T11F MCC: 3007 Monday 1020h

Earthquake Geology and Hazards of East Asia II *(joint with S)*

Presiding: **Y Chen,** National Taiwan University**; K Mueller,** University of Colorado**; Y Sugiyama,** National Institute of Advanced Industrial Science and Technology

T11F-01 1020h INVITED

Surface Deformation and Earthquake Potential of Tainan Tableland, Southwestern Taiwan

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During the past 100 years several damaging earthquakes in the foreland of southwestern Taiwan have originated from rupture of blind thrusts that are manifested only by folding on the surface. It is important to identify the location, geometry, and size of the causative blind fault segments in order to estimate the potential for major earthquakes in this region. Geodetic measurements of surface deformation on the folded terrains are used to determine the fault geometry and the slip behavior at depth. We carried out repeated GPS and precise leveling measurements on the Tainan tableland, southwestern Taiwan in order to better understand earthquake potential in this densely populated urban area. Analysis of GPS campaign data set from 1999 to 2003, together with data recorded at eight continuous GPS sites in the surrounding areas, indicate that the Tainan tableland block moves northwest at 12 mm/yr relative to a fixed west coast site. For the domain east of the tableland, site velocities increase to 17 mm/yr with directions E-W relative to the fixed site. To the north and south of the tableland, from west to east, E-W-directed velocities increase gradually from 17 to 40 mm/yr. Comparisons of five precise leveling surveys across Tainan tableland over a period of 2 years indicate a uniform uplift rate of about 11 mm/yr for benchmarks within the 5-km-wide tableland. Elevation changes are virtually undetectable for benchmarks on west of the tableland. East of the tableland, on the contrary, uplift rate changes abruptly from 11 mm/yr to nearly zero near the margin of the tableland across the Houchiali fault. Farther east, benchmark uplift rate increases again from 0 to 12 mm/yr over a distance of 4 km to the eastern end of the leveling profile. By a dislocation model in an elastic half space, the geodetic data indicate that the Tainan tableland deformed as a pop-up structure with a major east-dipping thrust and a west-dipping backthrust. Both thrusts are blind faults. The backthrust (the Hochiali fault) are formed possibly due to a change of dip angle of the major east-dipping fault (the Tainan fault), which likely connects to a sub-horizontal regional detachment farther to the east. From the best-fit model we obtained a rapid slip rate of 23 mm/yr on the 32° east-dipping Tainan fault and a relatively slow slip rate of 5 mm/yr on the 75° west-dipping Houchiali fault. Both faults extend from near surface to a depth of 4 km, where the two faults are connected. With empirical relations between rupture area and earthquake magnitude, we estimate a single segment earthquake Mw 5.7 could take place on the Houchiali fault.

T11F-02 1040h

Finite Source Imaging of Seismogenic Structures of Central Taiwan: Results from six Mw > 5.8 Chi-Chi, Taiwan Aftershocks

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Central Taiwan is located in the collision zone between the Luzon arc of Philippine Sea plate and the Chinese passive margin of the Eurasia plate. Here the Chinese passive margin, with normal and strike-slip fault structures, enters into the convergent boundary where contractional processes dominate. Recently, the 1999, Chi-Chi sequence provides a great opportunity using earthquake sources to map the deep crustal structures of Central Taiwan. Several seismicity and moment tensor studies have already illuminated the geometry of important seismogenic faults at depth. We want to connect these data points using the planar slip models derived from finite fault inversions using strong motion data of 6 large aftershocks of the Chi-Chi, Taiwan earthquake. For each event, we derived a preferred model by testing different focal mechanisms, hypocenters, rupture velocities, and dislocation rise times, as well as different combinations of stations in more than 1000 inversions. We have assigned high levels of confidence for 3 of the preferred slip models. Two of them ruptured on the southern extension of the mainshock fault plane along the Puli-Chusan lineation. In cross section these two aftershocks form a flat-ramp geometry. One strike-slip aftershock nucleated within the basement but ruptured mainly within the overlying sedimentary strata, suggesting that seismogenic deformation in the basement can influence shallow structures. We assigned lower levels of confidence for the remaining slip models because other geophysical data were needed for interpretation, even though their waveform fits are also good. One aftershock occurred on a west-dipping backthrust at shallow depth near the town Puli. Another aftershock ruptured on a west-dipping fault in the basement. One aftershock near the town Chaiyi shows slightly better waveform fits for a west-dipping fault plane in the basement. The steep dip angles of these basement-involved slip models suggest that these events ruptured on pre-existing weak zones, presumably normal faults along the passive margin. In sum, this study imaged fault structures in the vicinity of proposed decollement. But at the same time, there were also strong evidence for basement-involved co-seismic deformation in the basement and above the decollement.

