Transient fluvial landscape and preservation of low-relief terrains in an emerging orogen: Example from Hengchun Peninsula, Taiwan

S. Giletycz, Nicolas Loget, C.P. Chang, Frédéric Mouthereau

► To cite this version:

S. Giletycz, Nicolas Loget, C.P. Chang, Frédéric Mouthereau. Transient fluvial landscape and preservation of low-relief terrains in an emerging orogen: Example from Hengchun Peninsula, Taiwan. *Geomorphology*, 2015, 231, pp.169-181. 10.1016/j.geomorph.2014.11.026 . hal-01109390

HAL Id: hal-01109390

<https://hal.science/hal-01109390>

Submitted on 26 Jan 2015

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1   **Transient fluvial landscape and preservation of low-relief**
2   **terrains in an emerging orogen: example from Hengchun**
3   **Peninsula, Taiwan**

4

5   S. Giletycz ¹, N. Loget ^{2,3}, C-P. Chang ^{1,4}, F. Mouthereau ^{2,3,5,*}

6

7   Affiliation

8   ¹ Institute of Geophysics, National Central University, Chungli 320, Taiwan

9   ² Sorbonne Universités. UPMC Univ Paris 06, UMR 7193, Institut des Sciences de la
10   Terre Paris (iSTeP), 4 Place Jussieu, F-75005 Paris, France

11   ³ CNRS, UMR 7193, Institut des Sciences de la Terre Paris (iSTeP), 4 Place Jussieu, F-
12   75005 Paris, France

13   ⁴ Geological Remote Sensing Laboratory, Center for Space and Remote Sensing
14   Research, National Central University, Chungli 320, Taiwan

15   ⁵ Laboratoire International Associé ADEPT, CNRS-NSC

16   * Now at Université Toulouse III - Paul-Sabatier, Laboratoire Geoscience Environment
17   de Toulouse, UMR 5563, 14 av. Edouard Belin, F-31400 Toulouse, France

18

19   Corresponding author:

20   Slawomir Jack Giletycz

21 Department of the Earth Sciences, National Central University; address: Chongda
22 Road, 300, Chungli, Taoyuan County, Taiwan ROC; tel: (03) 4227151 ext. 57671;
23 email: geojack.slawek@gmail.com

24

25

26

27

28

Abstract

The oblique collision of Taiwan orogen led to a progressive southward uplift and emergence of a submarine accretionary wedge. The Hengchun Peninsula located at the southernmost tip of Taiwan island represents the most recently emerged landform of an antecedent submarine surface. In this study we examine the geomorphic evolution of this newly emerged and uplifted landscape. The extraction of geomorphic parameters (knickpoints distribution, steepness index of rivers) indicates a transient nature of the landscape but shows that a simple model of regressive erosion consecutive to sudden uplift is unsatisfactory. Knickpoints migration modeling shows that only the upstream Sizhong basin can be explained by this single process. On the other hand, the occurrence of a relict landscape (Mutan Ponds low-relief) developed at low elevations, and today uplifted in the core of the peninsula, has strongly influenced the drainage evolution. Numerous knickpoints are linked to capture processes around the Mutan Ponds area, indicating a dynamic reorganization of the drainage system. We propose that the landscape of the Hengchun Peninsula is in a transient stage and results from a combination between rejuvenation and drainage rearrangement caused by the late stage of emergence of the south of Taiwan.

52

53 Key words: transient landscape, orogen, Taiwan, fluvial processes, knickpoint

54 retreat

55

1. Introduction

The early stage of fluvial landscape development associated with emerging mountain ranges is often difficult to capture in natural systems. First, this is because the juvenile geomorphic surfaces need to be unambiguously distinguished from former submarine processes that shaped the landscape. Second, they are basically transient and therefore the rate at which this landscape is preserved directly depends on tectonic forcing and prevailing erosional processes (Burbank, 2002). Better understanding of these processes as well as the time response of landscape to tectonics or climate in active areas requires an approach that aimed at quantifying the early stages of geomorphic development (Willett and Brandon, 2002; Whipple, 2004; Crosby and Whipple, 2006; Garcia-Castellanos, 2006; Ramsey, 2006; Whittaker et al., 2007; Craddock et al., 2010; Walker et al. 2011).

Taiwan is classically described as an active orogenic system that reached a steady-state (Whipple, 2001) and where transient stages of landscape development are expected to be hardly preserved. However, due to convergence obliquity that induces uplift to propagate southwards (Suppe, 1981; Willett et al., 2003), the southern tip of Taiwan appears to be ideally located to assess the role of outboard marine inherited landscape and the geomorphic processes at play during the initial stage of mountain building (Fig. 1). Previous studies in central Taiwan have shown that topographic steady-state can be reached where high erosion rates 2-5 mm/yr are recorded (Willett et al. 2003; Siame et al. 2011). However, in contrast to the northern and more mature part of the mountain belt, the Hengchun Peninsula in the

79 south is characterized by low erosion rates as indicated by old, pre-orogenic fission-
80 track ages (Fuller et al., 2006), indicating this region did not reach an exhumational
81 steady-state. Transient stages of landscapes are mostly characterized by knickpoints
82 in their river profiles linked to a base-level drop or an increase of the tectonic uplift
83 (Whipple and Tucker, 1999; Bishop et al., 2005; Loget et al., 2006; Whittaker, 2007;
84 Attal et al., 2008; Gallen et al., 2013). Numerous works have attempted either to
85 calibrate erosional models or extract tectonic information from river profiles but in
86 most of cases they start from an inherited continental domain or antecedent
87 drainage systems (e.g., Roberts and White, 2010). Few works concern the
88 adaptation and organization of a drainage system following a large and recent
89 emerging domain (e. g., Rosenbloom and Anderson, 1994). A coupled approach of
90 river incision and organization/reorganization could be used as a marker of the
91 dynamic of emergence of continental domains.

92 In this paper, we examine the landscape evolution of the Hengchun Peninsula where
93 transient geomorphic processes, including patterns of drainage reorganization
94 (capture, knickpoints/knickzones) and relicts of low-relief high-elevation areas are
95 present. We first detailed the main geomorphic features of the peninsula
96 characterized by a N-S low-relief area pinned along the western side of the main
97 divide that are incised successively with time by the western and eastern flanks,
98 respectively. We then discuss on the origin of the main knickpoints positioned
99 around the low-relief area using a knickpoint celerity modeling approach and
100 steepness index maps. Geomorphological analyses of the large drainage basins of
101 the Hengchun Peninsula reveal that river channels recorded recent dynamics of the

youngest Taiwan orogen. We show that a simple rejuvenation stage cannot explain the main geomorphic features. A mixed model of knickpoint propagation and drainage rearrangement with captures caused by the late stage of emergence of the peninsula is proposed. These erosive and landscape evolution patterns appear to be compatible with an uplift originated from a deep crustal block related. The recent uplift in the Hengchun Peninsula is caused by the continuing progression of the collision towards the south of Taiwan.

