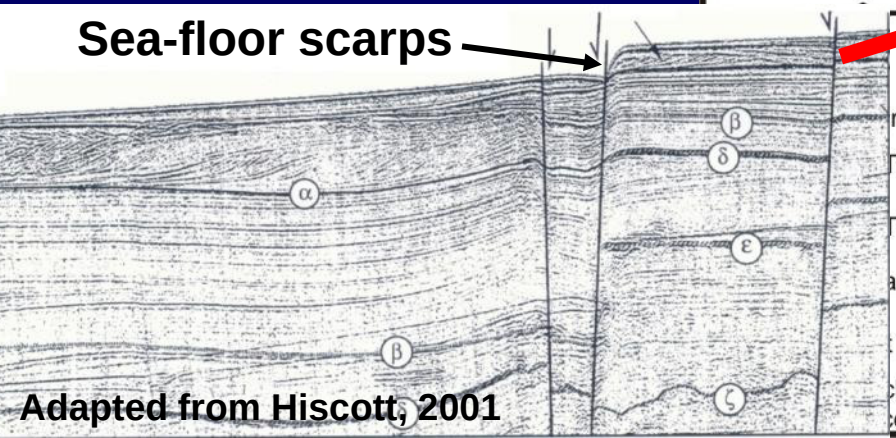
Schematic example of the impact of different sources of stress acting a different scales on the in-situ stress orientation (in white)

