

# The structure of the central Taiwan mountain belt

## *La estructura de la parte central de la Cordillera de Taiwan*

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**Abstract:** The structure of the Taiwan mountain belt is thought to be that of an imbricate thrust and fold belt developed above a shallowly dipping basal detachment. In recent years, however, a growing amount of seismicity data from the internal part of the mountain belt indicates the existence of widespread fault activity in the middle and lower crust. Here, we present new geological mapping from the central part of Taiwan. We suggest that the foreland basin part of the Western Foothills comprises an imbricate thrust system that is structurally and kinematically linked to a basal detachment at between 7 and 10 km depth. To the east of the foreland basin, in the Hsuehshan Range, our data show the presence of major faults that are steeply dipping and which penetrate deep into the crust. A structural and kinematic model in which this part of the mountain belt forms a zone of transpression better fits the available data. Eastward, in the Central Range, deep water sediments appear to form an allochthon that is being overthrust by Mesozoic basement rocks. The involvement of Mesozoic basement in the deformation is suggestive of the reactivation of pre-existing basin-bounding faults.

**Key words:** Taiwan, trust belt, transpression.

**Resumen:** La estructura de la cordillera de Taiwan se considera constituida por un sistema de cabalgamientos y pliegues desarrollados sobre un despegue basal con suave inclinación. En años recientes, sin embargo, una cantidad creciente de datos de sismicidad procedentes de las partes internas de la cordillera indican la existencia de actividad generalizada de fracturas en la corteza media e inferior. Aquí presentamos un nuevo mapa geológico y datos de campo de la zona central de Taiwan. A partir de ellos sugerimos que parte de la cuenca de antepaís incluida en la Western Foothills incluye un sistema de cabalgamientos imbricados que están estructural y cinemáticamente conectados a un cabalgamiento basal situado entre 7 y 10 km de profundidad. Sin embargo, al este de la cuenca de antepaís, en la Hsuehshan Range, nuestros datos muestran la presencia de fallas mayores con alta inclinación y que penetran hasta partes profundas de la corteza. Un modelo estructural y cinemático en el que esta parte de la cordillera forma una zona transpresiva encaja mejor con los datos disponibles. Hacia el este, en la Central Range, sedimentos marinos profundos constituyen una unidad aloctona que cabalga sobre rocas del basamento Mesozoico. El hecho de que el basamento Mesozoico esté involucrado sugiere la reactivación de fallas preexistentes.

**Palabras clave:** Taiwan, cordillera de cabalgamientos, transpresión.

## INTRODUCTION

The structure of the faulted and folded rocks of the Eurasian continental margin involved in the Taiwan mountain belt is often presented as an imbricate thrust and fold belt developed above a shallowly eastward-dipping basal detachment (e.g., Suppe, 1980, 1981). The bulk of the data for this interpretation of the structure comes from surface geological observations, shallow reflection seismics, and borehole data along the western flank of the mountain belt, in what is known as the Western Foothills (Figure 1). The more internal parts of the mountain belt are less well understood because of difficult access in the areas of high rugged topography and heavy forest cover. Nevertheless, collapsing and selective picking of

relocated small magnitude (between  $M_L$  1 and 4) earthquake hypocenter data appears to validate the interpretation of extending a detachment from beneath the Western Foothills across the entire mountain belt. Combining these seismicity data with surface geological data from published geological maps from the Western Foothills and the western part of the Hsuehshan Range, others have also interpreted the basal detachment to extend eastward, with ramps and flats, beneath the entire mountain belt. In this latter interpretation, the more internal units are structurally linked to the basal detachment, forming three imbricate thrust sheets with the largest of these, the Tili thrust sheet, transporting nearly the entire Taiwan mountain belt at least several 10's of kilometers westward.

There is, however, a growing amount of geophysical data from the internal part of the mountain belt that indicates widespread fault activity in the middle and lower crust, well below the level of the proposed detachment (e.g., Wu *et al.*, 1997, 2004). For example, recent magnetotelluric experiments show a prominent electrical conductor that extends into the middle crust, crossing the proposed detachment. Similarly, analyses of seismicity data also indicate that there are several steeply dipping faults that penetrate into the middle and perhaps even the lower crust. On the basis of these data, it has been suggested that any model for the structural architecture of the Taiwan mountain belt needs to incorporate a number of steeply dipping faults that involve nearly the entire crust. A corollary to this is that these faults would have to cut the basal detachment proposed in the imbricate fold and thrust belt model. This proposal therefore has significant implications for the geometric, mechanical and kinematic evolution of the Taiwan mountain belt that are very different from what has so far been presented on the basis of the imbricate thrust belt model.