T11F-03 1055h

Present-day Crustal Deformation Across Central-Western Taiwan Fold-and-Thrust Belt From GPS Observations, 1996-1999

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Development of arcuate fold-and-thrust belt in central-western Taiwan is controlled by salients in the portions of the foreland basin. Published GPS data in central-western Taiwan are too sparse to clarify the present-day crustal deformation of individual geological structures in this region. An 80-km aperture GPS network with 5-km station-spacing has been deployed by Central Geological Survey of Taiwan since 1996. Here we use GPS campaign data from 1996 to 1999 to estimate the velocity field and strain rate variations in this region. GPS velocity field with respect to a stable continental margin site (Penghu) suggests a gradual increase in motion from west (2.0-7.7 mm/yr) to east (11.9-18.6 mm/yr) in central-western Taiwan. Except in southwest coastal area, site velocities increase abruptly from west (6.3 mm/yr, 32°) to east (10.7 mm/yr, 349°). This velocity boundary which extends 20 km long in N10°E direction is located just 5 km east of the coast. Such a contrast in velocity field creates a notable principal shortening rate 1.2 μstrain/yr 120° across this boundary. Farther to the east, block motions of Pakua anticline which located between Changhua Fault and Chelungpu Fault are moving 4.9-6.3 mm/yr in NW direction relative to the west of the Changhua Fault. The principal strain rates at Pakua anticline are 0.3 μstrain/yr 13°, and -0.3 μstrain/yr 103°. East of Pakua anticline, the shortening rate of Chelungpu Fault is 6.0 mm/yr in 320° relative to the west of Pakua anticline. The dramatic change of GPS velocity field in southwest coastal area suggests the existence of a low-angle blind fault. Growth of this fault is likely resulted from westward propagation of Taiwan deformation front. Variations of velocity field across Changhua Fault indicate a left-lateral motion, which may be caused by localized wrench deformation along the northern edge of Peikang high. By using a simple elastic dislocation model, GPS observations will be used to estimate the slip rates of each fault in this area.

T11F-04 1110h

A Multi-Source Assessment of Motion Along the Chaochou Fault, Southern Taiwan

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The Chaochou Fault (CCF) is both an important lithologic boundary and a significant surface feature in the Taiwan orogenic belt. It is the geologic boundary between the Slate Belt Range to the east, and the Western Foothills Range to the west. Although the fault is known to be a high angle, oblique sinistral thrust fault in places, both its kinematic history and its current role in the development of the orogen are poorly understood. We have divided the CCF and study area into three segments: the Southern area extends from the southern coast up to Tachin, the Middle area from Tachin to Laonung, and the northern section from Laonung to just north of Meishan, into the Yushan National Forrest along the Southern Cross Island highway. Field fabric data suggest that structural orientations vary along strike, particularly in the middle segment, the suspected location of the on-land Eurasian continent-ocean boundary (COB). Foliation/solution cleavage is oriented NE-SW and in the northern and southern segments, but ESE-WNW in the middle segment. Slip lineations also reveal a change in fault motion from dip-parallel in the north to a more scattered pattern in the south. This correlates somewhat with recent GPS results, which indicate that the obliquity of current motion changes along strike. The magnitude of horizontal surface motion vectors, relative to Liudau Island, decreases to the south. Horizontal vectors are directed from relatively NW-SE in the north, to nearly N-S in the southern field area. The magnitude of vertical motion is highest in the northern area and decreases dramatically to the south. Geomorphic data also suggest that fault activity decreases from north to south. Both mountain front sinuosity and basin area increase toward the south. These observations correlate well with published apatite/zircon fission track data that indicate un-reset ages in the south, and reset ages in the northern segment. We suggest that in the northern segment, the Slate Belt is currently undergoing rapid uplift related to oblique arc-continent collision between the Eurasian continent and the Luzon arc. We also suggest that in the southern segment, the CCF is significantly less active because the orogen is not yet involved in direct arc-continent collision.

T11F-05 1125h

3-D kinematics analysis of surface ruptures on an active creeping fault at Chihshang, Eastern Taiwan

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The Chihshang fault is one of the most active segments of the Longitudinal Valley Fault, the plate suture between the converging Philippine and Eurasian plates. A destructive earthquake of M 7.1 with substantial surface scarps resulted from rupturing of the Chihshang fault in 1951. From that on, no big earthquake greater than M 5.5 occurred in this area. Instead, the Chihshang fault reveals a creeping behavior at a rapid rate of about 20 mm/yr at least during the past