Tingay et al., 2006

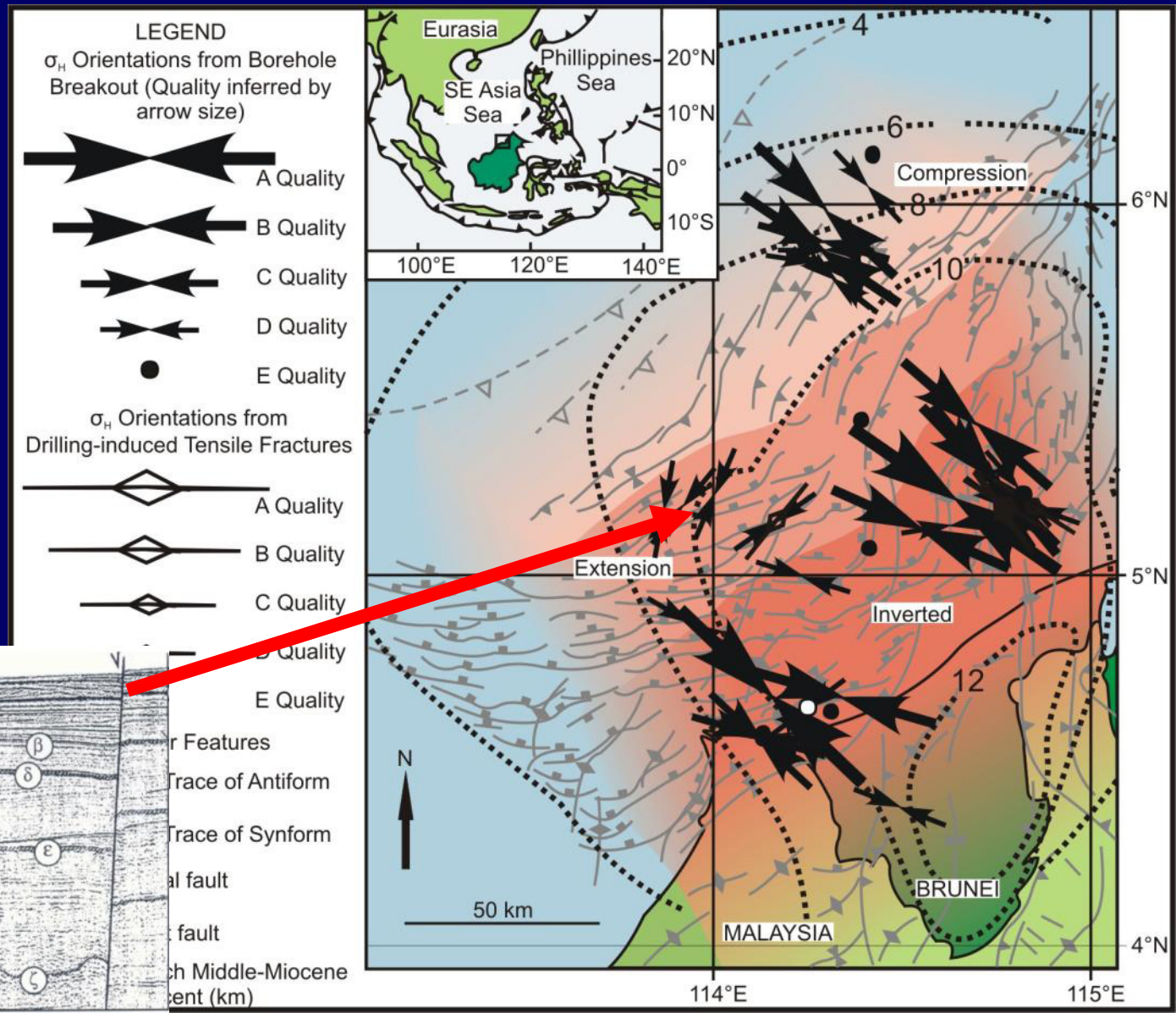
Local Influences on Stress Field

Shape of Deltaic Wedge: Baram Basin, Brunei

- Localized margin-parallel (NE-SW) S_{Hmax} at the shelf edge.
- Active margin-parallel faulting by gravitational extension of clastic wedge.



