Revolution in earthquake studies and understanding of Earth's crustal structure

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Focal mechanism solutions for earthquakes generally rely on the interpretation of geology to reduce ambiguity in the definition of the resultant hypocentre fault plane and type. It has been known for some time that earthquakes are most likely to occur at plate boundaries where convergence (e.g. the Pacific Rim) or divergence (the mid- Atlantic ridge) is active. Intraplate rifting (for example, the East African Rift system) is also associated with significant seismicity.

New research by Subterrane has innovated links between seismic tomographic mapping of Earth's internal structure, and focal mechanisms computed from arrival time measurements at seismometers. In 2017, a large intraplate fault was discovered on the East African margin mapped from satellite gravity and magnetics (Long, 2017). Subsequently Subterrane has mapped further evidence of relic and active intraplate structure across the African plate, and globally over other tectonic plates. These large scale, regional crustal faults envelope many common geological processes such as rifting and volcanism.

By making correlations between seismic tomography models, earthquake seismicity, geological outcrop, and recent gravity and magnetic data, it is possible to identify the regional fault planes that control the ductile creep of the crust, the far field stresses imposed and the devastating release of strain energy (elastic rebound theory).

The Chi Chi Earthquake, Taiwan

Taiwan occupies a region subject to persistent strain at the junction of two prominent and active subduction zones to the east and south of the island. In the year prior to the 1999 Chi Chi earthquake, onshore Taiwan was largely aseismic. Following the earthquake, Taiwan was subject to considerable seismic activity leading to further devastating earthquakes (e.g. Chengkung 2003). Initial research by Subterrane reveals a broad crustal fault system that controls the distribution and occurrence of the seismic activity, culminating in brittle failure along their fault planes and released as large (> 4.9) magnitude earthquakes.

Early work by *Kao and Chen (2000)* revealed a thrust front has been reactivated on the Shuangtung fault system. Subterrane has determined the Shuangtung thrust is part of a regional sinistral sense fault system. This new mapping puts further definition on the western aseismic zone described by *Wang et al (2010)*. **Figure 1** shows regional seismicity (source: *IRIS data sources*) in Taiwan for the year 1999, together with the annotated fault structures (red and black) defined by *Kao and Chen (2000)*, new fault structure (white) mapped by Subterrane (2019), on a residual gravity base derived from free air gravity (source: *Sandwell et al, 2014 [version 27-1]*).

The offsets in the Pakuashan, Chelungpa and Shuangtung faults along the strike of their fault traces are clearly controlled by sinistral movement along a set of north striking faults on an extensional releasing bend that extends offshore of the western coastal plains of Taiwan. The fault system is generally sinistral in sense, apart from the Shuangtung thrust which is controlled by a convergent dextral duplex which envelopes the northern Shuangtung (thrust) fault section where it terminates in the north against the Slate belt. The latter is defined by a prominent gravity peak (red). The Shuangtung thrust zone exhibits a mid-range residual gravity peak (yellow) in contrast to the residual gravity troughs (blue) that characterise the dominant extensional compartments that comprise the releasing bend to the south west.

The Shuangtung fault terminates in the south against the major north east striking sinistral fault along which the Chi Chi earthquake emanated in 1999. This major regional fault defines the boundary between the Slate belt, and the Central Range and Coastal Plains in the east. The restraining bend south of the Chi Chi epicentre is controlled by deeper crustal deformation that partially explains the north-westward Philippine plate motion. The restraining bend occupies a pole of rotation equidistant between the Manilla Trench to the south and the Ryukyu Trench to the north east.