2. Geological background

The Taiwan arc-continent collision is the result of the convergence between the Chinese continental margin of the Eurasian plate and the Luzon arc belonging to the oceanic Philippine Sea plate (Fig. 1). Collision started 6.5 Ma as inferred from initial orogenic loading in western Taiwan (Lin et al., 2003) and onset of cooling, above the underthrust continental crust, recorded at 7.1 Ma by low-temperature thermochronological data (Mesalles et al., 2014). The emergence of the mountain belts and coupling with surface processes become efficient after 5 Ma in northern Taiwan and not before 3.5 Ma in southern Taiwan (Mesalles et al., 2014). Unreset apatite fission-track ages in southernmost Central Range and Hengchun Peninsula (Fuller et al., 2006; Simoes et al., 2012; Mesalles et al., 2014) argue for a slower or more recent exhumation in the region with respect to the northern Taiwan. Overall, these constraints are consistent with the obliquity of the convergence, implying that collisional uplift and exhumation in southern Taiwan is the most recent.

124 The southward propagating model places the Hengchun Peninsula as the most lately
125 emerged region in Taiwan. As a result, the evolution of the fluvial landscape is also
126 probably the most recent, but it is yet to be determined. In particular, the patterns of
127 river captures and regressive erosion along river trunk streams have never been
128 described, thus precluding further quantification of geomorphic processes.

129 The peninsula comprises folded, non metamorphic or slightly metamorphosed,
130 Middle to Late Miocene sandstones and siltstones (Fig. 2). They correspond to
131 turbiditic sequences characterized by slope gravitational instabilities sedimentary
132 features. Lenticular conglomeratic bodies with channeling forms are locally
133 abundant and can be easily identify in the landscape due to their rough topography
134 (see Fig. 2, Shimen conglomerates). They are composed of reworked Miocene
135 sandstones, basalt, gabbros and ultramafic rocks (Pelletier and Stephan, 1986). Two
136 other sandstone members can be distinguished on the northwest and southeast tips
137 of the peninsula. Adjacent to the Miocene formation, to the west, there is the Kenting
138 ophiolitic Mélange (Kenting Formation of Fig. 2), interpreted as sheared and locally
139 faulted tectonic mélange that developed from the Late Miocene to Plio-Pleistocene.

140 The studied area is the onshore equivalent of southern accretionary prism. Its uplift
141 and exhumation appear to be driven by the accretion of a transitional crust
142 composed of the extremely-thinned continental basement of the South China Sea
143 that is tectonically stacked with Miocene post-rift deposits (McIntosh et al., 2013).

144 Well-developed Holocene marine terraces containing abundant remnants of corals
145 are found along the southern and southwestern coasts of the peninsula (Lee and
146 Liew and Lin, 1987; Chen and Liu, 1993) (Fig. 2) uplifted from few to 40 meters

above the sea level. Their radiocarbon dating gives ages of 10 kyr suggesting mean uplift around 3.5 mm/yr during Holocene (e.g. Wang and Burnett, 1990). Coral platforms corresponding to Hengchun Limestone are also observed on 200-meter high cliffs of the southwestern part of the Hengchun Peninsula- Hengchun Hill (Cheng and Huang, 1975; Chen and Lee, 1990)(see Fig. 2, Hengchun Limestone). Their ages are estimated around Late Pleistocene (~100 ky) suggesting mean uplift rates around 3-4 mm/y during Pleistocene. Few recent ages are published more inland and only lacustrine deposits in Mutan Ponds low reliefs gives an age of deposition between 2 and 20 ky (Yang et al., 2011). Synchronism of inland lacustrine sediments and the uplifts of the Holocene marine terraces argue that the uplifts of the marine terraces along the coasts could impact the deposition of the Mutan Ponds within the drainage basins of the Hengchun Peninsula.

3. Geomorphic characteristics of the Hengchun Peninsula

In Taiwan, a combination of very humid and monsoonal climate coupled with active tectonics causes rapid fluvial erosion forming high-relief terrains and unstable slopes (Fuller et al., 2006; Ramsey et al., 2007; Giletycz et al., 2012). Heterogeneous character of the rock strength or uplift results in local preservation of geomorphological patterns. This particular setting gives us the opportunity to examine the response of fluvial processes and landscape adjustment to short-term/transient acceleration of subsurface deformations. Previous studies on Taiwan geomorphology show that drainage systems ultimately control the regional denudation and shape the orogen (Whipple, 2001; Wobus et al. 2006; Ramsey,

2006; Ramsey et al. 2007; Stolar et al. 2007). For example, Stolar et al. (2007) suggested that tectonic perturbations are balanced by channel response along the eastern Central Range. This contrasts with southern Taiwan where the drainage system reveals ongoing dynamic adjustment.

Because the southward propagation of the arc-continent collision is thought to occur at a rate of 55 mm/yr, Stolar et al. (2007) estimated that 1.8-2.3 Myr are required to reach topographic steady-state after emergence above the sea level. Due to the space-time equivalence, topographic steady-state becomes apparent at a distance of 100-125 km from the southern tip of Taiwan. At this latitude individual drainage basins yield rapid increase of the uplift of the southern Central Range (Ramsey et al., 2007). However, Whipple (2001) argues that the timescale for the Quaternary climate fluctuations and fast uplift is not enough to achieve topographic steady-state, thus mountainous landscapes of Taiwan have been capable only to adjust to 'mean climatic conditions'. The irregularity of the drainage system and the high asymmetry of the orogen at the Hengchun Peninsula reflect its landscape to be the youngest of the emerging Taiwan orogen.

The only geomorphological study carried out over Hengchun's Peninsula (Ramsey, 2006) indicates a dynamic drainage system rearrangement suggesting a short duration of the geomorphic response to tectonic/climatic imprint. Ramsey (2006) also suggested a lithological control for the drainage basins by the emergence of Holocene coral reef limestones along the coast (Fig. 2). The uplifted limestone acted as a barrier for sediments sourced from perched drainage basins, hence keeping the

discharge low enough to trap sediments in the upstream part of the drainage system
but this hypothesis hardly explains the initial shaping of low reliefs areas.

