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Taiwan Integrated Geodynamics Research (TAIGER)
A Comprehensive imaging and modeling project

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Synopsis

The collision of the Luzon arc with the southeast China continental margin is the most active arc-continent collision in the world. This collision, forming the Taiwan mountains, began in northern Taiwan 4-5 million years ago and some researchers thinkg that it is only just starting in the south. Thus Taiwan provides an exceptionally explicit opportunity to studying the structural variation along strike as a proxy for time slices in orogenic evolution. Of particular importance here are the special opportunities to investigate some of the most fundamental questions of mountain building:

- Does continental subduction play a controlling role in arc-continent collision? Is the Eurasian continental lithosphere subducting beneath Taiwan? If it is not subducting, what is taking place?
- One of the fundamental issues in orogeny is mass balance. How do factors such as erosion, crustal thickening, mantle flux, etc interact quantitatively?
- How did the orogen evolve through time? With the differing degrees of collision from north to south, we can quantitatively track the various crustal components (upper, lower, continental, oceanic) from undeformed to fully involved, tracking deformation and mass transfer through the orogenic system.
- How does surface kinematics relate to deep structure? The present rate of crustal uplift may exceed 2 cm/yr--what were the rates of corresponding root formation? Estimates of seismic anisotropy should aid in tracking mass flow thru this system on the lithospheric scale. Imaging of major fault systems should provide linkage between surface deformation and deeper driving forces.
- How does anisotropy vary in space, laterally and vertically? Do the S-splitting directions change with depth? Is the deformation of the orogen vertically coherent from surface to upper mantle? To answer these questions we need to image the region from the surface to the mantle depths, extract the information from regional earthquakes and cast them in geodynamic models. Thus we propose an integrated geophysical imaging, earthquake recording and geodynamic research program to study the Taiwan orogeny. By combining detailed 2-D studies along transects and 3-D images for the whole region, the orogen and its evolution can be characterized. Our data acquisition program includes broadband regional seismic and teleseismic recording, onshore-offshore and land refraction-reflection seismic transects, magnetotelluric sounding, petrophysics and gravity modeling. The geometry of the plate interactions, the mode of crustal deformation, and the material properties will provide a new quantitative basis for geodynamic modeling. This project involves collaboration from six US institutions as well as collaboration and support from Taiwanese, French and Japanese groups. Taiwanese groups plan to provide the use of their research vessel and pay for part of the US research vessel costs. In addition they will share costs for the onshore activities and provide personnel to participate in all phases of the acquisition, processing, and interpretation of the geological and geophysical data. The French groups will participate in both onshore and marine activities, providing a number of ocean bottom seismometers and land seismic instruments to complement US and Taiwanese instrumentation.

Taiwan tectonics

I am including my recent paper published in the AGU special volume on South Island, New Zealand as an introduction. The paper compares Taiwan to South Island so it contains information on both collision mountain belts although nearly all the information on South Island is contained in other papers in the volume. The paper touches on the basic geology, seismicity, tomographic images, GPS etc.

TAIGER experiments and their status

Table I

Experiment	Action Periods	Studies	Team Leaders
Geodynamics	2004-2009	2-D comprehensive model.	L. Lavier; W. Wang
Petrophysics	Sampling: 2005 Measurements: 05-07 Analysis: 2006-2008	Hexagonal and orthorhombic measurements on samples. Correlation with S-splitting	N. Christensen
Magnetotellurics	Field work: 2005-2007 Analysis: 2006-2008	Preliminary results along profiles obtained	M. Unsworth C. S. Chen
Passive seismology	Deployment 2005/4-2006/4 Demob: 2008/5	Antelope database est. 2007/1 Initial data analysis: 2007 SKS/SKKS-splitting	F. Wu B. Huang
Broadband OBS	1st deployment: 2007/11 2nd deployment 2008/5:	10 instruments 07/11-08/05; 20 instruments 08/05-09/06	K. McIntosh C. Lee
Land active source (explosions)	Field test: 2006/10 Transects: 2008/2-2008/3	Field work just completed; archive and analysis started	D. Okaya C. Wang
Marine MCS/SPOBS TAIGER II-Taiwan; sea-land	2009/4-2009/7 R/V Langseth + land arrays.	TAIGER six transects plus "TAIGER II" transects	K. McIntosh, C. Liu (sea) / D. Okaya, C. Wang (land)
Auxiliary Research using other data sources	2004-2009	LET, seismicity and plate configurations Deformation of Taiwan based on continuous GPS data	F. Wu L. Kuo et al.

