RELATIONSHIPS BETWEEN STRESS STATES AND SLAB MORPHOLOGYOF SUBDUCTING SLABS

Chantal Newallo, Adam Holt

University of Miami

ABSTRACT

Subduction represents one of the most fundamental processes on earth, with the slab pull that it provides being the driving force behind plate tectonics. The stress states within subducting slabs coupled with the types of seismicity occurring throughout are important as it gives us a better insight into how these key features deform and evolve over time. This study seeks to investigate whether there is a correlation or relationship between the slab depth and the depth at which the stresses within the bending region of the slab (outer rise) as well as within the deep slab, transition from extension to compression. Using tomography models from previous research studies, along with python scripts and the Generic Mapping Tools (GMT) we extracted data and made cross-sectional plots of these subduction zones. With the information from these models, correlational graphs were used to determine the presence of any relationships and the findings analyzed and discussed. We find that here seems to be no correlation between the outer rise stress transition depth and the slab depth as well as the slab depth and slab transition depth. However, there were interesting relationships found between slab depths and slab transition depths in subduction zones that were less than a depth of 1000km, more than 1000km and that flattened before or near the viscosity interface boundary.

INTRODUCTION

The evolution of subducted slabs depends on the balance of driving and resisting forces, how these forces change with depth and time, and the geometry imposed by the larger-scale tectonic environment (Billen, 2008). These driving forces include ridge push originating from spreading centers and negative buoyancy (downward slab pull) resulting from phase changes, while resisting forces include the bending of the lithosphere, frictional plate coupling as well as the upward forces exerted at the viscosity interface at a depth of 660km (Billen, 2008). **The forces of the downward slab pull coupled with the upward positive buoyancy forces create zones of compressional and tensional stress states within the subducting slab. The bending of the lithosphere also generates zones of compressional and tensional forces within the slab bend which results in varying degrees of shallow normal faulting and deeper thrust faulting within the plate** (Craig et al., 2014). The depth of the transition within the thickness of the slab between these compressional and tensional forces in the bend is known as the outer-rise stress transition depth. This research aims to investigate whether there is a relationship between the outer-rise stress transition depth as well as the transition depth within the slab between extensional and down-dip compressional forces and the depth of the subducting slab and, if so, the nature of this relationship.