4. Methods

4. 1. Topographic and Relief analyses

Swath averaged-profiles of topography were built across the studied region to report the main landscape characteristics from the Central Range in the north, down to low-elevated areas of the southern Hengchun Peninsula (Fig. 3). Each profile was taken perpendicular to the divide's strike where the mean, maximum and minimum elevations of the DEM (SRTM 90) along an E-W 10 km window are projected into cross-section planes.

In order to track the mean orientations of local relief in the Hengchun Peninsula, we used a 3D analysis approach using a 5x5 m scale DEM (e.g. Ahnert, 1984) collected by the Aerial Survey Office, Forestry Bureau- Taiwan. To carefully map the low-relief areas, we adopted a circular sliding window of 5 km diameter where the mean local relief (difference between the highest point and lowest point) is reported on the center of this relief grid (Fig. 4).

Field campaigns were conducted from 2011 to 2014 to establish a direct control on geomorphological features recognized from the DEM. In particular, areas of potential river capture were investigated to evaluate the possible control by local lithological or artefacts. Overall, field surveys allowed us to improve our understanding of the incision processes in upstream regions in complement to quantitative analyses.

4.2. Steepness index and concavity index

In addition to the two-dimensional topographic analysis of river profiles we estimated the slope-area relationship that is characteristics of erosional processes. The channel slope (S) is linked to the drainage area (A) by an inverse power law such as:

$$S = k_s A^{-\theta} \text{ (Eq. 1)}$$

where (k_s) and (θ) correspond to steepness index and concavity index, respectively (Hack, 1957; Flint, 1974; Snyder et al., 2000; Lague and Davy, 2003). If we assume that fluvial erosion follows a detachment-limited erosional pattern, the erosion (E) is governed with a stream power law such as:

$$E = KA^m S^n \text{ (Eq. 2)}$$

where K represents the erodibility of rocks, A the upstream drainage area and S the local slope (Howard, 1994; Whipple and Tucker, 1999).

In the specific case of steady state where E equal uplift rate (U), equation 2 becomes:

$$S = (U/K)^{1/n} A^{-m/n} \text{ (Eq. 3)}$$

Where $(U/K)^{1/n}$ and $-m/n$ represent k_s and θ , respectively. In a log-log plot, θ , which is sensitive to the basin hydrology, corresponds to the slope of the regression line whereas k_s is the intercept. Both k_s and θ , are known to be highly sensitive to tectonic uplift (e.g., Snyder et al., 2000). The concavity θ typically varies in the small range of 0.4 to 0.6. This enables us to adopt a reference concavity index (θ_{ref}) where different stream profiles can be directly compared by a normalized steepness index (k_{sn}) (Wobus et al., 2006; Kirby and Whipple, 2012). We keep in mind that

these parameters are often deduced from an equilibrium stage of river profiles. However for transient cases the response time of rivers may be longer than the tectonic forcing as indicated by the presence of knickpoints in river profiles. In that case, one may consider that knickpoint separates an upstream section in a paleo-equilibrium stage from a downstream oversteepened part in a final equilibrium stage (Whipple and Tucker, 1999).

Here, we have adopted the automated method for extraction of steepness and concavity indexes on stream profiles developed by Whipple et al. (2007) on a ArcGIS-Matlab environment that can be freely downloaded at geomorphertools.org.

4.3. Modeling knickpoint retreat

An important point concerning the morphological evolution of Hengchun Peninsula is to evaluate if this landscape is a result of a uniform or more distributed uplift. A uniform uplift would induce a wave of regressive erosion in a radial pattern in the watersheds (Crosby and Whipple, 2006; Berlin and Anderson, 2007). By contrast, a distributed uplift would induce a mixing of wave of erosion, shifting and capture of rivers (e.g., Jackson et al., 1996).

To investigate the hypothesis of a wave knickpoint migration, we tested a knickpoint celerity model. The model predicts knickpoints position at each time step (Crosby and Whipple, 2006; Berlin and Anderson, 2007; Loget and Van Den Driessche, 2009; Gallen et al. 2013) such as:

$$V = dx/dt = CA^P \text{ (Eq. 4)}$$

where V is upstream knickpoint migration rate, C is a constant dimensional coefficient representing erodibility and efficiency of the knickpoint retreat, A is an upstream area and p is a non-dimensional constant for the power law dependence on a drainage area. We have considered a uniform erodibility at the scale of the basin as suggested by the uniform lithology of the Mutan turbidites.

We hypothesized an initial upstream area or a starting point for the knickpoint migration as the converging point of main knickpoints in the basin coupled to the presence of knickpoints in all upstream sub-watersheds. In the absence of data for incision or knickpoint migration rates, we tested two end-member classes of parameters for the modeling that fit with response time around 10^4 to 10^5 years for knickpoint migration. We used the model parameters of Crosby and Whipple, (2006) (hereafter abbreviated CW) with $V=7.9 \cdot 10^{-7} A^{1.1125}$ (that favors large upstream area with a low efficiency for knickpoint retreat) and the model of Loget and Van Den Driessche (2009) (hereafter abbreviated LVDD) where $V = 10^{-4} A^{0.5}$ (that favors small upstream area with a high efficiency for knickpoint retreat). Both models were stopped when the modeled knickpoint reach the farthest knickpoints (KP5).

4.4. Asymmetry Factor (AF) observations

To highlight the areas with potential captures, we have adopted the non-dimensional Asymmetry Factor (AF) (Hare and Gardner, 1985):

$$AF=100(A_r/A_t) \text{ (Eq 5)}$$

where, A_r represents the drainage area to the right of the main trunk stream looking downstream and A_t is the total drainage area. A symmetric catchment with a mean value of $AF = 50$ indicates equal development of the drainage basin both on the right and left side of the basin. Decrease or increase of the AF value indicates the development of asymmetry on either side of the drainage area. Such asymmetry can potentially emphasize an area where one drainage basin through a capture adopted new tributaries. In our AF analyses we targeted small drainage basins along the main divide and coasts, where the AF is more sensitive to local variances.

5. Results

5.1 Topographic and relief analyses

The Central Range of Taiwan evolves from a well-organized transverse drainage system that progressively turns southwards into asymmetrical and disordered drainage system stretched over the whole Hengchun Peninsula (Fig. 3). Across the Central Range, the highest elevation on the swath profile (mean, maximum or minimum altitudes) is located near the divide (Fig. 3a). This contrasts with the Hengchun Peninsula where the highest elevation and main divide split in two different eastern and western subdomains and associated divides (Fig. 3b).

