UNIVERSITY OF CAMBRIDGE

Earthquake distributions and their relationship with structural, chemical and thermobaric heterogeneities in subducting slabs

R. Myhill* D. McKenzie K. Priestley

* Corresponding author: rm438@cam.ac.uk

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1. SUMMARY

The subduction of oceanic plates is usually accompanied by zones of intense but heterogeneous seismicity in the descending slab. The non-uniform distribution of earthquakes within these Wadati-Benioff zones may be controlled by several factors. Ambient stress, strain rate, temperature and pressure, as well as structural and chemical heterogeneities may all play roles in determining the locations of earthquakes within subducting slabs.

2. MODELLING SLAB SURFACES

Focal mechanism orientations are an important indicator of external influences on seismic activity in subducting slabs. Analysing these orientations requires accurate modelling of the shape of the slab. Rotating the seismicity such that the best fitting plane is horizontal allows deviations on a scale of 100 km to be modelled using a continuous curvature surface algorithm [1].

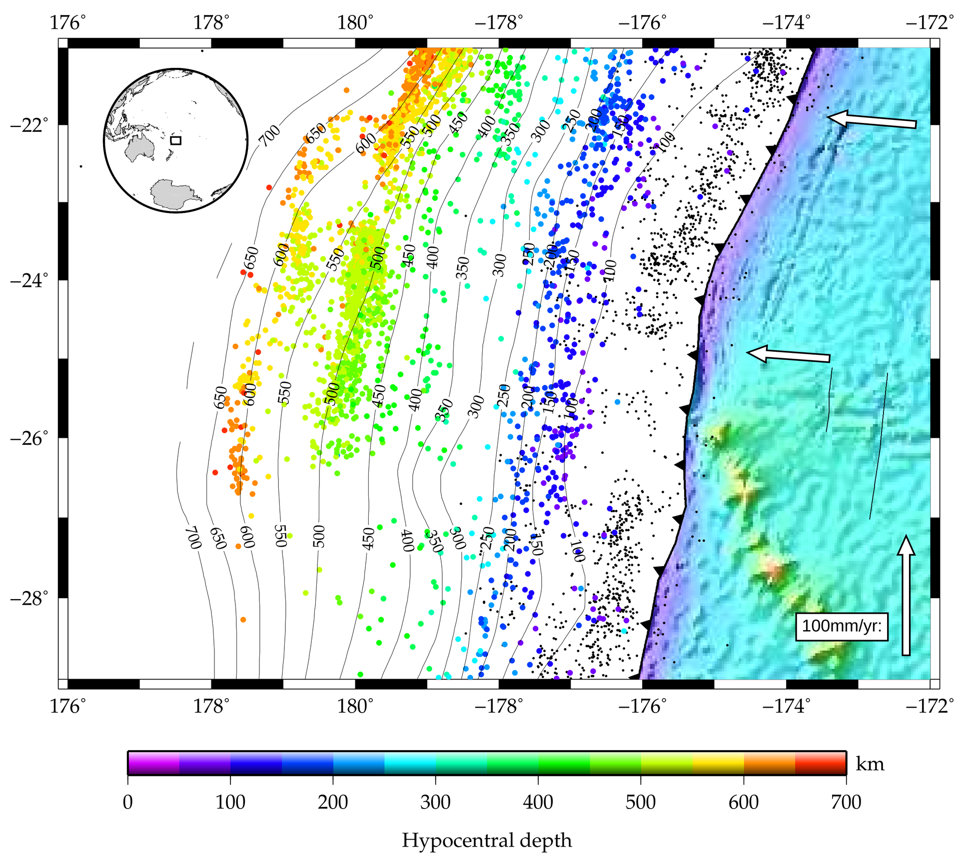

Figure 1: Earthquake hypocenters associated with subduction of the Pacific Plate beneath Kermadec, from the catalogue of Engdahl, van der Hilst and Buland [2]. Contours represent the surface fit to the coloured hypocenters. Arrows indicate Pacific Plate motion with respect to Australia [3]. Bathymetry [4] is shown east of the trench.