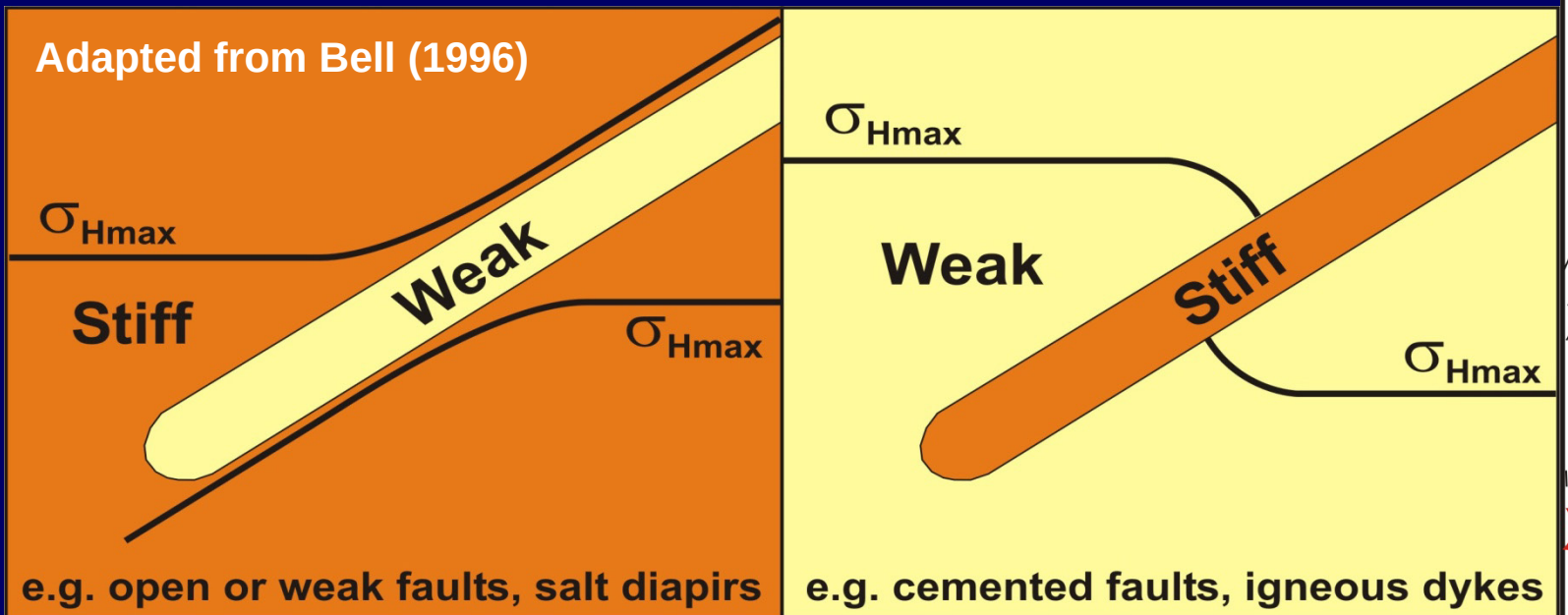
Adapted from Hiscott, 2001

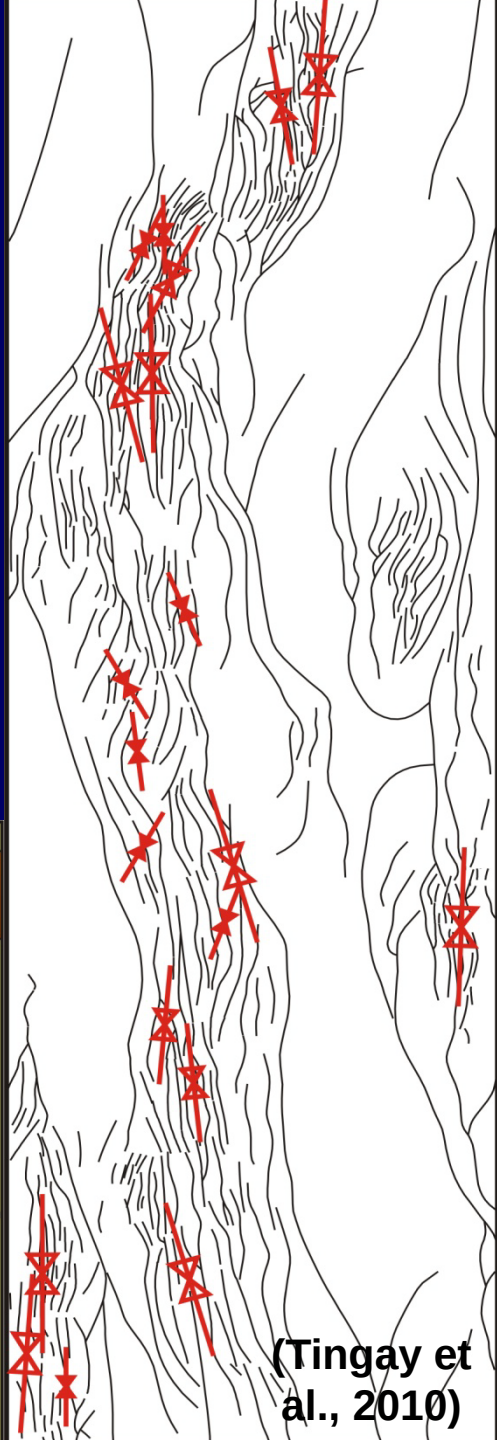


Local Influences on Stress Field

Pladang-Platong Trend Pattani Basin, Thailand

- Stress orientations appear to parallel changes in fault strike.
- Approximately N-S, but rotating to NE-SW and NW-SE in fault ‘jogs’.
- Suggests mechanically ‘weak’ faults.

