Cenozoic stratigraphy, subsidence, and flexure of the West Taiwan basin of the South China Sea margin

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Outline

- Introduction
- Setting and Stratigraphy
- Methods and Results
- Discussion
- Conclusions
Introduction

- Use seismic and well data
- Foreland basin
- Bouguer gravity anomaly → Surface loading → Buried loading
- The effective elastic thickness of the lithosphere: $T_e$
Setting and Stratigraphy

OT: Okinawa Trough
RT: Ryukyu Trench
COB: Continent-Ocean Boundary
DR: Dongsha Rise
ET: Eastern Transect
MT: Manila Trench
MB: Macclesfield Bank
RB: Reed Bank
NPB: North Palawan block
DG: Dangerous Grounds
Setting and Stratigraphy

The westernmost edge of the Taiwan foreland

Thrust front
Setting and Stratigraphy

The westernmost edge of the Taiwan foreland
KYP: Kuanyin Platform
NJB: Nanjihtao Basin
TB: Taihsi Basin
PHB: Penghu Basin
PHP: Penghu Platform
TNB: Tainan Basin
ND: Northern Depression
CUZ: Central Uplift Zone
SD: Southern Depression
WF: Western Foothills
HR: Hsuehshan Range
BR: Backbone Range
CoR: Coastal Range
Setting and Stratigraphy

BU: breakup unconformity
IRU: intra-rift unconformity
ROU: rift-onset unconformity

Onlap

Conglomerate

Up to 100-m thick conglomerate bed consisting of basalt, sandstone, and shale clasts
Setting and Stratigraphy

BFU: basal-foreland unconformity
BU: breakup unconformity
IRU: intra-rift unconformity
ROU: rift-onset unconformity

Onlap

Taihsi Basin (South)

BFU
BU
IRU
ROU
Mesozoic Pre-rift
Palaeogene Syn-rift
Oligo-Miocene Post-breakup
Seabed
Latest Miocene–Recent foreland basin

10 km
West
East

TWT (s)
Setting and Stratigraphy

BFU: basal-foreland unconformity
BU: breakup unconformity
ROU: rift-onset unconformity

Onlap

Transitional stratigraphy
Setting and Stratigraphy

BFU: basal-foreland unconformity
BU: breakup unconformity
ROU: rift-onset unconformity
Setting and Stratigraphy

Foreland basin
Post-breakup
Syn-rift
Pre-rift (Basement)

BFU: basal-foreland unconformity
BU: breakup unconformity
ROU: rift-onset unconformity
Setting and Stratigraphy

(Sources: this study; Huang, 1982; Ho, 1986)
Setting and Stratigraphy

(1, 2, 3: Rift events)
Methods and Results

- **Surface loading**

It is useful when considering the state of isostasy in orogenic belts to consider the topography as a load on the surface of the lithosphere that responds by some form of downwarping. Topographic and bathymetric maps suggest that surface load is made up of both an onshore (i.e., subaerial) and (i.e., submarine) offshore component.

Use a 3-D flexural response function technique [Walcott, 1976] to quantify the contribution of surface loading to the development of the West Taiwan basin.
Methods and Results

Reconstruct the paleobathymetry

Estimate the surface load

Combine subaerial and submarine surface loading to show the flexure

Flurial to shallow shelf

Slope
Methods and Results

Estimated flexure

Observed flexure

Discrepancy

Fit
Methods and Results

Unable to explain the shape of the foreland basin
Methods and Results

(a) Crustal Structure and Flexures along Profile 2

(a) from Yeh et al. 1998
(b) from Yeh et al. 1999

(b) Gravity Anomaly

- Observed gravity anomaly
- 3D continuous plate ($T_p = 13$ km)
- 2D continuous beam ($T_p = 13$ km)
- 2D broken beam ($T_p = 13$ km)
- Airy

Suture
Methods and Results

- Buried loading

The buried load has been replaced by a terminal force or bending moment that is applied to the end of the underthrust plate.

Irrespective of its geological interpretation, the Bouguer gravity anomaly high is a useful indicator of the size of the buried load.