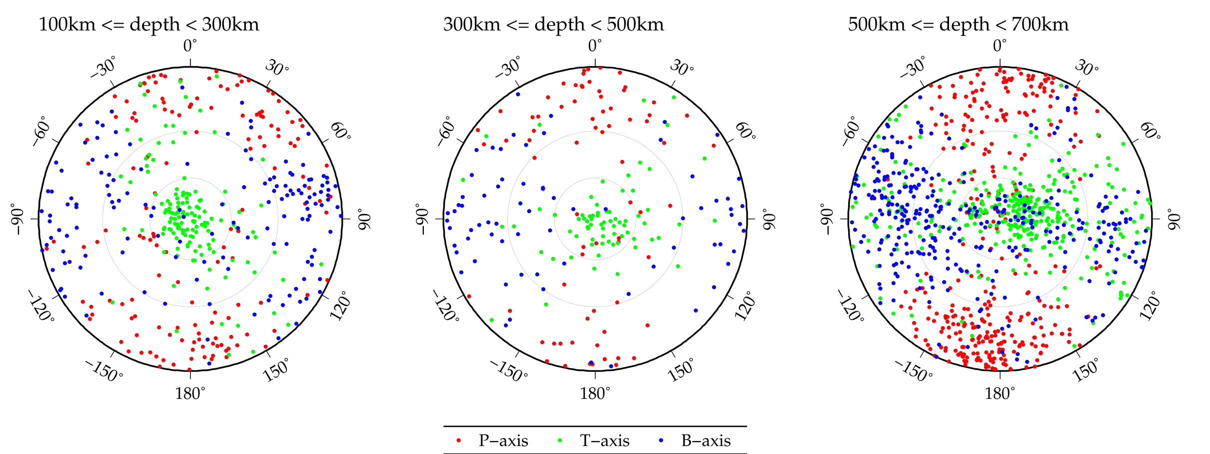

Figure 2: Lower hemisphere projection of P (compressional), T (tensional) and B (neutral) axes rotated into the local orientation of the Kermadec slab. Orientations are derived from centroid moment tensor (CMT) solutions [5]. 0° represents the down dip direction, and the center is normal to the slab. Between 100 and 500 km depth, the focal mechanism orientations are in good agreement with the stress guide hypothesis [6]. Some exchange of P and T axes may result from bending of the slab. At greater depths, greater variation in orientation attests to complex slab shape and deformation.

3. NODAL PLANE ORIENTATIONS AND SLAB STRESSES

We plot the intersection of the slab surface with the nodal planes for each earthquake to confirm observations of shear within the Kermadec slab [7].