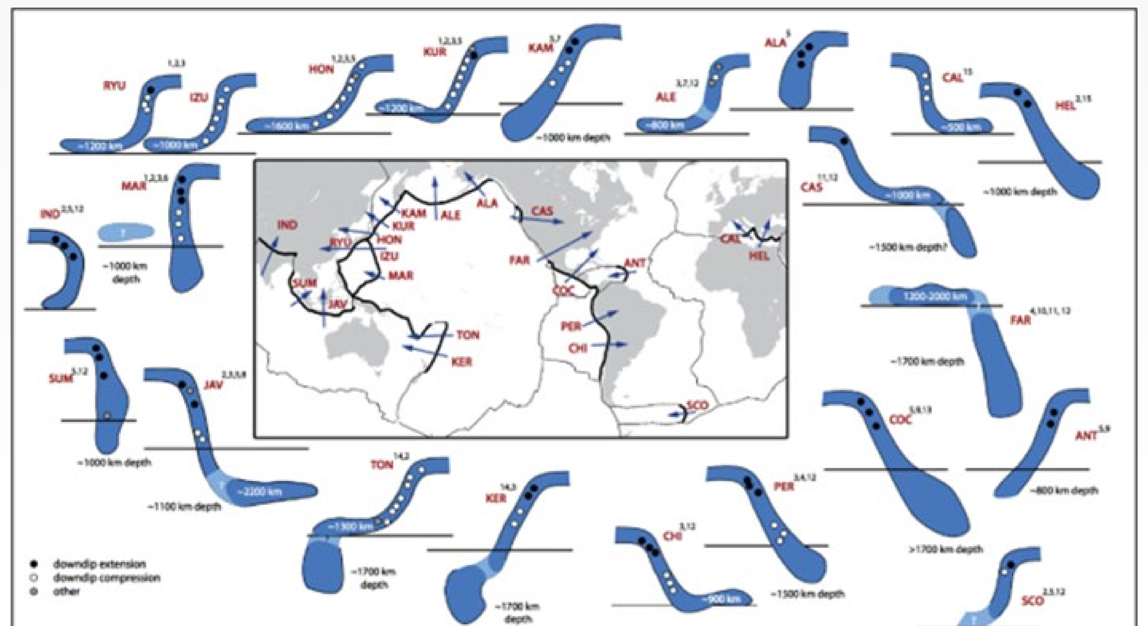

Figure 1: Slab morphologies of transition-zone slabs and their Benioff stress state with the black line representing the base of the transition zone -660km (Figure 2 from Goes et al., 2017).

METHODS

- Five scientific research papers were read and analyzed.
- Using a subduction zone map from Bailey et al. 2012 (Figure 4),the subduction zones selected to be studied include South America, Japan, Tonga, Kurile, Marianas, and Izu-Bonin.
- The depths of transition from extensional to compressional earthquakes were recorded from previous research studies (Bailey et al. 2012), as well as the outer rise transition depths (Craig et al., 2014)
- The slab depths and slab shapes were then characterized using the Fukao et al. (2013) P-wave tomography model of the mantle which produced subducted slab images along with python scripts used to extract cross sections and GMT (Generic Mapping Tool) scripts to plot cross sections of the subduction zones being analyzed.
- Using these plots and data, correlational graphs were made and analyzed for potential relationships between the depths of the slabs and the slab transitional depth within the slab along with the outer rise transitional depth (Figure 9).

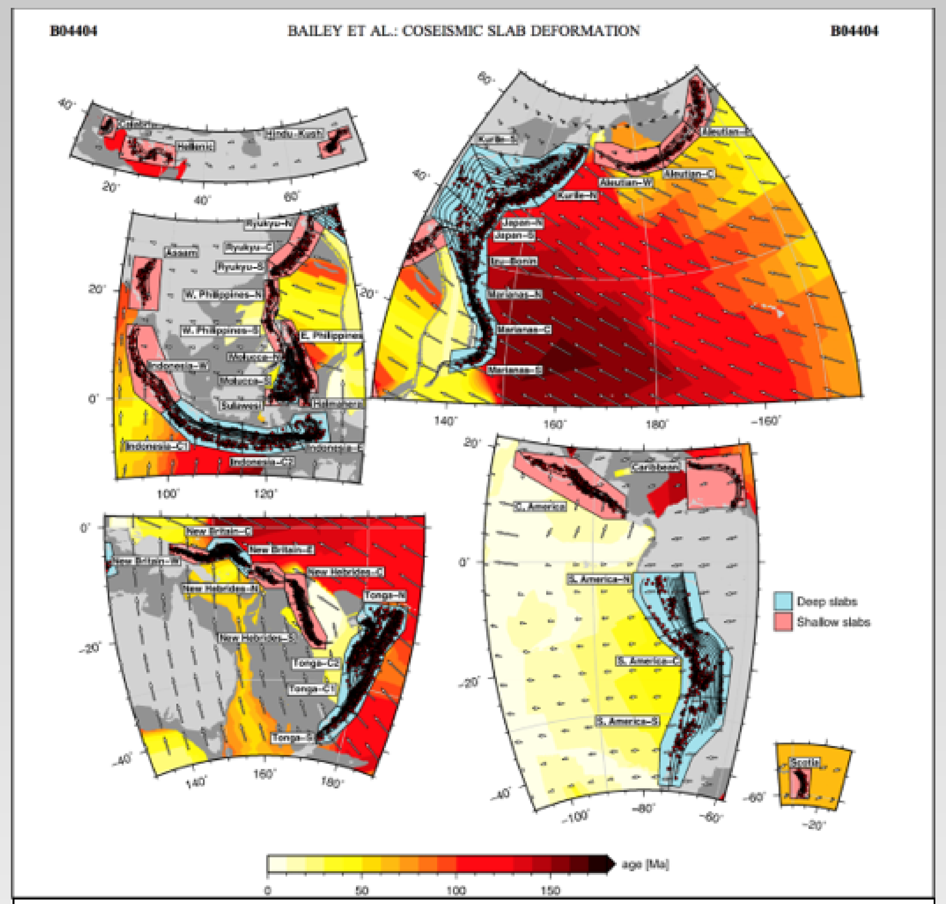

Figure 4: Geographical locations of the deep slab (blue) subduction zones of interest in this study (Bailey et al., 2012).