One of the underlying principles of the experiments are that we would like to image several stages of the mountain building. As it is generally concluded that the mountain ranges are younger from north to south along the trend of the island, we lay out 3 transects to catch the mature stage in the north and central Taiwan and the young stage in the south and offshore of southern Taiwan. The transects include land and/or marine active source profiles. We also densify the Taiwan networks with temporary (1 to 2 years) broadband stations, in order to perform 3-D imaging for the island as well as under ocean in the nearby areas.

TAIGER experiments

The main experiments and their purposes are as follows:

1) Passive seismology: 47 broadband stations mainly along three transects on-land, but also at sites in the mountainous areas in NE Taiwan where only a few stations exist. We also deploy 10 (stage #1) and 20 (stage #2) broadband OBS. Figures 1 show the land and ocean deployment sites. The data, combined with those from the existing Taiwan stations, will be used for tomography, receiver function, seismicity, focal mechanisms

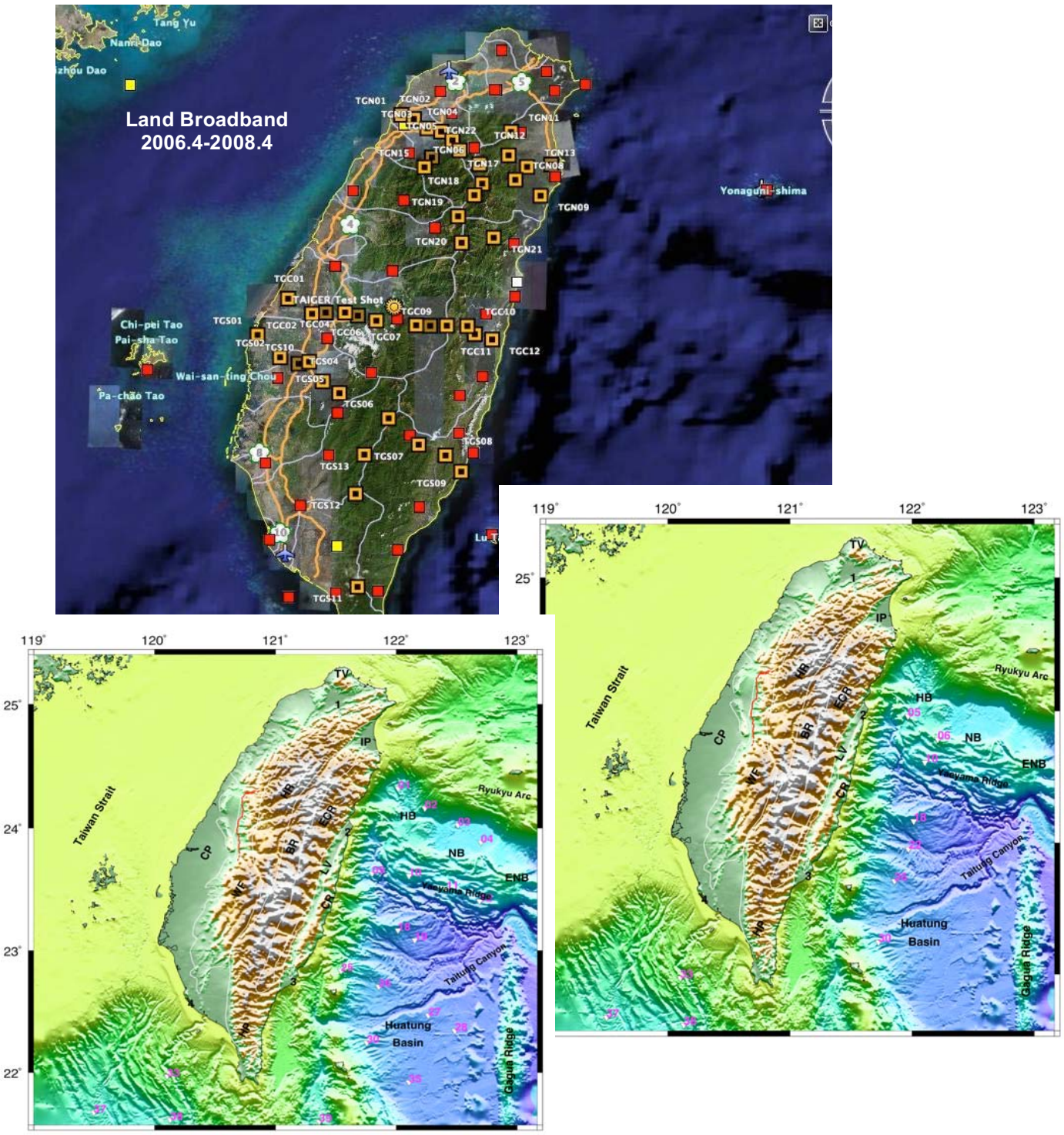

Figure 1. Land and ocean bothom broadband station sites. In the upper frame the square yellow symbols represent TAIGER stations. In the BBOBS figures in the lower part the inverted triangles with pink numbers are the station sites.

studies, S-splitting analyses etc. The 20 OBS currently on site will be recording the marine airguns next March-June for additional sources. The combined land and ocean bottom instruments will also enable us to image upper mantle structures to a greater depth than possible with only land data.