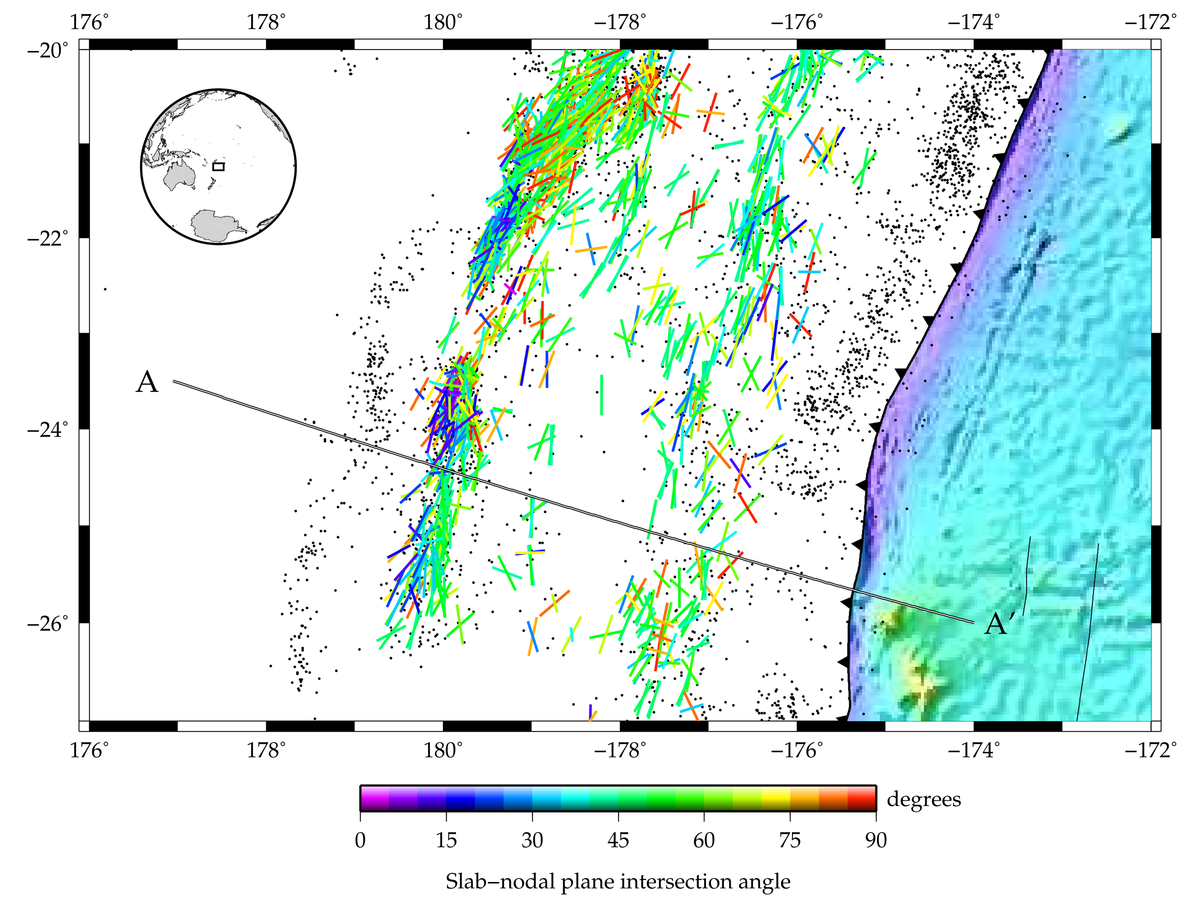

Figure 3: Slab-nodal plane intersections within the Kermadec slab, modelled after removing events within an outboard slab fragment. Events with low angle slab-nodal plane intersections represent downward shear of the modelled section of slab relative to the seismicity further to the west.