RESULTS

Plots and graphs made to analyze the stresses, seismicity and slab morphology features of the subduction zones being studied are summarized here, with a focus on the outer-rise stress transition depth in the slab bend, along with the slab transitional depth from extension to compression within the slab and the overall slab depth.

Western Pacific

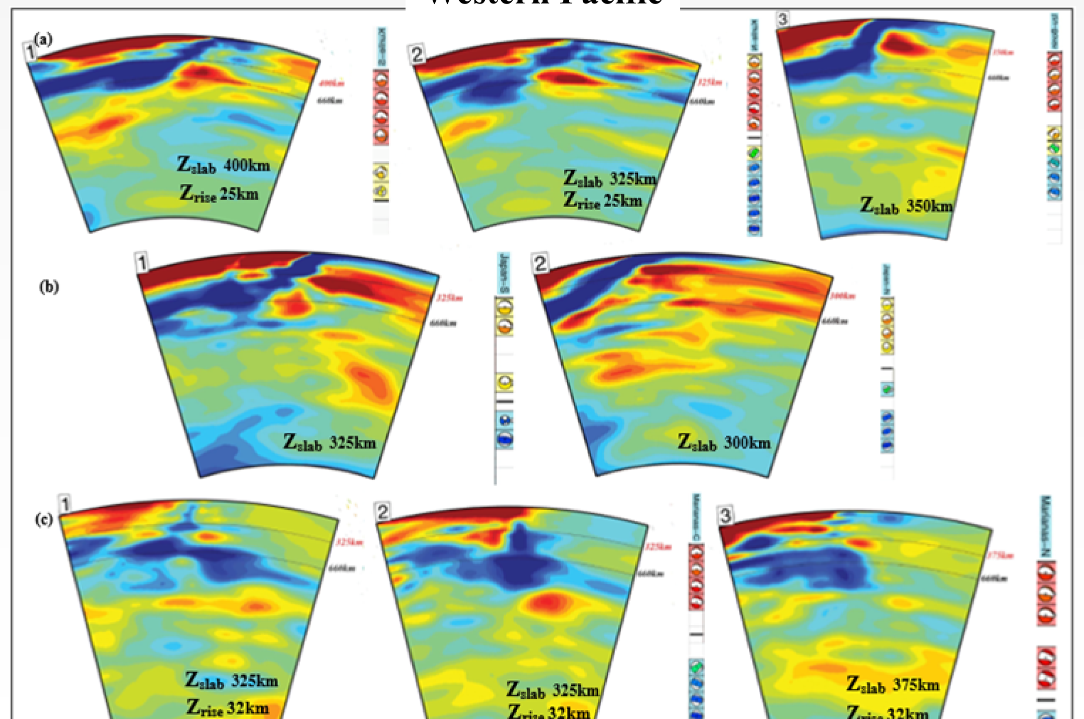

Figure 6: Slab morphology and transitional depth from extensional to compressional forces plots. (a) Shows the subduction zones Kurile South, Kurile North and Izu-Bonin. (b) Shows the subduction zones Japan South and Japan North. (c) Shows the subduction zones Marianas South, Marianas Central and Marianas South. On the earthquake panels, blue represents down-dip compressional, yellow represents oblique and red represents extensional (Bailey et al., 2012).