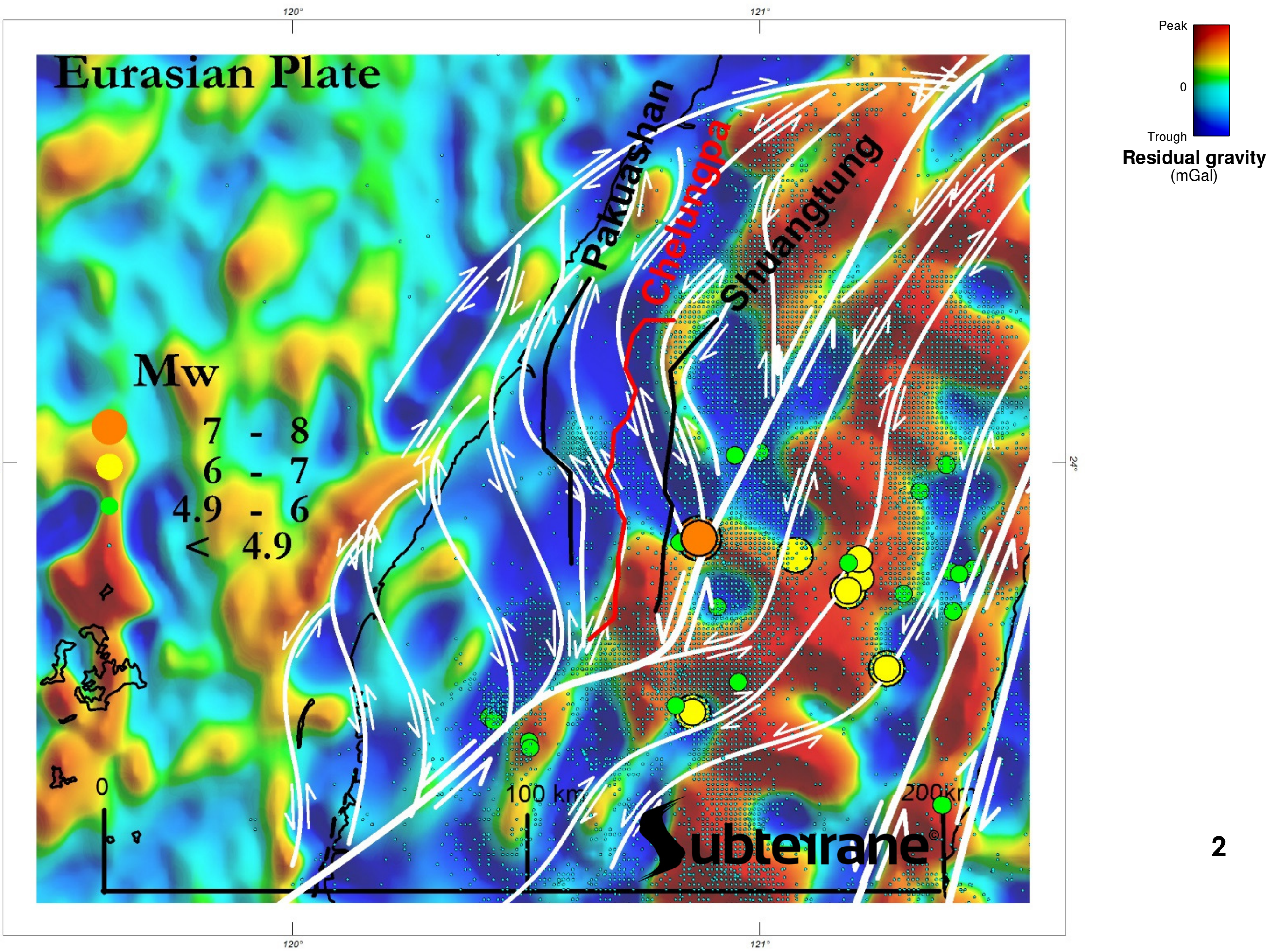

Figure 1: Seismicity for the year 1999 (*source: IRIS data sources*), residual gravity base derived from Sandwell et al (2014), red and black faults annotated from *Kao and Chen (2000)*, white faults (Subterrane, 2019)

Chi Chi focal mechanism solutions

A number of solutions have been calculated and later reviewed by *Wang et al (2010)* as part of their study on the possibility of a co-seismic source rupture for the Chi Chi event. These are presented in **figure 2**. The white segments indicate compression, while the grey sections indicate extension. The plane annotated "U" indicates the fault plane or primary nodal plane. Although there is good agreement for the solutions to the dip of the fault plane, there is some variation in the strike of the fault plane with solutions provided for north north west and north north east strike directions. The Chi Chi normal fault appears to have ruptured on the branch of a north north west trending sinistral fault, and a major north north east fault described earlier. The former comprises the western front of the Shuangtung fault, and provides agreement to the USGS solution, whereas the north north east striking major crustal fault agrees with the other two solutions. The slip angle on the latter two solutions is significantly higher than the USGS solution. The USGS solution may indicate oblique extensional slip peripheral to the older Shuangtung thrust front, while the other solutions may correlate with synthetic fault extension at an acute angle to the major sinistral fault striking north north east.

Botswana intraplate earthquake, 2017

The Botswana 2017 earthquake requires an intraplate setting given its location on the African plate, on the margin of stable cratonic crust. Focal mechanism solutions indicates the strain release occurred as a normal fault with some oblique slip. The main event, together with the later aftershocks, including the final event on 12th August 2017 have been determined (through new work by Subterrane) to indicate synthetic fault extension on the margins of a regional intraplate fault system that has subsequently, and recently been reactivated. As suggested by *Moorkamp et al (2019)*, there are strong indications this is linked to the extension occurring within the East African Rift System. This intraplate fault system was initiated as earliest as the Permian following the final accretion of Gondwana in Neo-Proterozoic times. The compelling evidence is provided by making correlation between dated faults (*MacGregor, 2017*), geological exposure, regional MT studies provided by SAMTEX (*Moorkamp et al, 2019*), airborne and satellite magnetics, satellite gravity, seismic tomography and locked seismicity.