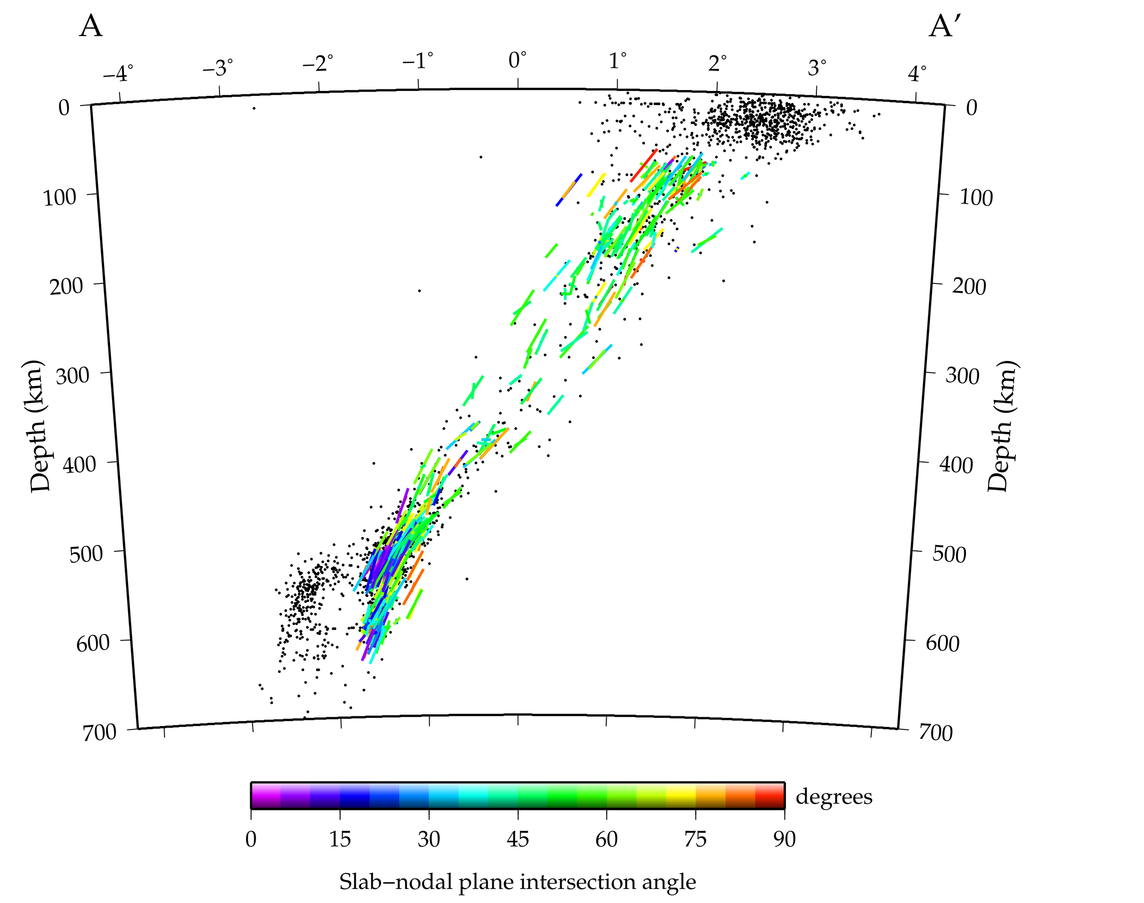

Figure 4: Cross section along the profile A-A′ from Figure 3, with a swath half-width of 275 km. Shear-related events dominate seismic activity below 450 km depth. Similar variations in focal mechanism are observed at the northernmost end of the Tonga subduction zone.

4. STRUCTURE WITHIN SUBDUCTING SLABS

Narrow seismically active shear zones have been identified at all depths within Wadati-Benioff zones [8]. These streaks of seismic activity have been linked to the subduction of transform faults at intermediate depths in the Sumatran [9] and Japan [10] slabs, but the association has not been observed at greater depths. If the transform faults formed far from a relatively stable pole of rotation between the two plates meeting at the ridge, and shearing and distortion of the subducted plate is minor, subducted faults approximate geodesics [11] (which are the shortest lines between two points on the surface of the slab). The geodesic continuation of seismic streaks within the Bonin slab align with transform faults at the surface.

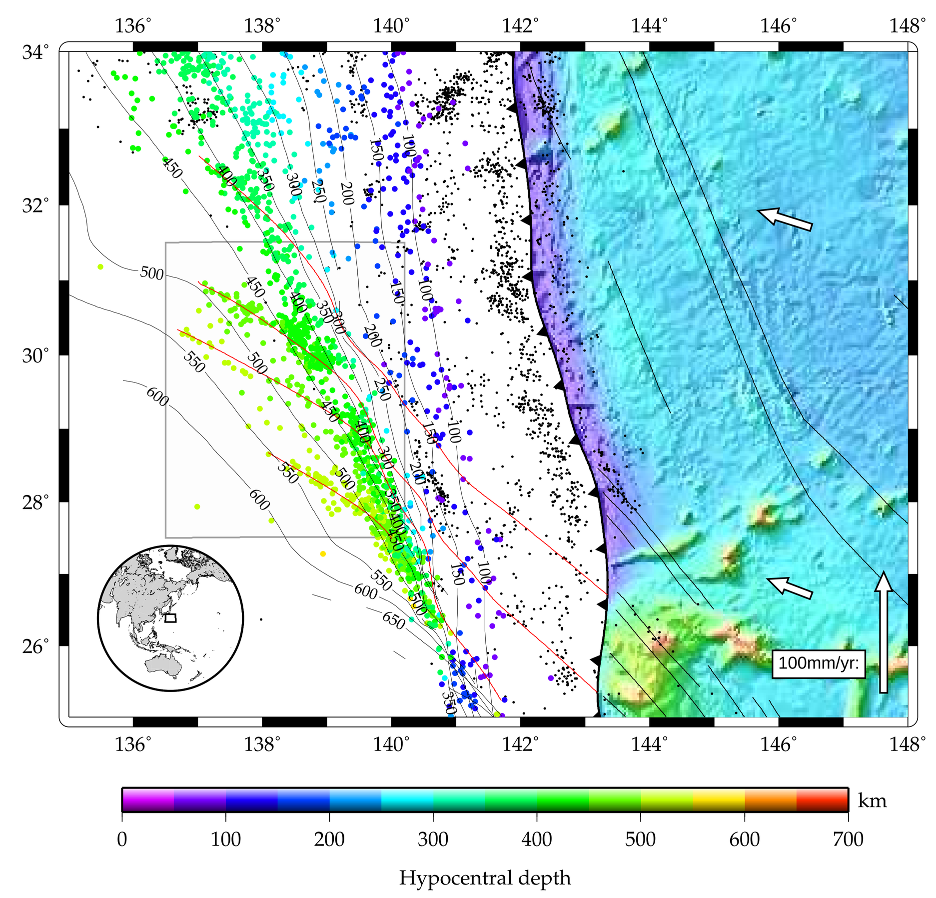

Figure 5: Earthquake locations beneath the Bonin Islands, where the Pacific is being subducted beneath the Philippines Plate. Modelled contours and colours are as shown in Figure 1. Geodesics (red) are aligned with streaks of seismicity in the deep slab. Fracture zones (black) at the surface are visible in the local bathymetry [4].