Tonga

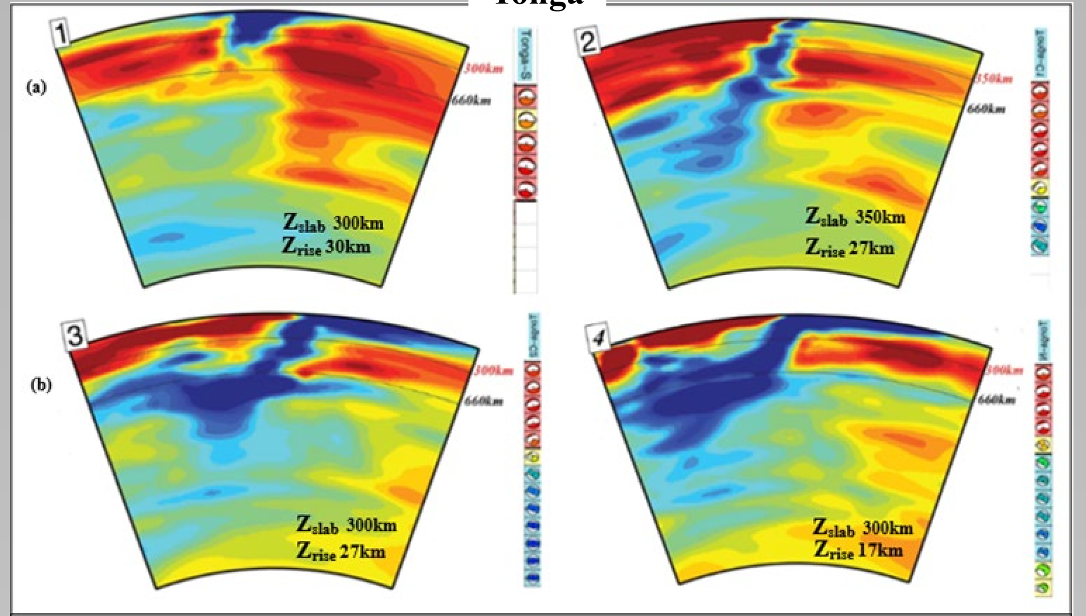

Figure 7: Slab morphology and transitional depth from extensional to compressional forces plots. (a) Shows the subduction zones Tonga South and Tonga Central 1. (b) Shows the subduction zones Tonga Central 2 and Tonga North. On the earthquake panels, blue represents down-dip compressional, yellow represents oblique and red represents extensional (Bailey et al., 2012).

South America and Indonesia

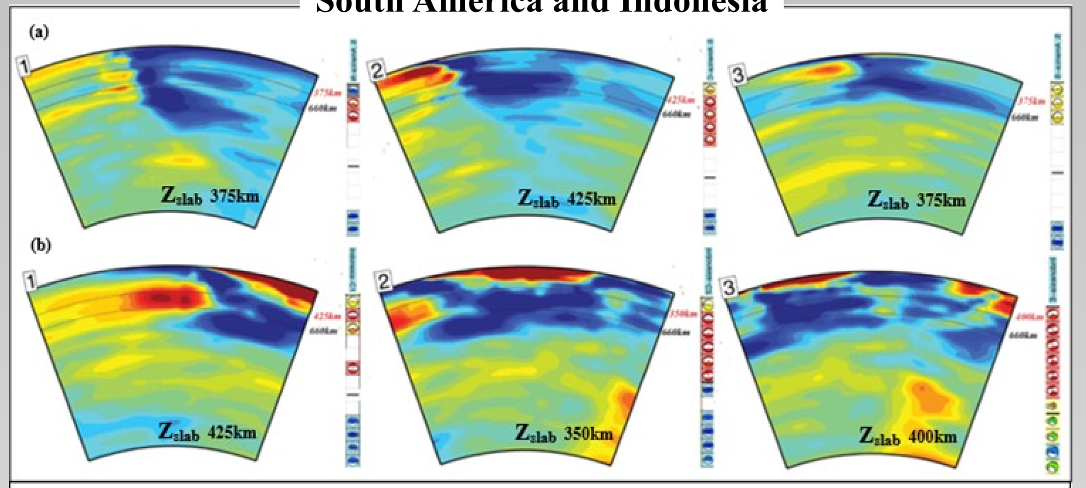

Figure 8: Slab morphology and transitional depth from extensional to compressional forces plots. (a) Shows the subduction zones South America North, South America Central and South America South. (b) Shows the subduction zones Indonesia Central 1, Indonesia Central 2 and Indonesia East. On the earthquake panels, blue represents down-dip compressional, yellow represents oblique and red represents extensional (Bailey et al., 2012).