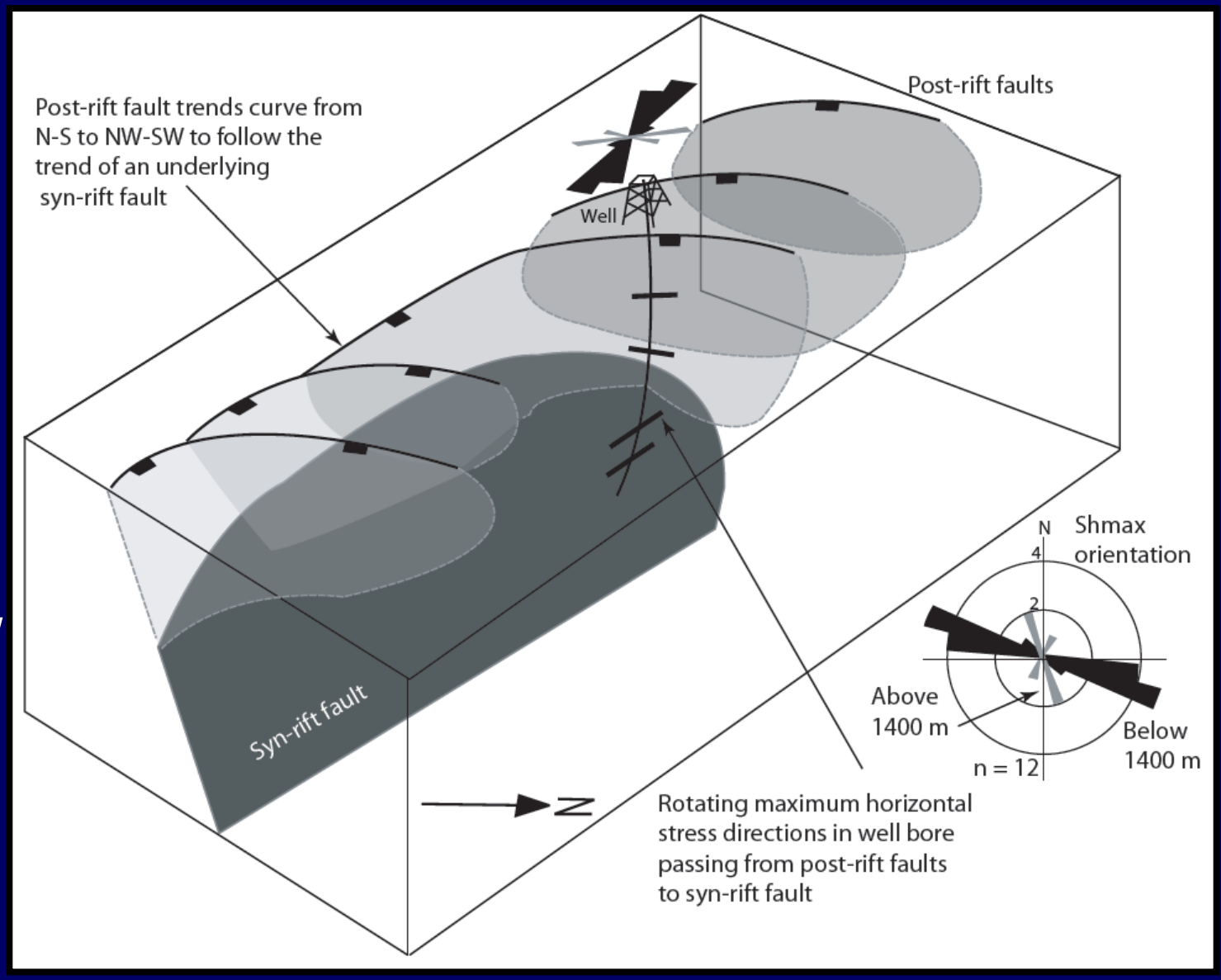




(Tingay et al., 2010)

Local Influence on Stress Field by Faults: Malay Basin

- Maximum horizontal stress rotates 60° anti-clockwise with depth.
- S_{Hmax} deflected parallel to shallow post-rift faults and deeper syn-rift faults



(Tingay et al., 2010)

