Effects of inherited continental margin structure in the south-central Taiwan fold and thrust belt

Efectos de la estructura heredada del margen continental en el cinturón de pliegues y cabalgamiento del centro-sur de Taiwán

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Abstract: Taiwan provides an unparalleled opportunity to investigate the influence of inherited structures of the continental margin in the development of a fold and thrust belt (FTB). There, the Luzon Arc is obliquely colliding with the Eurasian continental margin forming the Taiwan Orogen. For this study we combine surface geological mapping and balanced cross sections with Vp tomography modelling and earthquake hypocenters. The margin's and FTB's basement is defined as pre-Eocene rocks. We use a Vp of 5.2 km/s as a proxy for the interface between basement and sedimentary cover. The south-central FTB includes significant along-strike changes in structure and stratigraphy that may be correlated with active structures in the basement. N to S changes in seismic velocities are interpreted as basement highs and lows and these correlate with areas where changes in the structural grain of the FTB take place. Several seismicity clusters align along the borders of these basement blocks. We interpret these features to indicate that basement is involved in the deformation and that the seismicity is imaging the reactivation of basement faults that influence the structure of the FTB.

Key words: Taiwan fold and thrust belt, earthquakes, tomography, basement reactivation, structural inheritance.

Resumen: *Taiwan nos ofrece una oportunidad inestimable para investigar la influencia de las estructuras heredadas del margen continental en el desarrollo de un cinturón de pliegues y cabalgamientos (CPC). En esta zona, el arco de Luzón colisiona oblicuamente con el margen continental euroasiático formando el Orógeno de Taiwan. Para este estudio combinamos la cartografía geológica y los cortes balanceados con la tomografía sísmica (Vp) y los hipocentros de los terremotos. Se definen las rocas pre-Eocenas como el basamento del margen y del CPC, y se utiliza la Vp de 5.2 km/s como representativa de la interfaz entre el basamento y la cobertera sedimentaria. En la zona centro-sur del CPC se producen cambios a lo largo de la orientación de las estructuras y de la estratigrafía, que pueden ser correlacionados con estructuras activas del basamento. Los cambios de las velocidades sísmicas de N a S se interpretan como altos y bajos de basamento y se correlacionan con las áreas donde se producen cambios de la dirección estructural del CPC. Algunos grupos de sismicidad se alinean a lo largo de los bordes de estos bloques de basamento. Interpretamos estas características como indicativos de que el basamento está involucrado en la deformación y que la sismicidad representa la reactivación de fallas de basamento que influencian la estructura del CPC.*

Palabras clave: *Cinturón de pliegues y cabalgamientos de Taiwan, terremotos, tomografía, reactivación basamento, herencia estructural*

INTRODUCTION & GEOLOGICAL SETTING:

The Eurasian margin is obliquely colliding with the Luzon Arc to form the Taiwan Orogen (Fig. 1). This configuration is particularly apparent in the south-central part of the island providing a case example to investigate the effects of structural inheritance in the development of the FTB.

The extensional tectonic history of the Eurasian margin began in the Early Eocene and culminated in the Late Eocene to Early Oligocene with sea-floor spreading and the opening of the South China Sea (Lin et al, 2003). Several NE trending basins developed during the rifting of the pre-Cenozoic basement. Further extension on the outer margin took place during the Middle to Late Miocene, forming basins whose sediments are now involved in the Taiwan FTB.

The margin's transition from the platform to the slope projects across south-central Taiwan and is oriented at a high angle to the active deformation front. This study is focussed in the south-central region in order to investigate the effects of inherited margin structures on the development of the FTB.

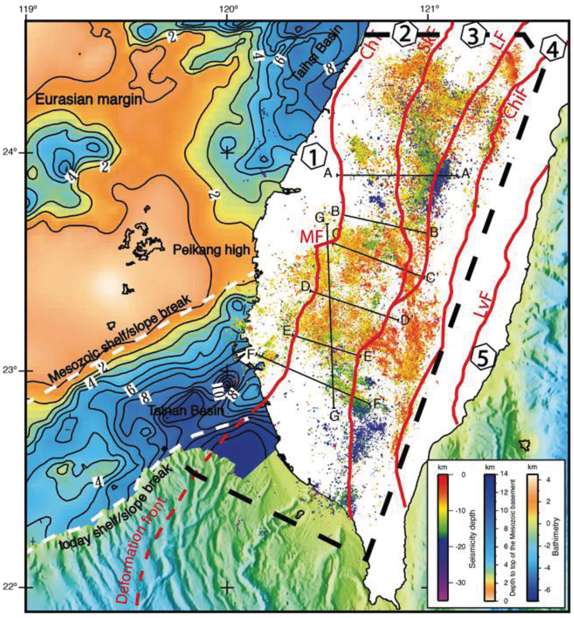

FIGURE 1. *Taiwan Island with depth to the top of Mesozoic basement in the Taiwan Strait (Lin et al, 2003). Location of earthquake epicenters with depth scale color coded, in black lines are showed all the tomography cross sections developed highlited one is shown in Fig.2., main faults in red line (ChT: Changua Thrust; MF: Meishan Fault; SkF: Shuilikeng Fault; LF: Lishan Fault; ChiF:Chinma Fault and LvF: Longitudinal Valley Fault), which divide Taiwan in four major tectonostratigra_c units, 1: Coastal Plain; 2: Western Foothills; 3: Hsuehshan Range; 4: Central Range and 5: Coastal Range. Black dashed line indicates the study area.*