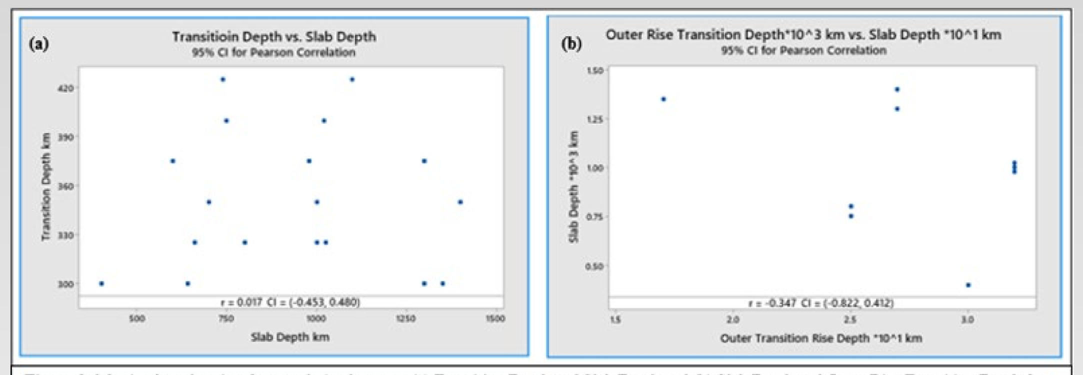

Figure 9: Matrix plots showing the correlation between (a) Transition Depth and Slab Depth and (b) Slab Depth and Outer Rise Transition Depth for subduction zones in South America, Indonesia, Izu-Bonin, Japan, (b) Marianas, Tonga and Kurile.