Karner and Watts [1983] showed that buried loading was an important contributor to the Bouguer gravity anomaly, explaining both the lows over the foreland and the highs over the flanking orogenic belt.
Methods and Results

Calculate gravity effect of the Moho based on Airy model

Obtain the Airy isostatic anomaly
Methods and Results

Calculate flexure that results from buried loading

Combine surface and buried loading to find the flexure
Methods and Results

![Diagram showing geophysical data with labels and measurements. Notable features include:
- $T_e = 13$ km
- Crust depth: 2800 kg m$^{-3}$
- Observed foreland base
- Seismic refraction Moho with error bars
- Upper/lower crustal interface from seismic refraction
- Flexure by surface loads: 3D continuous plate, $T_e = 13$ km
- Flexure by surface loads: 2D continuous beam, $T_e = 13$ km
- Flexure by surface loads: 2D broken beam, $T_e = 13$ km
- Airy Moho

Additional notes:
- From Yeh et al. 1998; 1999
- 1km mark on the diagram]
Methods and Results

Profile 1

- Gravity
- Observed vs. Computed
- Isostatic anomaly

Profile 2

- Loading ratio
- Observed vs. Computed

Profile 3

- Flexure
- Observed vs. Computed
- Best fit $T_e = 13$ km (rms 0.107 km)

Fit

Fit

Not fit

$d)$ Sensitivity

RMS (km)

$T_e$ (km)

0 10 20 30 40 50

0 10 20 30 40 50

0 10 20 30 40 50
Methods and Results

- Backstripping

A modeling technique to assess the geologic history of rock layers through the use of geologic cross sections or seismic sections. Removal of the youngest layers of rock at the top of the section allows restoration of the underlying layers to their initial, undisturbed configurations. Successively older layers can be removed sequentially to further assess the effects of compaction, development of geologic structures and other processes on an area.

Backstripping techniques were applied in order to determine the tectonic subsidence and uplift history of the South China Sea. [Watts and Ryan, 1976]
Methods and Results

Restore sediment thickness and density of individual layers

Syn-rift (~58-30Ma)

Post-breakup (~30-6.5Ma)

Foreland-basin (~6.5-0Ma)
Methods and Results

Porosity-depth relationship curves

Restore sediment thickness and density of individual layers

(Model: Audet, 1995, 1996)
Methods and Results

Tectonic subsidence obtained by backstripping
Discussion
Discussion
Discussion

South China Sea seafloor spreading

Volcanism (Ho, 1986; Juang, 1996)
Kungkuan stage (23-20 Ma),
Chiaopanshan stage (13-7.1 Ma)
Discussion

First extension (A)  Thermal subsidence (B+C)

(a) Rifting (~30–21 Ma)
(b) Tectonic Quiescence (~21–12.5 Ma)

Second extension (D)

Equivalent lithostratigraphic units:

- Sequence set A: Wuchishan Formation, Mushan Formation & equivalents
- Sequence sets B + C: Piling Shale to Kuanyinshan Sandstone & equivalents
- Sequence set D: Nanchuang Formation & equivalents
Volcanism (Ho, 1986; Juang, 1996)
Kungkuan stage (23-20Ma),
Chiaopanshan stage (13-7.1Ma)

Foreland subsidence: accelerated through time because of the orogenic loads
Conclusions

- Flexure modeling shows that surface loading is unable to explain the depth of the West Taiwan basin. Other, subsurface or buried loads are required.
- The depth of the base of the foreland sequence in the northern part of the West Taiwan basin can be explained well by an elastic plate model with an effective elastic thickness, $T_e$, of 13km. In the southern part of the West Taiwan basin, however, the depth of the base of the foreland sequence dips too steeply to be explained by elastic plate models.
- These differences in the flexural response along-strike of the West Taiwan basin are reflected in seismicity patterns west of the thrust front.
Conclusions

di: dike intrusions
ex: extrusive rocks
IC: induced small-scale mantle convection
th: thermal metamorphism
up: underplated igneous bodies

PHB: Penghu Basin
TNB: Tainan Basin
TB: Taihsi Basin
Thank for your attention!