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20 years. The surface breaks of the creeping Chihshang fault can be observed at the several places. A typical feature is reverse-fault-like fractures on the retaining wall. We deployed small geodetic networks across the fault zone at five sites. Each network comprises of 5 to 15 benchmarks. Trilateration measurements including angles and distances as well as leveling among the benchmarks have been carried out on an annual basis or twice a year since 1998. Compared to previous other measurements which have shown the first order creep rate for the entire fault zone, the present geodetic data provides the detailed information of the surface movements across the fault zone which usually composed of more than one fault strands and folds structures. According to our data from the local geodetic networks, we are able to reconstruct the 3-D kinematics of surface deformation across the Chihshang fault zone. Multiple fault strands are common along the Chihshang fault. Oblique shortening occurred at all sites and was characterized by a combination of thrusts, backthrust and surface warps. Strike-slip motion can also be distinguished on some fault strands. It is worth to note that the cultural feature, such as concrete basement of strong resistance, sometimes acted as deflection of surface ruptures. It should be taken into consideration for mitigation against seismic hazards.

T11F-06 1140h

Fault Slip Rates From Repeating Microearthquakes on the Chihshang Fault, Eastern Taiwan

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The Chihshang fault is the most active segment of the collision boundary between Eurasia and the Luzon arc of the Philippine Sea plate in eastern Taiwan. Seismicity study shows that the Chihshang fault is a narrow SE-dipping listric thrust extending from near surface to a depth of 25 km. Geodetic measurements indicate a 2 cm/yr surface slip rate on the Chihshang fault, however, the fault slip behavior at depth is virtually unknown. In this study we determine fault slip rates at depth by using identified clusters of repeating earthquakes with highly similar waveforms. 1487 earthquakes occurred in Chihshang area with magnitude of 1 - 6 recorded by Taiwan Seismic Network from 1991 to 2002 are used. Recurrence intervals and moment release rates from repeating earthquake sequences are analyzed to estimate fault slip rates for different sequences. Event pairs with waveform cross-correlation coefficient larger than 0.9 at two or more stations are selected as the earthquake repeaters. For the data we have processed so far, 17 repeating earthquake sequences recurred 3 to 9 times are found. Those sequences show both quasi-periodic (recurrence intervals of 0.6 - 4.3 years) and aperiodic types with magnitude range of 2.1 - 3.8 at 12 - 23 km depths. Calculated fault slip rates vary from a constant rate (2.2 cm/yr) at depths of 12 - 15 km to a gradually increase rate (4.2 - 6.5 cm/yr) from depths of 17 to 21 km. Five aperiodic sequences showing irregular recurrence intervals are likely influenced by the occurrences of nearby 1995 M5 earthquakes. The constant 2.2 cm/yr slip rate at 12 - 15 km depth range is consistent with surface creep rate (2 cm/yr) as observed from geodetic measurements. This suggests that the Chihshang fault may have a very shallow locking depth so as to allow the fault creeps freely from surface to a depth of 12 km. Future efforts will focus on completing the search for repeating earthquake sequences and calculating the subsurface slip rates on the Chihshang fault.

T11F-07 1155h

Prehistoric Earthquakes Along The Sanchiao Fault, Taipei Basin, Northern Taiwan

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Although numerous large earthquakes in Taiwan have produced surface rupture during the last century, little is known about fault slip rates and recurrence intervals of fault displacement in metropolitan Taipei city. Previous studies along the Sanchiao Fault, a major normal fault that flanks the western boundary of the Taipei Basin, suggest that the fault has a long-term slip rate of 2.3mm/yr for the past 400,000 years. The Sanchiao Fault cuts the Quaternary Sunshan Formation and contains evidence for the age of subsidence of Taipei Basin. Strata from eight boreholes were examined in order to document the late-Pleistocene-Holocene record of earthquakes along the fault. Grain size analysis, total carbon content, lithology, texture, sedimentary structures, paleosols and fossil abundance were used to correlate subsidence stratigraphic units. Woody material and detrital charcoal from the boreholes were processed to provide radiocarbon dates. Borehole SCF05 and SCF06, drilled at the northern section of the fault, show two stages of hanging wall thickening. The amount of net offset between SCF05 and SCF06 abruptly changes from 5 to 8m, implying rapid subsidence of about 3 meters at about 9.3 9.4 kyr B.P. Similarly, net offset between SCF05 and SCF06 abruptly changes about 2 m occurs at about 11.1 kyr B.P., suggesting rapid subsidence. Borehole SCF01 and SCF02, located at the central section of the Sanchiao Fault, also display similar thickening and rapid subsidence. The net offset between SCF01 and SCF02 abruptly changes from 8 to 12m, suggesting rapid subsidence of about 4 m at about 8.4 8.6 kyr B.P. Earlier subsidence at about 8.9 9.1 kyr B.P. records similar displacement. Borehole SCF14, SCF15, SCF16 and SCF17, located at the southern section of the fault and do not show substantial Holocene offset. According to our subsurface stratigraphic correlations, we suggest that the Sanchiao Fault generated episodic earthquakes during the past 10,000 years. The amount of vertical offset for each event ranges from 2 to 4.8m. If we assume that 3.5m offset represents the average surface displacement, simple scaling relationships between surface displacement to moment magnitude yields a Mw 7.1 earthquake. Damage from large magnitude earthquakes along the Sanchiao Fault would be substantially different from that produced in the 1999 Mw 7.6 Chi-Chi earthquake. A large magnitude earthquake on the Sanchiao fault would rupture eastward, directing energy into the densely populated basin.