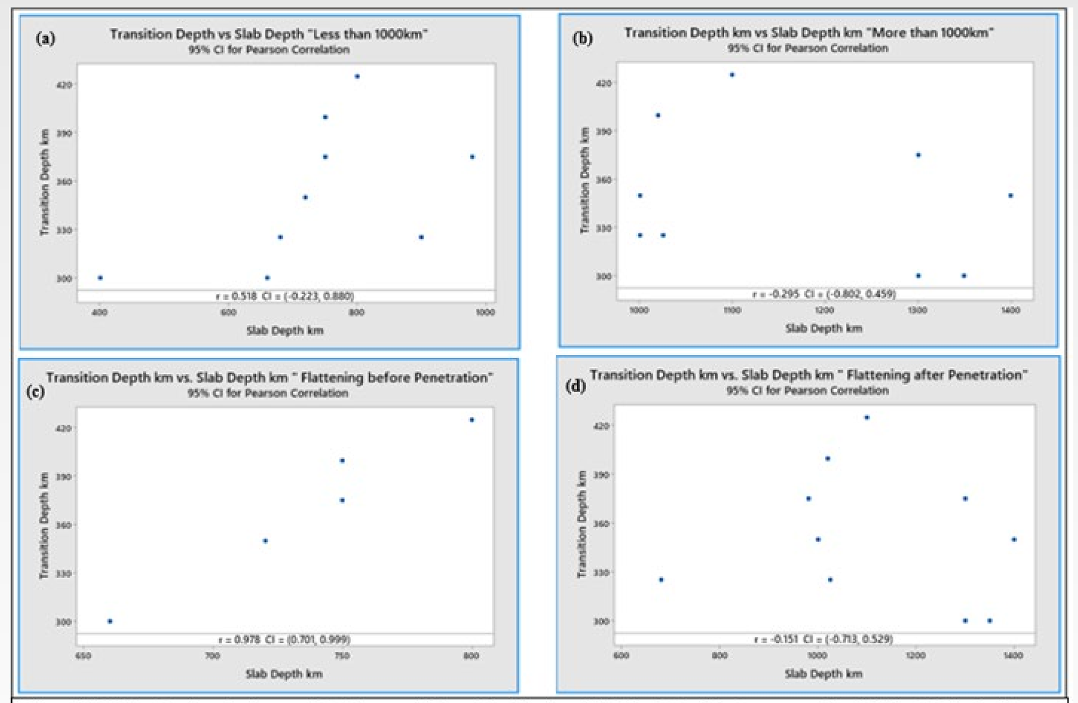

Figure 10: Matrix plots showing the correlation between (a) Transitional Depth and Slab Depth in subduction zones with < 1000km slab depth. (b) Transitional Depth and Slab Depth in subduction zones with > 1000km slab depth. (c) Transitional Depth and Slab Depth in subduction zones that flatten before penetrating 660km. (d) Transitional Depth and Slab Depth in subduction zones that flatten after penetrating 660km.

DISCUSSION

- There **is no direct relationship between the depth of the subducting slab and the transitional depth from tensional forces to compressional forces in the slab** when considering the subduction zones in South America, Indonesia, Tonga, Kurile, Izu-Bonin and Japan all together (Figure 9a).
- Trends between the depth of the slab and the transitional depth were observed when these subduction zones are put into groupings such as: slab shape, slab depths of less than and more than 1000km, and flattening vs penetrating slab morphologies.
- Subduction zones that flatten just above or very near to the 660km boundary such as the subduction zones in Japan and southern Kurile (Figure 6a, b) all show a **trend of increased slab depth with increased slab transition depth.**
- A depth of 1000km seems to be significant in the transitional depth of extensional to compressional forces within the slab, with **slabs reaching depths of less than 1000km having the opposite relationship to those that exceed 1000km up to 1400km.**
- With the exception of northern Kurile and northern Marianas with depths greater than approximately 900km, the subduction zones that do not exceed 1000km in depth show a pattern **of increased slab transitional depth with the depth of the subducting slab.**
- The relationship between the transitional force and the slab depth in the subduction zones in excess of 1000km depth, shows the opposite relationship **with a decrease in the transitional depth as the slab depth increases (Figuer 9).**
- A notable observation was the lack of correlation between the four main locations. Indonesia was the only region to show a direct relationship between the slab depth and the depth of transition between extensional and compressional forces.
- The outer rise transitional depths within the bending regions of the slabs being studied seem to show little or no relationship with the overall respective slab depth (Figure 9b).

CONCLUSION

- Though this study did not determine a correlation between slab depth and the depth of transition from extensional to compressional stresses in both the slab and within the slab bend for the subduction zones in this study, a few key discoveries were made when breaking up these subduction zones into smaller categories.
- The most significant finding is the relationship between the slab depth and transitional depth in slabs that do not exceed 1000km in slab depth. Within these subduction zones, we found a strong positive correlation between subduction zones that were within the range of slab depth between 600km and 800km, with 3 outliers that reduced the correlation coefficient to 0.518 (Figure 10a) .
- With the viscosity interface depth of 660km being called into question based on recent research studies, this pattern that changes at the depth of 1000km is interesting as it could be linked to the proposal of a new viscosity interface structure.
- Overall, the findings of this study have been both surprising and intriguing while informative about deep slab subduction zones and their interaction with the surrounding forces within the mantle as well as internal stresses.

RFERENCES

- Craig, T. J., Copley, A., & Jackson, J. (2014). A reassessment of outer-rise seismicity and its implications for the mechanics of oceanic lithosphere. *Geophysical Journal International*, *197*(1), 63–89. https://doi.org/10.1093/gji/ggu013
- Billen, M. I. (2008). Modeling the Dynamics of Subducting Slabs. *Annual Review of Earth and Planetary Sciences*, *36*(1), 325–356. https://doi.org/10.1146/annurev.earth.36.031207.124129
- Bailey, I. W., Alpert, L. A., Becker, T. W., & Miller, M. S. (2012). Co-seismic deformation of deep slabs based on summed CMT data. *Journal of Geophysical Research: Solid Earth*, *117*(4), 1–19. https://doi.org/10.1029/2011JB008943
- Fukao, Y. and Obayashi, M. (2013). Subducted slabs stagnant above, penetrating through, and trapped below the 660 km discontinuity. Journal of Geophysical Research, 118