For instance, the highest domain of the peninsula (~1000m) is observed in the Lilong Range that sets close to the western coast. Conversely, the Mutan Ponds in the eastern part of the peninsula is lower (~400m) but are located along the main divide (Fig. 3b).

304 Relief map (Fig. 4) shows that the maximum local relief (between 400 m and 800 m)
305 is located in the northwest part of the Hengchun Peninsula, in the Lilong Range. The
306 southern and eastern parts of the peninsula are characterized by an alternation of
307 moderate (between 250 m and 400m) and low reliefs (lower than 250m). Figure 4
308 further reveals that the both low and high relief domains are oriented N-S.

309 The main drainage basins are Fengkang, Sizhong and Gutou (Fig. 5). They drain over
310 60% of the peninsula's surface (of the area of $3 \times 10^2 \text{ km}^2$), while over 20 basins
311 distributed along the coasts have drainage areas in the 2 to 5 km^2 range with only
312 three basins of $\sim 1 \text{ km}^2$ and two of $\sim 20 \text{ km}^2$. The significant feature is that
313 headwaters of the two main basins (Fengkang and Sizhong) are positioned in the
314 low-relief area of the Mutan Ponds, while their outlets set at the high-relief region in
315 vicinity of the Lilong Range.

316 They drain northern and central Hengchun Peninsula and therefore are the most
317 suitable targets to examine the fluvial network response of the landscape to the base
318 level change. Gutou drainage basin at the southern part of the peninsula flows into
319 the Pacific Ocean to the east. Its whole basin is situated in the low-relief zone and
320 together with Mutan Ponds in the north form the youngest landscape of the
321 emerging wedge (Fig. 4). Headwaters of the Fengkang, Sizhong and Gutou basins
322 begin at comparable elevations of 350-400 meters, but only Sizhong and Fengkang
323 expose apparent shrinkage of the relict landscape.

324 Fengkang basin channels expose knickpoints in the upstream area. This contrasts
325 with the Sizhong basin that is characterized by a more extensive distribution of the
326 knickpoints, probably reflecting a more dynamic response to the relative base level

fall. In the Gutou basin, knickpoints are apparent only in the vicinity of the drainage divide (Fig. 5). East of the main divide, a number of knickpoints reveal advancing fluvial processes, however their irregular vertical distribution suggest different origin. Some of knickpoints located close to the main divide are related to capture events of the Sizhong basin at the Mutan Ponds area.

5.2. Long river profiles, steepness and concavity indices

River profiles are commonly used to infer the uplift pattern in active tectonic area (Snyder et al., 2000; Kirby and Whipple, 2001; Kirby and Whipple, 2012). We extracted the main profiles of Fengkang, Sizhong and Gutou (trunk and tributaries) (Fig. 6). One particular feature of these basins is that headwaters of main trunks are located at low-elevation close to the Mutan ponds and are thus at lower altitudes than their tributaries. None of three basins presents full graded or concave up profiles arguing for a transient stage. They present numerous knickpoints and knickzones that are located in the upstream part of the trunks and in the tributaries that join them at a maximum distance of 10-15 km from the headwater. Knickpoints are located at an altitude of about 300m in the Fengkang basin, between 200 and 500 m for Sizhong basin, and between 200 and 400 m for Gutou basin.

The slope-area relationship for Fengkang, Sizhong and Gutou main trunks show the same pattern with some remarkable breaks in regression lines corresponding to the position of knickpoints (Fig. 6). θ values for Fengkang river are 0.42 and 0.43 upstream and downstream of the break, respectively. We choose a value for θ_{ref} of 0.45 consistent with previous works on Taiwan (Wobus et al., 2006). This θ_{ref} value

corresponds to k_{sn} values of 7.19 and 33.4 upstream and downstream of the break, respectively. This kind of pattern with a break in the slope-area relationship and a sudden rise of k_{sn} values upstream may be interpreted as a transient profile due to an increase of uplift rate (e.g., Whipple et al., 2013). We obtained similar values for Sizhong's k_{sn} (9.52 to 30) but the increase is lower toward the south for Gutou basin (11.3 to 16.4). We also calculated k_{sn} values at the scale of the Hengchun Peninsula with the auto-ksn tool developed by Whipple et al. (2007) that allows to do regression over a specified moving window (here 0.5 km) (Fig. 7). Results obtained confirm the pattern observed with relief maps. Highest values of k_{sn} (60-200) are located in northwest part whereas lowest values (0-15) are located in the southern part and in the Mutan Ponds. With this analysis we confirm that k_{sn} values are lower in the upstream part than downstream for Fengkang, Sizhong and Gutou basins. This trend is not observed on rivers that flow toward the east. This reflects the fact that inherited low-relief domains also characterized low k_{sn} values are confined on the western side of the main divide and are incised with rivers flowing toward the west.

5.3. Modeling knickpoint retreat: Is there a wave of regressive erosion in the Hengchun Peninsula?

The only basin where k_{sn} in the main trunk is higher or in the same order than tributaries is the Sizhong basin and could correspond to a local wave of regressive erosion.

372 If one examines the map distribution of knickpoints on the Hengchun Peninsula,
373 they do not appear to follow a full radial pattern in the different watershed of the
374 peninsula except for the Sizhong basin (Fig. 5). We further notice that k_{sn} in main
375 trunks are not statistically higher than their tributaries (Fig. 7) as commonly
376 expected for a wave of knickpoint migration (Wobus et al, 2006). Results of
377 knickpoint migration modelling reveal that none of two end-member models can fit
378 both west and east sub-catchments of Shizong (Fig. 8). In the west sub-catchment,
379 the celerity model derived from the parameters used in CW model fits better the
380 position of the five current knickpoints than those derived from LVDD model. The
381 position of three knickpoints is well reproduced and the two others do not exceed 1
382 km of misfit assuming CW model for a time duration of 17 Ky. With the LVDD model
383 only one knickpoint is reproduced and four with misfit higher than 1 km for a time
384 duration of 36 ky. In the east sub-catchment, the LVDD model well reproduced the
385 position of one knickpoint and the other one with error of more than 1 km. In
386 contrast, the CW model reproduces both knickpoints within an error of more than 1
387 km and less than 1 km, respectively.