While geophysical and thermochronological data can provide significant insights into the geometry, kinematics, and mechanics of the Taiwan mountain belt, in order to further advance our understanding of the structures that provide first order controls on these types of data much more surface geology data is needed from its interior. In this paper we present new geological mapping in the central part of Taiwan which spans nearly the entire width of the mountain belt (Fig. 1).

## STRUCTURE AND KINEMATICS

Our surface geological mapping presented here indicates that in Central Taiwan, from the buried Changhua thrust in the west to the Tananao Unit in the east, the mountain belt can be divided into six distinct, roughly northeast-southwest trending fault bounded units.

These data corroborate the previous interpretations of a gently eastward-dipping detachment at about 7 to 10 km depth below the Western Foothills. Like the previous interpretations, to the north of the Choshui River we place the detachment to the Changhua-Chelungpu imbricate thrust system within the Chinshui shale member of Cholan Formation synorogenic sediments. South of the Choshui River, however, there is a significant change in the location of this basal detachment as it ramps down section into the older Miocene rocks, placing them on top of Pleistocene rocks in the Neilin anticline. Rare kinematic indicators found in the field indicate a top-to-the-northwest (oblique) sense of movement is taking place.

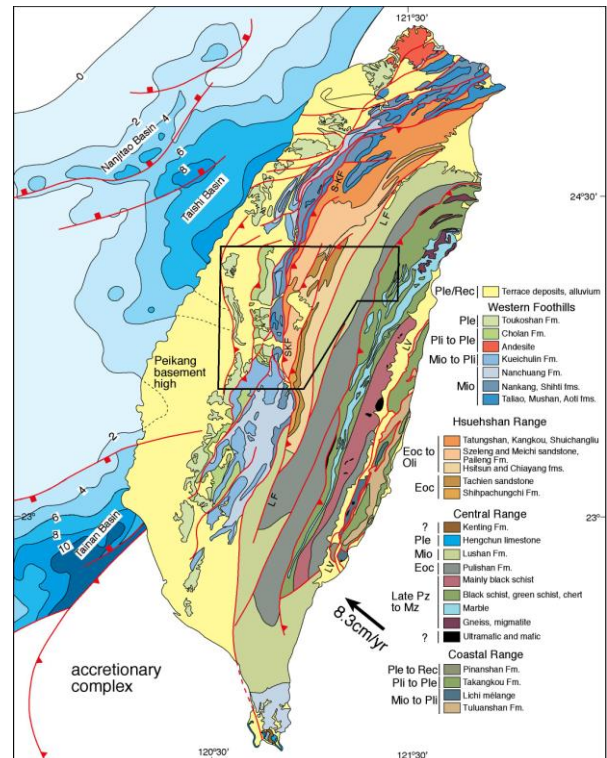


FIGURE 1. Geological map of Taiwan. The location of the Peikang basement high is shown, as is that of Figure 2. SKF = Shuilikeng fault, LF = Lishan fault, LV = Longitudinal Valley.

Unlike previous interpretations, we suggest that the detachment beneath the Changhua-Chelungpu imbricate thrust system does not continue eastward beneath the Hsuehshan and Central ranges. Instead, it appears to be truncated by, or is perhaps somehow linked with, the Shuilikeng fault. We recognise that there are problems in interpreting the geometry of the Shuangtung thrust at depth. In this study, we suggest that since it cuts down section through the Miocene and into Eocene-aged Paileng Formation rocks it is more likely to be structurally and kinematically linked to the Sun-Moon Lake Unit, although its eastern flank has been cut by the Shuilikeng fault. With the current data, however, it is not possible to determine the nature of this linkage. In the surface geology, the Shuangtung thrust places Miocene rocks on top of the upper part of the Toukoshan Formation, indicating that it was active during the late Pleistocene to Holocene.