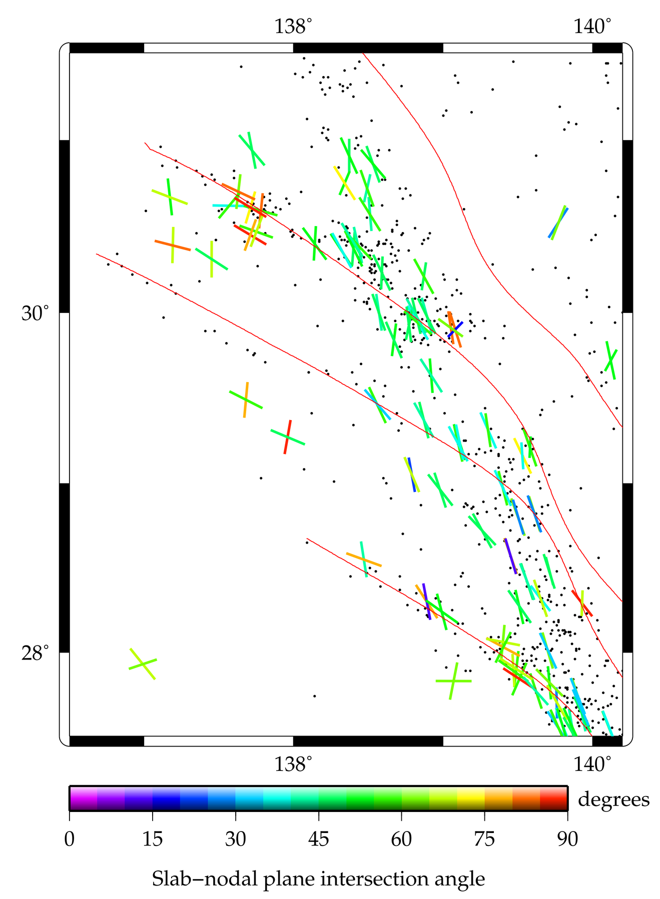

Figure 6: Slab-nodal plane intersections and geodesics (red) within the subregion marked on Figure 5, superimposed on background seismicity. Nodal planes parallel to the seismic streaks commonly dip steeply into the slab, as might be expected of earthquakes rupturing along subducted transform faults.

5. SLAB THERMAL ESTIMATES

Thermal modelling can be used to estimate local temperatures within the slab. 1D thermal modelling incorporating temperature-dependent conductivity [12] is combined with the EarthByte database of global oceanic plate ages and relative plate motions [3] to calculate the thermal evolution of the uppermost mantle. Deep-focus earthquakes are thought to occur in the mantle part of the slab, so obtained temperatures are maximum estimates of the conditions under which faulting occurs.