T12A MCC: Level 1 Monday 1330h

Structure and Evolution of Nonvolcanic Rifted Margins II Posters

Presiding: **D S Sawyer,** Rice University**; K Louden,** Dalhousie University

T12A-0430 1330h POSTER

Evidence for asymmetric rifting at the Newfoundland margin from SCREECH Transect 2 wide-angle data and numerical modeling

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Recent geophysical investigations on the nonvolcanic margins of the North Atlantic have shown us that the basic structure of the two conjugate ocean-continent transitions (OCTs) is remarkably different. The evolution of the Iberian margin seems to have been controlled by a shallow low-angle fault, and mantle exhumation clearly preceded the onset of mid-ocean spreading. In contrast, no evidence for large crust-penetrating faults have been found on the Newfoundland margin, and slow-spreading oceanic crust appears to abut the edge of continental crust. These observations have been explained by development of a concave-downward detachment fault in a late stage of the continental rifting, with the Newfoundland margin representing the hanging wall of the detachment. Numerical modeling of this scenario shows that lithospheric thinning brings up hot asthenospheric mantle beneath the Newfoundland margin crust shortly before break-up. During this last phase, ductile flow of the lower crust may have formed a weld between the Newfoundland margin and incipient oceanic crust. Results from a tomographic inversion of seismic refraction data of SCREECH Transect 2 are consistent with such a sequence of events. The thinned continental crust is characterized by seismic velocities ranging from 5.4 km/s below basement to 7.0 km/s in the lowermost crust. A 3 km thick lower crustal layer pinches out towards the OCT, where upper crustal seismic velocities reach 6.4 km/s over a width of 10 km. This high velocity anomaly may be the result of lower crustal diapirism in the wake of break-up of the continental lithosphere.

T12A-0431 1330h POSTER

Seismic Characterization Of Crust On The Newfoundland Non-Volcanic Rifted Margin: Prestack Depth Migrations Of The SCREECH Survey Around ODP Leg 210 Sites 1276 And 1277

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The presence of 70 km of seismically featureless basement on the Newfoundland non-volcanic margin seaward of unambiguous continental crust and landward of recognized seafloor spreading anomalies has long fueled a debate concerning the affinity of crust within this ocean-continent transition zone. Proposed models include highly extended and intruded continental crust, slow-spreading oceanic crust, and serpentinized peridotite, each of which carries specific implications for margin formation and incipient seafloor spreading. One means of distinguishing between different crustal types is seismic reflection character. We present a grid of prestack depth migrated seismic reflection sections from the Newfoundland margin around recently drilled ODP Leg 210 Sites 1276 and 1277. Previously determined P-wave velocities and Poisson's Ratios calculated on SCREECH Transect 2 suggest the presence of over 75 km of oceanic crust on the Newfoundland margin that is not found on the conjugate Iberian margin. However, drilling at Site 1276, which lies in the transition zone, did not reach basement, so the affinity of this crust remains uncertain. Seismic and drilling investigations on the Iberian margin have revealed the presence of large tracts of exhumed, serpentinized peridotite between normal oceanic and normal continental crust. As a result, characterizing enigmatic crust on Newfoundland is essential for constraining the transition from late stage rifting to initial seafloor spreading. Drilling at Site 1276 recovered diabase sills an estimated 100-200 meters above basement. These sills typically have velocities of 5500-6000 m/s and are separated by lower velocity sediments, a small proportion of which have very slow seismic velocities and low densities (1600 m/s, 2.1 g/cc); initial shipboard work suggests that these sills might be the source of bright reflections that are found above transitional basement on SCREECH Transect 2. Large contrasts in density and velocity would be expected to generate a series of very large reflection coefficients in the lowermost sedimentary section and would likely impede signal penetration beneath the bright package of resulting reflections. Because these sills overlie a critical section of crust on the Newfoundland margin, understanding whether the featureless character results from signal penetration or properties of the crustal rocks themselves is critical to characterizing this unusual crust and thus placing constraints on the transition from amagmatic rifting to seafloor spreading.