2) Active source profiles on land. Although 3 transects were planned the middle line instruments were deployed but not shots were fired. However the 800 4.5 Hz instruments recorded local earthquakes and 2 teleseisms. The data from these experiments will be used in the wide-angle refection analyses to obtain 2-D profiles along these transects both the shot arrival and the local earthquakes recorded on the short period instruments will be used in local tomography.

Figure 2 shows the deployment lines (sensors at 200 m spacing) and shot points. In addition to in-line recording we also set up instruments in the middle section of the central line (line 5) to record the northern shots in "fan-shot" configuration.

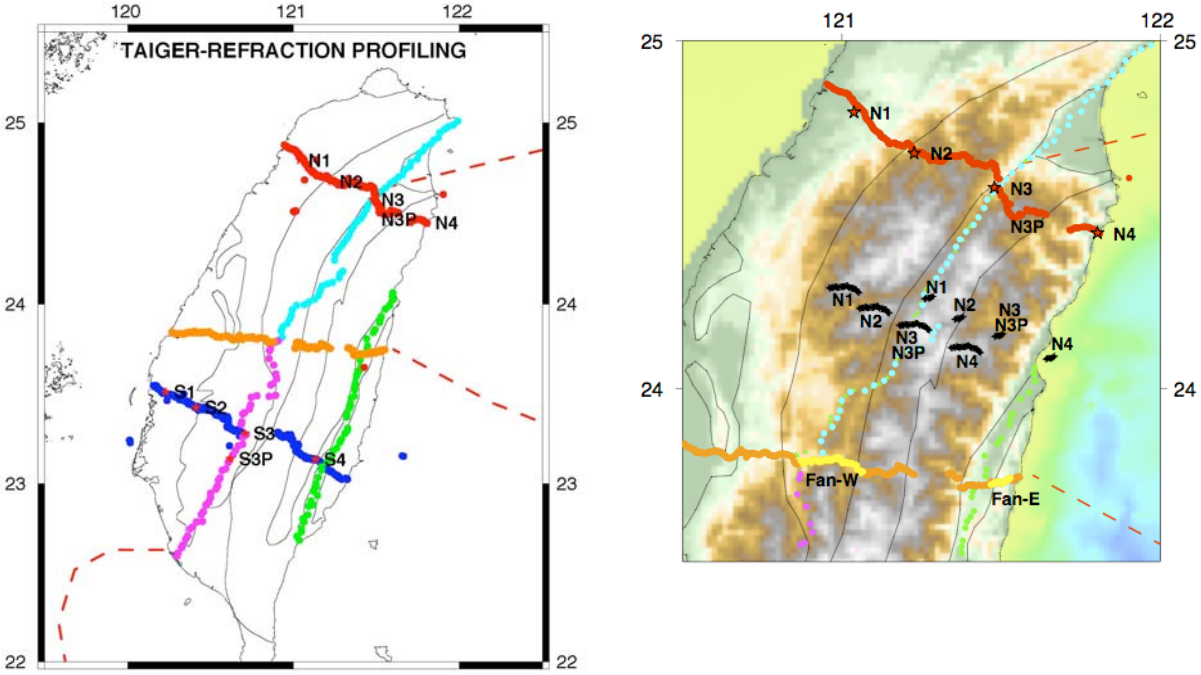

Figure 2. The land active source lines and the shot points (left) and the fan-shot reflection points.

3) Marine MCS and short period OBS transects with land instruments along transects. The transects are shown in Fig. 3. The TAIGER plan called for 6 transects; work is enhanced with Taiwan participation. This part of the project will provide large offset data for modeling the structures along the transects. The full sequence of profiles from the area south of Taiwan where typical island arc conditions exist to northern Taiwan where the mountain building has gone on longer. The land component of this operation (~300 and with 2 Hz sensors) will record continuously for about 3 months. The

combined dataset should cover many corners of the area where image quality has been lacking.