We suggest that the Shuilikeng fault, rather than being a single discrete feature, comprises a system of faults and folds that splay off the main fault, resulting in a regional map pattern that is strongly suggestive of a transpressive or strike-slip system fault. This Shuilikeng fault “system” dominates the structure of the Sun-Moon Lake Unit in the map area. The bending of folds (e.g., the Tingkan syncline or the Tsukeng anticline), together with the bending and truncation of the Tili Unit, against the Shuilikeng fault indicates that it has a sinistral component of displacement.

The Tili thrust marks a clear structural and metamorphic boundary in the Hsuehshan Range. It juxtaposes lower metamorphic grade rocks of the Sun-Moon Lake Unit against higher grade rocks with a well-developed cleavage of the Tili Unit. It also represents an abrupt change in structural style from the Sun-Moon Lake Unit, with fault propagation folding becoming dominant and a well-developed axial planar cleavage being developed.

We confirm, for the first time, the presence of a clearly defined zone of intense ductile strain that coincides with the location of the Lishan fault. This high strain zone, together with the recent finding of large foraminifera that are assigned to the NP14 biozone in rocks along the western side of the Lishan fault confirm that it juxtaposes Early to Middle Eocene higher metamorphic grade rocks of the Tili Unit against Middle Miocene lower metamorphic grade rocks of the Lushan Unit.

To the east of the Lishan fault, the Lushan Unit displays highly noncylindrical folding. In general, the structure displays an overall northwest vergence, which we can determine from the well developed, moderately southeast-dipping cleavage. Nevertheless, it is not possible to determine the deep subsurface structure in this part of the Central Range because of the lack of seismicity. There is only a minor increase in both the horizontal and vertical components of GPS velocity vector from the Tili Unit to the Lushan Unit.

We have very little geological data from the Tananao Unit, which is being thrust westward over the Lushan Unit along the Chinma fault. This fault outcrops very well along the Central Cross Island Highway, where it clearly dips ca. 60° to the southeast.

## RELATIVE DEFORMATION SEQUENCE

We interpret the earliest deformation associated with the Taiwan orogeny in our map area to be the development and emplacement of the Tili and Lushan units. It is not possible to accurately constrain the age and timing of emplacement of these units, but the first appearance of lithic clasts containing a cleavage in the forearc region of the Coastal Range and in the Western Foothills foreland basin sediments occurred during the Early Pliocene, or some 3.5 to 4 My ago. This indicates that these rocks were above sea level and being eroded by this time. Further indications that this is one of the earliest events recorded in the map area is given by the geometric relationships between faults. For example, the Tili Unit is cut by the Shuilikeng fault system in the southwest and appears to be cut by the Lishan fault in the northeast (out of the current map area). Similarly, along its western flank the Lushan Unit is cut by the Lishan fault and, in the east, by the Chinma fault. These geometric relationships indicate that activity along the Shuilikeng, Lishan, and Chinma faults must

post-date the emplacement of the Tili and Lushan units. We therefore suggest that, despite the different metamorphic conditions undergone by the Tili and Lushan units, that there is a close enough similarity in the structural style and in the orientations of bedding and cleavage between the two to interpret that they developed at the same time, early on in the history of the Taiwan orogeny, and that they were both being emplaced by at least the Early Pliocene. These units were subsequently juxtaposed along the Lishan fault at some unknown time.

The second phase of deformation related to the Taiwan orogeny that we see in the current study area is the in-sequence development of the Shuangtung, Chelungpu, and Changhua units, respectively. On the basis of foreland basin sedimentation, geomorphic structures, and magnetostratigraphy, it has been estimated that the Shuangtung thrust became active at ca. 1.1 Ma, the Chelungpu thrust at 0.7 to 0.9 Ma., and the Changhua at 0.62 to 0.65 Ma.

The last fault activity to start in the study area is related to the Shuilikeng fault system, and possibly the Lishan fault. The Shuilikeng fault system is active and has been so throughout the Holocene. Our mapping clearly shows that it affects the eastern margin of the Shuangtung Unit and therefore post-dates its emplacement. At the moment, it is not possible to place any constraints on the age of activity along the Lishan fault. Although, within our map area, seismic activity along its southern part indicates that it is active.

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