388 Two conclusions arise from the quantitative modeling of knickpoint retreat. First, if
389 our starting point of knickpoint migration is valid, then the response time according
390 to 10^4 - 10^5 celerity parameters can be estimated to about 17 Ky (according to the
391 best fit model) in the west sub-catchment of Sizhong. In the Hengchun Peninsula, a
392 wave of knickpoints migration can be observed but is limited to a local scale (here
393 $\sim 20 \text{ km}^2$) that excludes a uniform uplift of the whole peninsula. Second, knickpoints
394 migration both in the eastern and western sub-catchments cannot be reproduced

with a simple celerity modeling. By testing two end-member models that are assumed to reproduce the whole range of knickpoint regressive erosion processes, we rule out an incomplete parametric study. We rather suspect changes in the upstream drainage area that can be explained by a process of capture of one sub-catchment by another one. This piracy process could explain why the altitude of the graded part of each trunk profile, for west and east sub-catchments, is different.

5.2. River capture

A significant part of knickpoints cannot be explained by a wave of regressive erosion moving upstream and incising an uplifting inherited landscape. The observation of capture points instead is remarkable in the Hengchun Peninsula. This argues for drainage reorganization caused by piracy or capture effects, especially in the Sizhong basin where this mechanism is probably the most significant. For example, a number capture points can be observed along the main divide suggesting its westward movement. Fieldwork investigations carried out along the main drainage divide confirm very active regressive erosion upstream of the eastern drainage basins (Fig. 9).

Figure 10 shows a good example where part of the Sizhong basin was captured by eastward draining tributary of the Xuhai channel. The knickpoint observed along the western tributary is very likely a capture point as indicated by the abrupt change of flows above the knickpoints and the large inflexion of the divide (Fig. 10b, red arrow).

The upstream reaches of Xuhai basin display an asymmetrical pattern (Fig. 10c). Using the shape of the main drainage divide, flow direction of the tributaries together with assumption that knickpoints are actually capture points, we obtained a possible drainage arrangement before the capture with a symmetrical basin model (Fig. 10d).

The regressive erosion that led to river capture is not only observed at the main drainage divide. For instance, the 'pre-capture' geometry is seen in the vicinity of the downstream of the Sizhong River (Fig. 11). Zhushe tributary of the Baoli River flows nearly 100 meters above the meander of the Sizhong main channel. An outside band of the Sizhong meander undercuts a hill slope removing western tributaries of the Baoli channel. This reflects that continuous regressive erosion is currently triggering a capture by merging the upper part of the Baoli basin with the Sizhong basin. This will result in the migration of the drainage divide toward the east. A very low Asymmetry Factor ($AF = 20$) of the central and upper part of the Baoli channel confirms the role of capture dynamics.

6. Discussion

The geomorphological analysis performed on the Hengchun Peninsula argues for a transient stage of the landscape evolution of the southern Taiwan (Ramsey et al., 2007; Stolar et al., 2007). The presence of preserved low reliefs may be classically attributed to a change of uplift not yet counterbalanced by fluvial erosion (e.g., Davis, 1989). The normalized steepness indexes of rivers (k_{sn}) are also strongly correlated to relief maps (Fig. 4 and 7) with an increase of k_{sn} downstream of

knickpoints in all main trunks (Fig. 6). In steady-state conditions, high and low values of k_{sn} represent high uplift zones and low uplift zones, respectively (Snyder et al., 2000). k_{sn} values show a sudden increase in slope-area relationships along river profiles that reflect an increase of the uplift rate in transient conditions (e.g., Whipple et al., 2013). This is well documented for Fengkang, Sizhong and Gutou rivers (Fig. 6). Both geomorphic markers- low reliefs and k_{sn} distribution maps reflect a transient landscape evolution consecutive to an increase of the uplift rate. However, the location of this relict landscape seems confined to the N-S trending axial part of the peninsula, which is bounded by knickpoints. This questions the scenario of a simple rejuvenation of an antecedent drainage system. Based on a celerity modeling of knickpoint retreat, we show that only upstream Sizhong area can be explained as the result of a wave of regressive erosion through the peninsula (Fig. 8). On the other hand, we have documented numerous capture points arguing for a drainage rearrangement of the drainage system during the last uplift stage (Fig. 10). Thus, the landscape of the Hengchun Peninsula evolves as result of coupling effect of uplift-wave of regressive erosion and drainage captures. We propose to correlate this pattern to the emergence of the southern Taiwan (Suppe, 1981; Pelletier and Stephan, 1986; Liew and Lin, 1987; Ramsey et al., 2007; Stolar et al., 2007). In this case, the drainage rearrangement is not related to a 'rejuvenation' of the topography, but rather to a birth of a new landscape. The studied landscape is recent because marine deposits younger than 100 ky are today uplifted in the southern part of the peninsula (Fig. 2). Holocene coral reefs indicate a surface uplift up to 30-40 m for the last 10 ky (Peng et al., 1977; Wang and Burnett,

1990) whereas Hengchun limestone suggests a surface uplift around 100-200 m for the last 100 ky (Cheng and Huang, 1975; Chen and Lee, 1990). Assuming the southward propagating model, the ancient coastline and outlet of drainage systems was positioned between the present low-relief of Mutan Ponds and the current coastline. Consequently, before this emergence in Late Pleistocene times, the low relief of Mutan Ponds should be in a direct continuation with the coastline. The landscape during this initial period was likely composed by reduced EW-directed transverse streams, and by the N-S drainage in the Mutan Ponds area at the southern limit of the island (Fig. 12a). The presence of current low reliefs with a N-S trend in the Gutou drainage basin (Fig. 4) argues for such a physiography during this pre-emergence period. The post 100 ky emergence of the submarine morphology resulted in an asymmetrical arrangement of the drainage pattern. The sudden emersion triggers a wave of regressive erosion upstream in drainage basins that were connected to the newly emerged prism. We have documented this wave of regressive erosion in western drainage basins especially for the Sizhong basin. This kind of pattern where transverse drainages coexist with or capture inherited longitudinal paleo-drainages at the termination of tectonic emerging structures has been described in growing folds (e.g. Ramsey et al., 2008).

One other possible effect of this emerged asymmetric area to the west is the shift of the drainage divide towards the center of the peninsula, triggering the isolation of the initial low reliefs (Mutan Ponds) (Fig. 12b). Such scenario could explain the current inflection of the drainage divide inside the Hengchun Peninsula.

Then, the continuation of regressive erosion of western catchments (Fengkang and Sizhong) will eventually capture these low reliefs. If we consider an endoreic system in Mutan Ponds due to lake deposits in Holocene times up to 2 ky (Lee et al., 2010), the capture event in the upstream part of Fengkang and Sizhong could be only few thousand years old. This can explain why we observe some misfits between eastern and western sub-catchments in Sizhong basin.