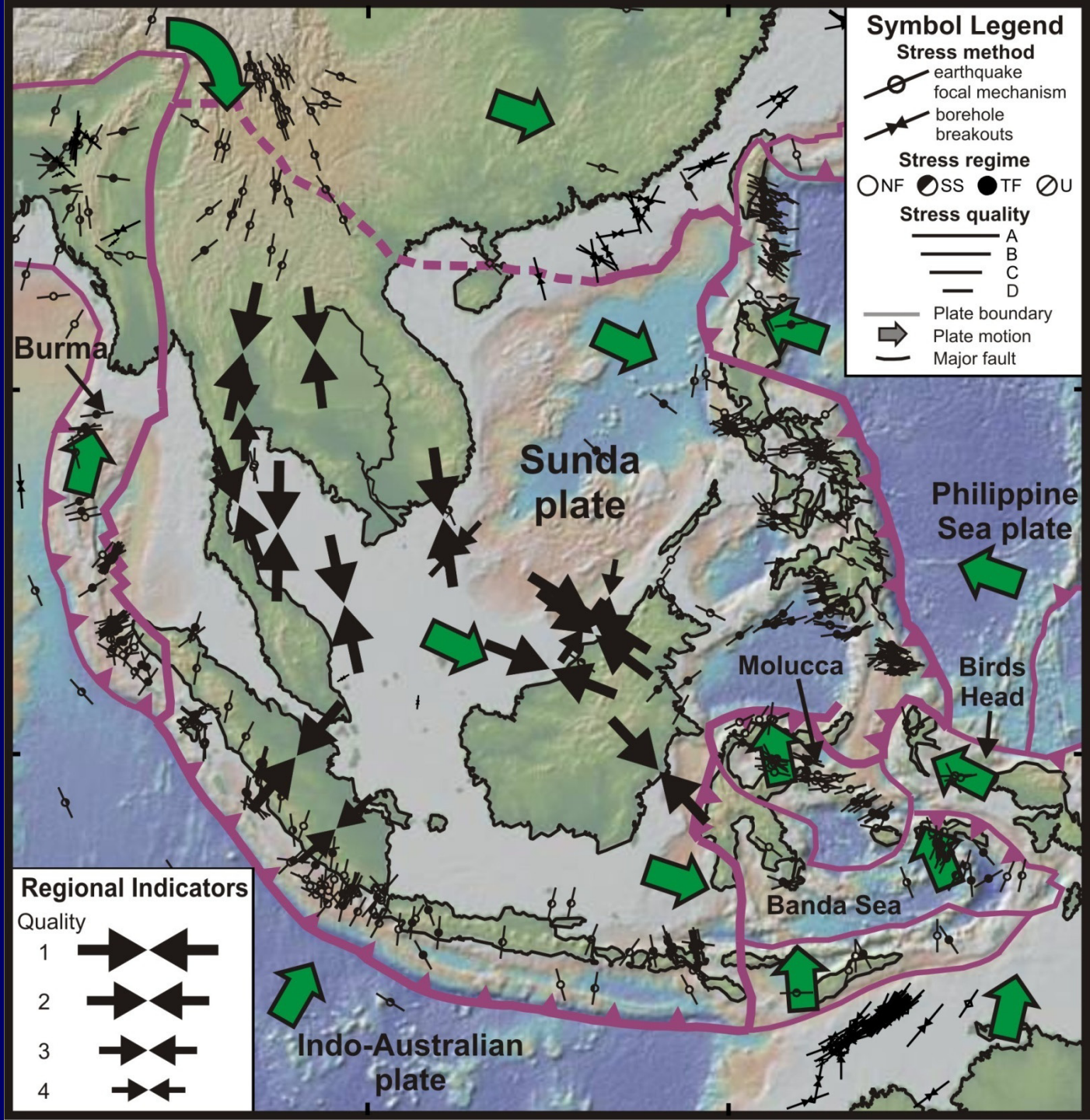
Present-day Stress Field of SE Asia

- INTRODUCTION
- PRESENT-DAY STRESS FIELD OF SE ASIA
- DISCUSSION: PLATE-SCALE STRESS FIELD
- DISCUSSION: LOCAL CONTROLS ON STRESS
- **SUMMARY**

Summary

- Stresses analyzed in 18 provinces.
- Complex stress pattern not aligned to plate motion.
- Stress appears to primarily reflect plate boundary forces.
- Local stress variations (~1 km scale) common next to faults in Thailand and Malaysia.

Average S_{Hmax} for SE Asia stress provinces



Acknowledgements

Shell Brunei, Shell Malaysia, PTTEP, Chevron, Total, Petronas, BP-MIGAS and the Brunei Petroleum Unit for providing data for this research and for permission to publish the results.

This research was funded through an Australian Research Council Discovery Project (DP0665194).