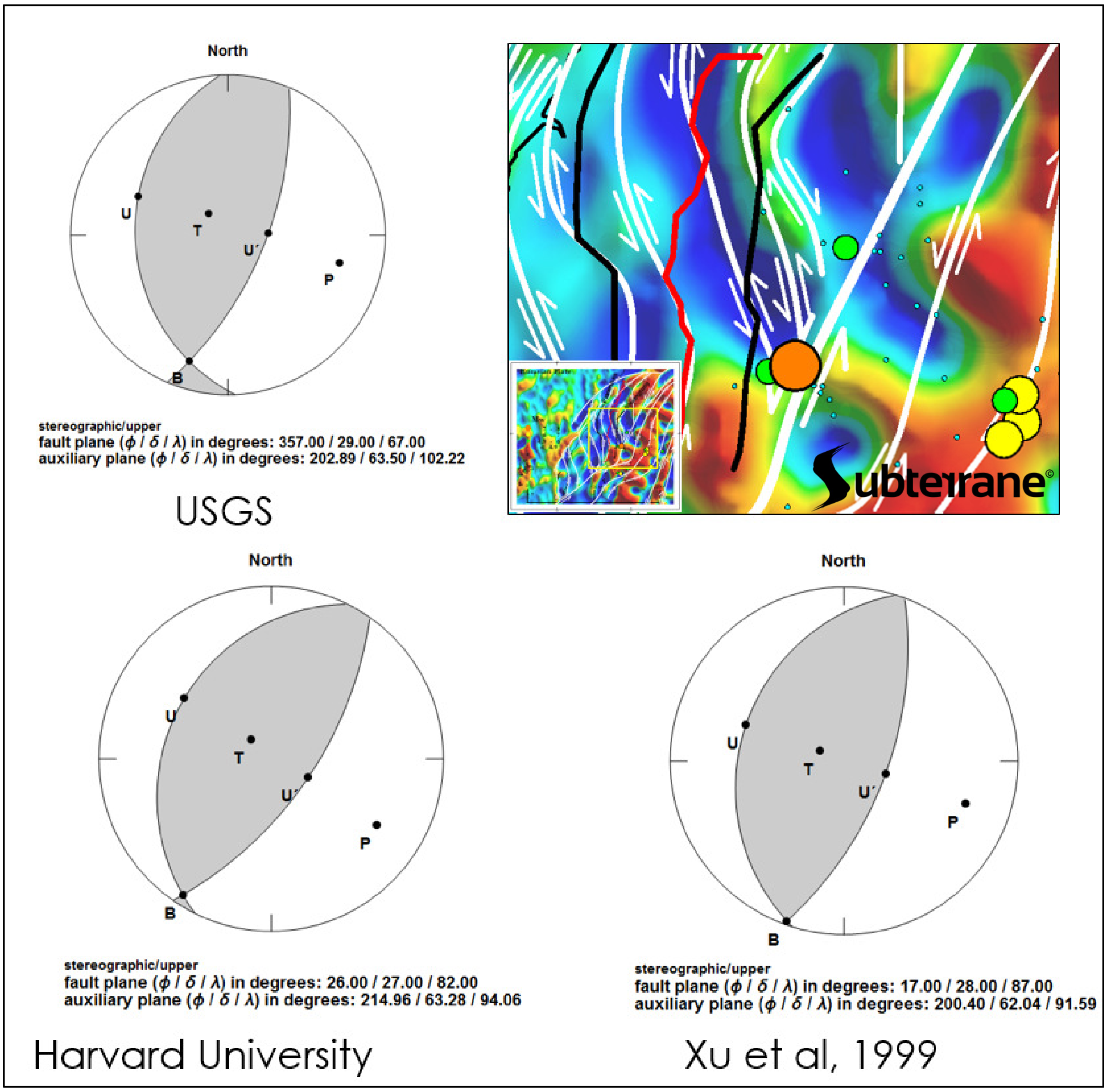

Figure 2: The three focal mechanism solutions as tabulated by Wang et al (2010), presented as plots utilizing *Scherbaum et al's (2009)* demonstration. Top right, with inset map marking the main map location in yellow, the Chi earthquake epicentre (orange, legend as per figure 1) at the junction of a north north west striking fault, and the major regional north north east striking sinistral fault. Residual gravity base as per figure 1

References

Earthquake focal mechanism plots citation:

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