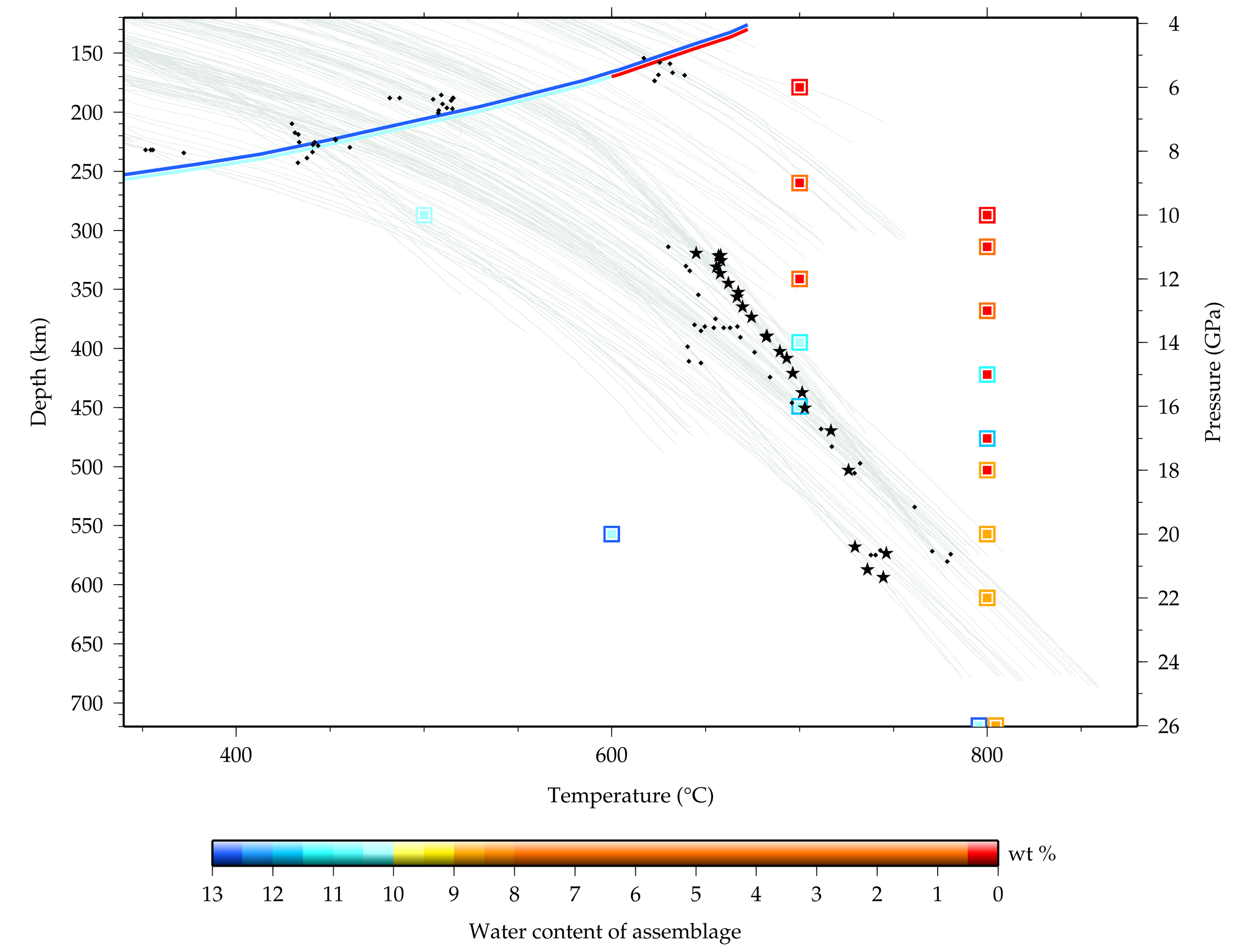

Figure 7: *P-T* paths of the uppermost mantle in Earth's major subduction zones (pale lines). Depths where seismic activity increases are shown in black circles (minor) and stars (major). Squares represent data points from high pressure experiments on serpentine [13]. The outer colour represents mass balance estimates of mineral-bound water content (assuming fluid released is pure H_2O). The inner colour signifies the maximum water content given reaction sequences along subduction *P-T* paths. The coloured lines represent initial and final water contents due to the presence and decomposition of antigorite [13].

Intermediate depth increases in seismicity correspond to where antigorite dehydration is expected. Figure 7 shows that deep focus earthquakes occur in material which experienced this reaction under 600°C; conditions under which dehydration is incomplete. Any hydrous uppermost mantle is expected to undergo another partial dehydration in the lower transition zone (from phase D and brucite to superhydrous phase B and fluid [13]).

6. DISCUSSION AND CONCLUSIONS

- On a large scale, the distribution of deep seismic activity is controlled by deformation due to interaction with the 670 km discontinuity. Focal mechanisms of earthquakes within the Kermadec Wadati-Benioff zone reveal a major shear zone within the slab.
- The correlation between deep seismic streaks and subducted transform faults implies that composition and/or grain size variation may be factors contributing to spatial variation in deep earthquake distribution.
- *P-T* conditions strongly influence the distribution of seismicity at intermediate depth. The possibility that hydrated minerals play further roles in the generation of deep focus seismicity cannot be ruled out without further experimental work between 600-800°C and 10-25 GPa.

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Bullard Laboratories, Department of Earth Sciences, University of Cambridge, United Kingdom