DATA AND METHODS:

The 3D local Vp tomography model (Kuo-Chen et al, 2012) and earthquake hypocenter data from 1994 to 2014 are used. Earthquake hypocenters were relocated using the same 3D velocity model and a double difference technic (Fig. 2).

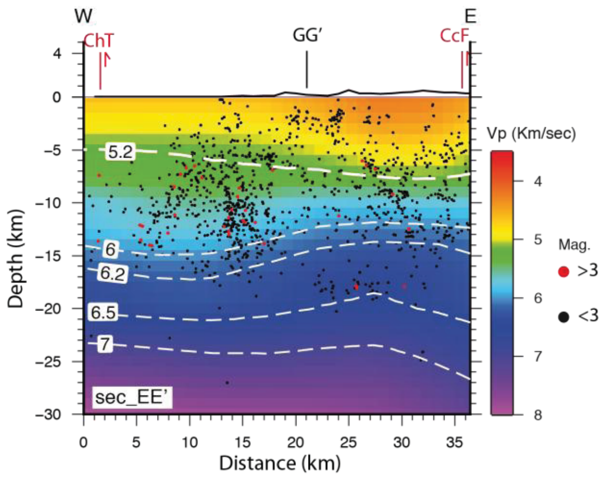

FIGURE 2. *Vertical tomography section EE' with hypocenters projected from 2 km each side. Magnitudes above 3 are in red and below in black. Key to abbreviations and location are in Fig. 1.*

The tomography and earthquake data are integrated with our new geological mapping from which several balanced geological cross sections are constructed (Fig. 3). The tomography and earthquake data help constrain the structure at depth.

RESULTS AND DISCUSION:

We define the basement as pre-Eocene rocks, and use a P-wave velocity (Vp) of 5.2 km/s as a proxy for the basement-cover interface (Camanni et al, in press). This interface is characterized by highs and lows that are interpreted to reflect basement topography.

In all the tomography cross sections we find that the seismicity is located above and below Vp 5.2 km/s contour, meaning that deformation is taking place not only in the FTB but also in the basement.

In the north, under the Hsuehshan Range (3) (Brown et al, 2012 and Camanni et al, 2014) there is a pronounced shallowing of high Vp across the Shuilikeng fault (SkF) (Fig. 4). It is accompanied by an east-dipping cluster of seismicity down to more than 25 km depth (Fig.1), and forming what appears to be a crustal ramp across which the Eocene-age Hsuehshan Basin is being inverted. In the Hsuehshan Range, the involvement and uplift of pre-Cenozoic basement is associated to higher topography and to the occurrence of Eocene-Oligocene sediments at the surface.

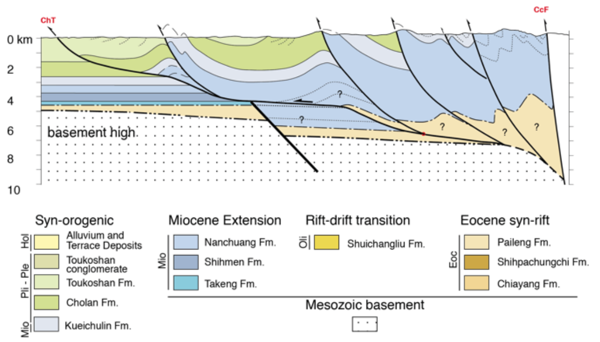

FIGURE 3. *Balanced geological cross section along EE'. Key to abbreviations and location are in Fig. 1.*

The 5.2 km/s Vp boundary defines the Peikang High in the west (Fig. 1 and Fig. 4), the southern flank of which is the onland projection of the Mesozoic shelf/slope break. Southward, there is an increase in seismicity that is associated with a NE-SW oriented Choshui lateral structure in the FTB, expressed at the surface as the Meishan Fault (MF), and continues westward beneath the Alishan Range (AR). In the Alishan Range, the shallowing of the 5.2 km/s Vp interface in the FTB is interpreted as a basement high (Alvarez-Marron et al, 2014). The alignment of MF and the Choshui lateral structure in the northern Alishan basement high is roughly parallel to the Mesozoic shelf/slope break. The increase of predominantly scattered seismicity that reaches greater than 20 km depth, suggest basement involvement in the deformation. In accordance with this, geological cross sections show thick Miocene stratigraphy in the imbricated thrusts of the Alishan Area.