As the surface uplift propagates southwards, the main drainage divide remained at the eastern flank of the peninsula. The continuous uplift of the low-relief Mutan Ponds increases incision from the east-draining basins. This wave of regressive erosion leads to the second stage of captures. As a result, the eastern basins enlarge their areas due to the west-draining catchments and consequently move the main divide to the west (Fig. 12c, red arrows). Documented captures of the east-draining basins as well as potential points of future piracies substantially support this concept (Fig. 10 and 11). However, the locations of the high and low reliefs as well as the distribution of normalized steepness index k_{sn} suggest the western low-relief terrains to be missing (Fig. 4). It can be related to a submarine topography west to the Hengchun Peninsula where the slopes are too steep to emerge a vast low-relief area or due to fast uplifts of the narrow accretionary wedge generated submarine landslides removing the west flank of the low-relief areas.

In summary, the model describing the evolution from the emerging submarine surface to the birth of a new landscape support the transient character of the Hengchun Peninsula. The drainage rearrangement pattern reveals localized waves of knickpoints retreat and shrinkage of the relict landscape as a coherent process

(Fig. 13). One of the significant assessments of this study is that the landscapes of the emerging orogens even in the short time span appear to be justified. Our geomorphological analysis and proposed evolutionary model does not allow distinguishing between the different modes of crustal accretion proposed for the Central Range of Taiwan further North: underplating of a subducted crust (Simoes et al., 2007) or ductile flow in the deep crust (Yamato et al., 2009). However, our data and results support a lack of distributed shortening/thrusting across the peninsula, in the southern Central Range. This suggests the region is uplifting as a crustal block, with shortening being accommodated by aseismic deformation in the deeper crust. This might support the onset of crustal shortening below the shallow accretionary wedge as proposed from nearby offshore observations (McIntosh et al., 2013).

7. Conclusions

In this study, we focused on the emerging topographic ridge at the southernmost tip of Taiwan orogen, which is the onboard continuity of the offshore accretionary prism. The extraction of geomorphic parameters shows a transient nature of the topography of the Hengchun Peninsula in particular attested by knickpoints distribution and steepness index of rivers. However, we demonstrate that a simple model of regressive erosion following uplift as a rejuvenation of the topography is unlikely at the scale of the entire Peninsula. Knickpoint celerity modeling shows that it is restrained to the upstream part of the Sizhong basin. On the other hand, the current asymmetrical drainage system, linked to a main divide flanked on the

eastern side of the Peninsula and where N-S low reliefs (Mutan ponds area) are pinned, is currently affected by numerous capture processes. This indicates a progressive rearrangement of the drainage system confirming the transient nature of the topography. We have proposed an evolutionary model of the Hengchun Peninsula that can explained: (i) how from an antecedent N-S drainage (due to a paleo-northern coastline) it is possible to generate low relief and offset divide (ii) then uplifted and captured by E-W transverse drainages (due to a progressive emergence and shifting coastline). In other words, the Hengchun Peninsula's topography results from a mixing between rejuvenation and drainage reorganization due to the emergence of the southern domain of Taiwan. The scale of this landscape perturbation and the lack of localized tectonic structures argue for an uplifted crustal block origin.

Acknowledgments.

This study was supported by National Science Council, Taiwan (NSC 101-2116-M-008-006、NSC 102-2116-M-008 -003、MOST 103-2116-M-008-024).

Bibliography.

Ahnert, F., 1984. Local relief and the height limits of mountain ranges. *American J. Science*, 284, 1035-1055.

- 553 Attal, M., Tucker, G.E., Whittaker, A.C., Cowie, P.A., Roberts, G.P., 2008. Modeling
554 fluvial incision and transient landscape evolution: Influence of dynamic channel
555 adjustment. *Journal of Geophysical Research*, 113, F03013.
- 556 Berlin, M.M., Anderson, R.S., 2007. Modeling of knickpoint retreat on the Roan
557 Plateau, western Colorado. *Journal of Geophysical Research- Earth Surface*, 112,
558 F03S06.
- 559 Bishop, P., Hoey, T.B., Jansen, J.D., Artza, I.L., 2005. Knickpoint recession rate and
560 catchment area: the case of uplifted rivers in eastern Scotland. *Earth Surface*
561 *Processes and Landforms* 30, 767–778.
- 562 Burbank, D.W., 2002. Rates of erosion and their implications for exhumation.
563 *Mineralogical Magazine*, 66, 25–52.
- 564 Chen Y.-G., Liu, T.-K., 1993. Holocene radiocarbon dates in Hengchun Peninsula and
565 their neotectonic implications. *Journal of the Geological Society of China*. 36(4),
566 457-479.
- 567 Chen W.-S., Lee W.-C., 1990. Reconsideration of the stratigraphy of the western
568 Hengchun Hill. *Geology*, 10, 2, 127-140.
- 569 Cheng Y.-M., Huang C.-Y., 1975. Biostratigraphic study in the west Hengchun hill.
570 *Acta Geol. Taiwanica*, 18, 49-59.
- 571 Craddock, W.H., Kirby, E., Harkins, N.W., Zhang, H., Shi, X., Liu, J., 2010. Rapid fluvial
572 incision along the Yellow River during headward basin integration. *Nature*
573 *Geoscience*, 3(3), 209–213.

574 Crosby, B.T., Whipple, K.X., 2006. Knickpoint initiation and distribution within
575 fluvial networks: 236 waterfalls in the Waipaoa River, North Island, New
576 Zealand. *Geomorphology*, 82, 16-38.

577 Davis, W. M., 1989. The geographical cycle. *Geogr. J.*, 14, 481 – 504.

578 Flint, J.J., 1974. Stream gradient as a function of order, magnitude, and discharge.
579 *Water Resources Research*, 10, 969-973.

580 Fuller, C.W., Willett, S.D., Fisher, D., Lu, C.-Y., 2006. A thermomechanical wedge
581 model of Taiwan constrained by fission-track thermochronometry.
582 *Tectonophysics*, 425, 1-24.

583 Gallen, S.F., Wegmann, K.W., DelWayne R.B., 2013. Miocene rejuvenation of
584 topographic relief in the southern Appalachians. *GSA Today*, 23, 2.

585 Garcia-Castellanos, D., 2006. Long-term evolution of tectonic lakes: Climatic controls
586 on the development of internally drained basins. *Society*, 2398(17), 283–294.

587 Giletycz, S.J., Chang, C.-P., Huang, C.-C., 2012. Geological structure as a crucial factor
588 facilitating the occurrence of typhoon-triggered landslides: Case from Hsiaolin
589 Village, 2009 Typhoon Morakot. *Western Pacific Earth Sciences*, 12, 1, 21-38.