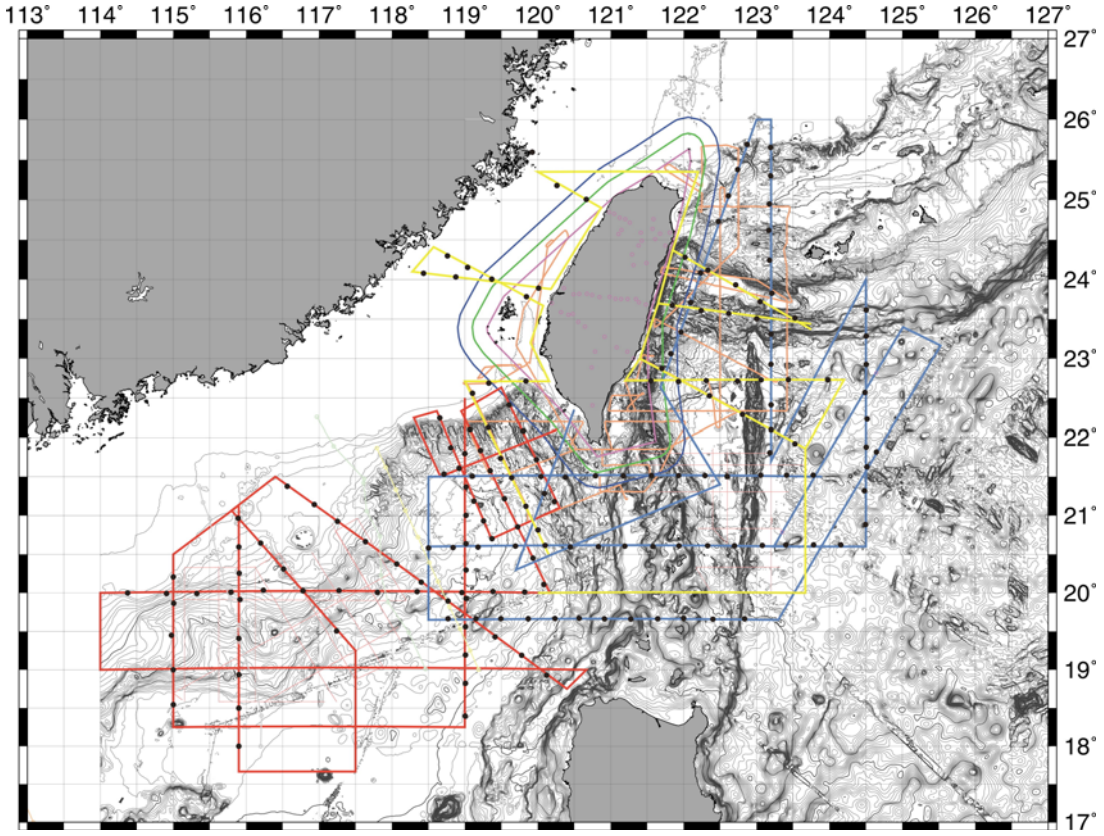

Figure 3. Planned marine ship tracks for R/V Langseth. The yellow lines are the original TAIGER lines. The red and blue lines are added.

4) Magnetotelluric sounding. The interpretation of seismic velocity can be enhanced with the addition of electrical resistivity data. The preliminary results show a (not quite expected) very resistive Central Range and (expected) conductive Coastal Plain. The Lishan fault seems to be underlain by a high-angle conductive zone.

5) Laboratory measurement of seismic velocity. For the first time the anisotropic P and S velocities in the metamorphic rocks in the Central Range have been measured. The fast direction is generally parallel to the direction of foliation. The data will be important in the interpretation of S-splitting data. The fast direction may help in delineating subsurface metamorphic structures.

6) Geodynamic calculation. So far 2-D models have been investigated. These results will allow us to interpret our data in terms of geodynamical processes. What mode of deformation is possible in the Central Range; is it different in the Foothills? What processes may be triggered as a result of crustal thickening? Can continent subduct? Is delamination taking place?

Future activities

The completed and the planned TAIGER experiments turn out to be larger in scale than originally proposed. Since an experiment in Taiwan requiring so much resources is not likely to happen again for a number of years (the last, much small TAICRUST experiment was 13 years ago) we aim to be as comprehensive as possible in our approach. Although data analysis is in progress as we speak the data to be collected next year will be more than what we have archived so far and hence will take several years to complete. The opportunities for detailed tomography with passive as well active, with local as well as teleseismic, with land as well as marine will probably swamp the current software and machines we are currently using. But we are enabling our software to be used on a grid and we are looking at whether our current database machine (running Antelope) can accommodate all the data.

Many hypotheses have been proposed for the collision orogeny of Taiwan. For some details of proposed tectonic models for Taiwan please refer to the Taiwan/South Island paper. The models differ and their implications on the deep structures are often critical for the discrimination of the models. Therefore tomographic imaging as well as the co-product of it, well-located seismicity, is critical for testing the models. The prospect of using the TAIGER dataset to test existing models and then perhaps proposed new models is exciting!