To the south, another zone of higher velocity is interpreted as a basement high crossing the FTB (Tainan High, Fig. 4). Associated with this basement high, there appears to be a SW-dipping cluster of hypocenters (Fig. 1). We interpret this as an extensional fault block (or blocks) that project from the upper slope area. The seismicity clusters are possibly imaging the reactivation of its bounding extensional faults.

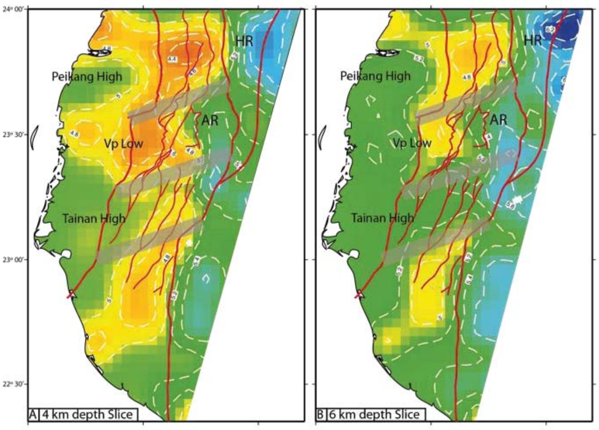

FIGURE 4. *Horizontal tomography slices at 4 and 6 km depth respectively. Major faults in red lines. Major basement structures are highlighted in the Coastal Plain. Transparent grey squares represent basement related structures in the FTB. Contours every 0.2 km/s. The same colour scale as in Fig.2. AR, Alishan Range*

The southern geological cross section shows thicker Miocene and Plio-Pleistocene sediments involved in the imbricated thrusts and the west verging dipping sole thrust is above the pre-Cenozoic basement (Fig.2)

Major along-strike changes in the geological map, such as in thrust strike, in fold traces, in the elevation of the thrusts and stratigraphic contacts and in the thickness of Middle Miocene sediments within the thrust system from N to S, are interpreted to be related to lateral structures in the thrust system. These changes present a good correlation with basement fault blocks that are interpreted from the Vp velocity model and earthquake location.

CONCLUSIONS:

- The geology of south-central Taiwan fold and thrust belt includes important along-strike changes in structure and stratigraphy, as well as in seismic velocities.

- Seismicity appears to be above and below the top of the Mesozoic basement and locally, reaches down to more than 25 km depth. We interpret this as deformation taking place not just in the cover but also in the basement, resulting in fault reactivation and, locally, basin inversion.

- Several major changes in strike and elevation in the orientation of structures, stratigraphic contacts and velocity distribution that take place from north to south are associated to lateral structures. We interpret them to be related to reactivation of inherited northeast-striking basement faults.

- The basement involvement in the deformation and the depth distribution of seismicity are associated to the reactivation of basement fault blocks that influence the building of the mountain belt.

- Our geological mapping, together with the geological cross sections provide an estimate of a minimum amount of horizontal shortening in the FTB of about 15 km. Displacement directions along the main thrusts are, overall, roughly northwest-directed.

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REFERENCES

- Alvarez-Marron, J., Brown D., Camanni, G., Wu, Y.-M. and Kuo-Chen, H. (2014): Structural complexities in a foreland thrust belt inherited from the shelf-slope transition: Insights from the Alishan area of Taiwan, *Tectonics*, 33.
- Brown, D., Alvarez-Marron, J., Schimmel, M., Wu, Y.-M., and Camanni, G., (2012): The structure and kinematics of the central Taiwan mountain belt derived from geological and seismicity data: *Tectonics*, v. 31, no. 5.
- Camanni, G., Chen, C.-H., Brown, D., Alvarez-Marron, J., Wu, Y.-M., Chen, H.-A., Huang, H.-H., Chu, H.-T., Chen, M.-M., and Chang, C.-H., (2014b): Basin inversion in central Taiwan and its importance for seismic hazard: *Geology*, v.42, no. 2, p. 147-150.
- Camanni, G., et al., (in press): The deep structure of south-central Taiwan illuminated by seismic tomography and earthquake hypocenter data, *Tectonophysics*. http://dx.doi.org/10.1016/j.tecto.2015.09.016.
- Lin, A. T., Watts, A. B. and Hesselbo, S. P. (2003): Cenozoic stratigraphy and subsidence history of the South China Sea margin in the Taiwan region. *Basin Research*, 15 (4), 453-478.
- Kuo-Chen, H., Wu, F.T., Roecker, S.W. (2012): Three-dimensional P velocity structures of the lithosphere beneath Taiwan from the analysis of TAIGER and related seismic data sets. J. *Geophys. Res.*, 117.