590 Hack, J.T., 1957. Studies on longitudinal stream profiles in Virginia and Maryland.
591 *U.S. Geological Survey Professional Paper*, 294-B, 97.

- 592 Hare, P.H., Gardner T.W., 1985. Geomorphic indicators of vertical neotectonism
593 along the converging plate margins, Nicoya Peninsula, Costa Rica. *Tectonic*
594 *Geomorphology*, 4, 75-104.
- 595 Howard, A., 1994. A detachment-limited model of drainage basin evolution. *Water*
596 *Resources Research*, 30(7), 2261-2285.
- 597 Jackson, J., Norris, R., Youngson J., 1996. The structural evolution of active fault and
598 fold systems in central Otago, New Zealand: evidence revealed by drainage
599 patterns. *Journal of Structural Geology*, 18, 2-3.
- 600 Kirby, E., Whipple, K.X., 2001. Quantifying differential rock-uplift rates via stream
601 profile analysis. *Geology*, 29, 415-418.
- 602 Kirby, E., Whipple, K.X., 2012. Expression of active tectonics in erosional landscapes.
603 *Journal of Structural Geology*, 44, 54-75.
- 604 Lague, D., Davy, P., 2003. Constrains on the long-term colluvial erosion law by
605 analysing slope-area relationship at various tectonic uplift rates in the Siwalik
606 Hills (Nepal). *Journal of Geophysical Research*, 108(B2), 2129.
- 607 Lee, C.-Y., Liew, P.-M., Lee, T.-Q., 2010. Pollen records from southern Taiwan:
608 implications for East Asia summer monsoon variation during the Holocene. *The*
609 *Holocene*, 20, 1, 1-9.

610 Lin, A.-T., Watts, A.B., Hesselbo, S.P., 2003. Cenozoic stratigraphy and subsidence
611 history of the South China Sea margin in the Taiwan region. *Basin Res.*, 15, 453–
612 478.

613 Liew, P.-M., Lin, C.-F., 1987. Holocene tectonic activity of the Hengchun Peninsula as
614 evidenced by the deformation of marine terraces. *Memoir of the Geological*
615 *Society of China*, 9, 241-259.

616 Loget, N., Van Den Driessche, J., 2009. Wave train model for knickpoint migration.
617 *Geomorphology*, 106, 376–382.

618 Loget, N., Davy, P., and Van den Driessche, J., 2006. Mesoscale fluvial erosion
619 parameters deduced from the modeling of the Mediterranean sea-level drop
620 during the Messinian (Late Miocene). *Journal of Geophysical Research*, 111,
621 F03005.

622 Lague, D., Davy P., 2003. Constraints on the long-term colluvial erosion law by
623 analyzing slope-area relationships at various tectonic uplift rates in the
624 Siwaliks Hills (Nepal). *Journal of Geophysical Research*, 108 (B2), 2129.

625 McIntosh, K.D., Kuochen, H., Van Avendonk, H.J., Lavier, L.L., Wu, F.T., Okaya, D.A.,
626 2013. Two-dimensional seismic velocity models of southern Taiwan from
627 TAIGER transects. *American Geophysical Union, Fall Meeting*, T21G-05.

628 Mesalles, L., Mouthereau, F., Bernet, M., Chang, C-P., Lin, T-S., Fillon, C., Sengelen, X.,
629 2014. From submarine continental accretion to arc-continent orogenic

630 evolution: the thermal record in the Taiwan mountain belt. *Geology*. doi:
631 doi:10.1130/G35854.1

632 Pelletier, B., Stephan, J.F., 1986. Middle Miocene obduction and late Miocene
633 beginning of collision registered in the Hengchun Peninsula: Geodynamics
634 implications for the evolution of Taiwan. *Memoir of the Geological Society of*
635 *China*, 7, 301-324.

636 Peng, T.-H., Li, Y.-H., Wu, F.-T., 1977. Tectonic uplift rates of the Taiwan island since
637 the Early Holocene. *Memoir of the Geological Society of China*, 2, 57-69.

638 Ramsey, L.A., 2006. Topographic evolution of emerging mountain belts. PhD Thesis,
639 *not published*.

640 Ramsey, L.A., Walker, R.T., Jackson J., 2007. Geomorphic constraints on the active
641 tectonics of the southern Taiwan. *Geophysics*, 170, 1357-1372.

642 Ramsey, L.A., Walker, R.T., and Jackson, J., 2008. Fold evolution and drainage
643 development in the Zagros mountains of Fars province, SE Iran. *Basin Research*,
644 20, 23-48.

645 Roberts, G., White, N. J., 2010. Estimating Uplift Rate Histories from River Profiles
646 using African Examples. *Journal of Geophysical Research- Solid Earth*, 115.
647 B02406. ISSN 0148-0227

648 Rosenbloom, N.A., Anderson, R.S., 1994. Hillslope and channel evolution in a marine

649 terraced landscape, Santa Cruz, California. *Journal of Geophysical Research*, 99 (B7),
650 14013–14029.

651 Siame, L.L., Angelier, J., Chen, R.-F., Godard, V., Derrieux, F., Bourlès, D.L., Braucher,
652 R., 2011. Erosion rates in an active orogen (NE-Taiwan): A confrontation of
653 cosmogenic measurements with river suspended loads. *Quaternary*
654 *Geochronology*, 6(2), 246–260.

655 Simoes, M., Avouac, J.P., Beyssac, O., Goffe, B., Farley, K.A., Chen, Y.-G., 2007.
656 Mountain building in Taiwan: a thermokinematic model. *J. Geophys. Res.*, 112,
657 B11405.

658 Simoes M., Beyssac, O., Chen, Y.-G., 2012. Late Cenozoic metamorphism and
659 mountain building in Taiwan: A review. *Journal of Asian Earth Sciences*, 46, 92-
660 119.

661 Snyder N.P., Whipple, K.X., Tucker, G.E., Merritts, D.J., 2000. Landscape response to
662 tectonic forcing: Digital elevation model analysis of stream profiles in the
663 Mendocino triple junction region, northern California. *GSA Bulletin*, 112, 1250-
664 1263.

665 Stolar, D.B., Willet S.D., Montgomery D.R., 2007. Characterization of topographic
666 steady state in Taiwan. *Earth and Planetary Science Letters*, 261, 421-431.

667 Suppe, J., 1981. Mechanics of mountain building and metamorphism in Taiwan.
668 *Mem. Geol. Soc. China*, 4, 67-89.

669 Walker, R.T., Ramsey, L.A., Jackson, J., 2011. Geomorphic evidence for ancestral
670 drainage patterns in the Zagros Simple Folded Zone and growth of the Iranian
671 plateau. *Geological Magazine*, 148, 901–910.

672 Wang, C.-H., Burnett, W.C., 1990. Holocene mean uplift rates across an active plate-
673 collision boundary in Taiwan. *Science*, 248, 4952, 204-206.

674 Whipple, K.X., Tucker, G.E., 1999. Dynamics of the stream-power river incision
675 model: implications for height limits of mountain ranges, landscape response
676 timescales, and research needs. *Journal of Geophysical Research*, 104(B8),
677 17661-117674.

678 Whipple, K.X., 2001. Fluvial landscape response time: how plausible is steady-state
679 denudation? *American Journal of Science*, 301, 313-325.

680 Whipple, K.X., 2004. Bedrock Rivers and the Geomorphology of Active Orogens.
681 *Annual Review of Earth and Planetary Sciences*, 32(1), 151–185.

682 Whipple K.X., Wobus, C.W., Kirby, K., Crosby, B., Sheehan, D., 2007. New Tools for
683 Quantitative Geomorphology: Extraction and Interpretation of Stream Profiles
684 from Digital Topographic Data. *Geological Society of America Annual Meeting*
685 *Course Notes*.

686 Whipple K.X., DiBiase R.A., Crosby B.T., 2013. Bedrock rivers. *Treatise on*
687 *Geomorphology*. 9, 550-573.

- Whittaker, A.C., Cowie, P.A., Attal, M., Tucker, G.E., Roberts, G.P., 2007. Bedrock channel adjustment to tectonic forcing: Implications for predicting river incision rates. *Geology*, 35(2), 103.
- Willett, S.D., Brandon, M.T., 2002. On steady states in mountain belts. *Geology*, 30(2), 175.
- Willett, S.D., Fisher, D., Fuller, C., En-Chao, Y., Chia-Yu, L., 2003. Erosion rates and orogenic-wedge kinematics in Taiwan inferred from fission-track thermochronometry. *Geology*, 31(11), 945.
- Wobus, C.W., Crosby B.T., Whipple, K.X., 2006. Hanging valleys in fluvial systems: Controls on occurrence and implications for landscape evolution. *Journal of Geophysical Research*, 111, F02017.
- Yamato, P., Mouthereau, F., Burov, E., 2009. Taiwan mountain building: insights from 2-D thermomechanical modelling of a rheologically stratified lithosphere, *Geophysical Journal International*, 176(1), 307–326.
- Yang, T.-N., Lee, T.-Q., Meyers, P.A., Song, S.-R., Kao, S.-J., Löwemark, L., Chen, R.-F., 2011. Variations in monsoonal rainfall over the last 21 kyr inferred from sedimentary organic matter in Tung-Yuan Pond, southern Taiwan. *Quaternary Science Reviews*, 30(23-24), 3413–3422.

Fig. 1. Geological setting of Taiwan arc-continent collision. Left: map showing the oblique collision between Eurasia and Philippine Sea plates resulting in the progressive emergence of Taiwan orogen towards the south (red arrow). Right: geological provinces of Taiwan: CP- Coastal Plain; WF- Western Foothills; HSR- Hsuehshan Range; BSR- Backbone Slate Range; TC -Tananao Complex; LV- Longitudinal Valley; CoR- Coastal Range.

Fig. 2. Geological map of the Hengchun Peninsula (modified after CGS 1989; Chang et al., 2002; Yen, 2003; Chen et al., 2005 and others)

Fig. 3. Swath topography profiles (with 10 km window) across the southern Central Range, northern and central Hengchun Peninsula, respectively. Each profile shows focal statistics of the highest, mean and the lowest elevation, respectively. The arrows locate the boundary of the main divide. The profile B-B' shows an offset of the main divide and the highest topography point- Lilong Mt.

Fig. 4. Relief map of the Hengchun Peninsula (computed with 5 km sliding window). N-S elongated low relief stretch at the eastern part of the peninsula from Mutan Ponds southwards (blue area). Note the main drainage divide (black-dashed line) cutting across the low relief N-S trending area.

Fig. 5. Drainage basins of the Hengchun Peninsula: 1- Fengkang, 2- Sizhong, 3- Gutou basins. Red stars represent main knickpoints.

Fig. 6. Long and log/log slope-area profiles of the major basins of the Hengchun Peninsula: Fengkang, Sizhong and Gutou.

Fig. 7. Normalized steepness index (ksn) of the channels at Hengchun Peninsula 9 (concavity index θ_{ref} for all channels is 0.45)

Fig. 9. Photograph looking to the west showing active regressive erosion in the upstream part of a tributary of the Xuhai basin (see location in figure 10).

Fig. 10. Capture processes in the western part of the Xuhai basin. a) DEM with drainage of the southern part of the the Xuhai basin showing recent capture channel in orange (location in Fig. 5). (b) Knickpoint of the upper channel (red arrow) indicates the capture point (a). (c) Present setting of the Xuhai upstream. Note the flow direction of the western tributaries and curve of the main drainage divide (black dashed line). (d) Potential scenario before the capture. The Asymmetry Factor (AF) shows almost symmetrical pattern of the Xuhai upstreams. (e) High slope values of the Xuhai channel suggest dynamic incision processes what also fueled the erosion leading to the capture. White star shows the location of the tributary presented in figure 9.

Fig. 11. Capture processes of the Zhushe River (tributary of the Baoli River) by the Sizhong River (location in Fig. 5). Due to progressive erosion of the lower elevated meander of the Sizhong River, the western tributaries of the central-upper part of the Zhushe sub-basin are missing. Note very low Asymmetry Factor (AF) of the marked area (orange) *versus* whole Zhushe sub-basin. A potential capture become apparent at the marked area in orange.

Fig. 12. Evolutionary model of the Hengchun Peninsula. (a) Tip of an emerging orogen develops channels in fan-shape pattern, where N-S drainage is the future Mutan Ponds area. (b) Asymmetric emergence elongates the channels and triggers the isolation of the initial low reliefs- Mutan Ponds. (c) The continuous uplift of the low-relief Mutan Ponds increases incision from the east-draining basins leading to the second stage of captures moving the main divide to the center of the peninsula.

Fig. 13. 3-D view of the Hengchun Peninsula's topography and its main basins. White dashed line shows the main divide, a yellow line shows highest topography ridge. A dotted yellow line shows the break of the highest topography ridge.