Using multi-temporal geomorphological data to assess the denudation rate and erosion characteristics of Gutingkeng mudstone in SW Taiwan

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ABSTRACT: The south-western part of the Western Foothills is located at the deformation front of Taiwan Orogen. As the southern section of the Western Foothills is a part of incipient collision zone, the Plio-Pleistocene Gutingkeng Mudstone crops out extensively. The terraces, meanders, badlands and mud volcanoes are the most distinct landscapes in the Gutingkeng mudstone area, and this area has been known to have high rates of erosion and drastic landform changes. This study used multi-temporal geomorphological data to analyze the landform changes in Gutingkeng mudstones, and to elaborate the denudation rate and erosion characteristics in the mudstone area.

This study adopted the Digital Elevation Model generated from 1921's topographic map and 1980's Orthophoto Base Map to assess the denudation rate; and used the archived satellite images to analyze the erosion characteristics of the mudstone area; finally estimated the surface erosion rate of a reserved mud-volcano district measured by 3D ground-based laser scanner in a typhoon event.

The results showed the erosion rate of the Gutingkeng mudstone is about 39 mm/yr in the last 60 years by subtracting the 1980's DEM from the 1921's ; The bald mudstone area has extended at a rate of 2.5 km^2/yr in the last 7 years estimated from satellite image analysis and encroaches on the vegetated lands in an outward and backward fashion. Using a 3D ground-based Laser Scanner to monitor the mud volcanoes changes, the results showed a high erosion rate in the Gutingkeng mudstone of at least 9.8 cm yearly, especially when attacked by the typhoons or/and torrential rainfalls.

INTRODUCTION

The Cenozoic arc-continent collision produced the Taiwan orogeny. The oblique collision between Eurasian Plate and the Philippine Sea plate initially occurred in the northern Taiwan, and propagated towards south. The Coastal Range residing on the Philippine Sea plate acted as a bulldozer pushing the continental crust, as if pushing a soil wedge, above the décollement and formed a series of fold-and-thrust belt in the western foothills (Figure 1, Suppe, 1981). The southwestern Taiwan is located in the deformation front of the initial collision stage, and this part of the mountain range is still growing or in pre-steady-state (Lacombe et al., 2001). The southwestern Taiwan is, therefore, tectonically active as revealed by large GPS horizontal velocity in Taiwan. Yu et al. (1997) calculated the Taiwan's GPS velocity from 1990 to 1995, and the result showed the horizontal velocities in Kaohsiung and Pingtung area were only less than the Coastal Range, with the GPS horizontal velocity of 41~40 mm/yr towards west to southwest direction, and may reactivate the escape structures (Figure 2).

The Plio-Pleistocene Gutingkeng Mudstone crops out vastly over the deformation front in southwestern Taiwan and is vulnerable to erosion. Hwang (1982) analyzed the sediment records of the 76 hydrological stations in 49 major rivers of Taiwan, and then estimated the denudation rate of the watersheds. The result showed the denudation rate of the Erren River, which runs through the most of the mudstone area, is estimated as 10951 mm in the last 100 years. Dadson et al. (2003) analyzed the sediment transport of the Gutingkeng mudstone in the last 30 years, and showed the annual erosion rate is about 30 mm in Gutingkeng mudstone area and the incision rate of the Erren River is 6.4 mm/yr. Hsieh and Knuepfer (2001) using dating data of river terraces in Gutingkeng mudstone, and then deduced the incision rate of the Erren River is 10 mm/yr. The high sediment transport rate and high erosion rate indicated the southwest Taiwan is an area of rapid changes in landforms.

This study used DTM, satellite images and ground-based LiDAR to access denudation rate and erosion characteristics of the Gutingkeng mudstone in the last 80 years. This study demonstrates the potential application of geospatial techniques in geologic interests on one hand, and provides erosional characteristics of mudstone terrains in three dimensions on the other hand.

METHOD

This study using satellite images, ground-based LiDAR and digital terrain model (DTM) to analyze the Landform changes in Gutingkeng mudstone in the last 80 years. There were two 40 m-resolution DEMs compared in this study. One was generated from 1921's Japanese topographic map and the other was made from aerial photo provided by Aerial Survey Office, Forestry Bureau of Taiwan. The DEMs were used to estimate the volumetric changes, erosion rate and bald area encroachment of mudstone area in the last 60 years. This study collected 4 satellite images of Gutingkeng mudstone from 2004 to 2011, then used supervised classification to detect the bald mudstone area and calculated the areal changes. Finally, the ground-based LiDAR and Virtual Reference Station-Global Positioning System (VRS-GPS) were used to establish the DEM of mud volcano cones in Wushanding Mud Volcano Nature Reserve, and then to estimate the erosion rate of mudstone area by comparing the DEMs of different date.

RESULT

The mass volume loss was estimated about 21128 million square meters in the last 60 years by subtracting 1980's DEM from 1921's, the elevation decreased averagely 233 cm, and the erosion rate were 39 mm/yr in the area studied. Figure 4 shows the distribution of cuts and fills, and locations where elevation difference more than 20 m were drawn in red or blue, and other areas were assumed no change in elevation. The cut areas in mudstone were found on southeast slope of the hills, while the fill areas were on northwest slope. Figure 5 is the virtual 3D map of the Gutingkeng mudstone, which shows the bald areas were located on southeast slope of the hills and conforms the results from DEM subtraction. This study further deduced the bald mudstone area encroaches on the vegetated lands in an outward and backward fashion.

The bald mudstone areas were estimated 24.9 km^2, 29.8 km^2, 39.6 km^2 and 42.6 km^2 in 2004, 2008, 2009 and 2011 respectively from the corresponding satellite imageries. The bald area increased almost 17.7 km^2 in the 7 years, and the encroaching rate is about 2.5 km^2/yr (Figure 6). The constant encroachment may be attributed as natural processes other than anthropogenic agents. The bald area increased the most between years from 2008 to 2009 with a total area of 9.8 km^2 and were possibly caused by typhoon Morak which yields 650 mm precipitation in 48 hours.

There were seven 3D ground-based Laser Scanning carried in Wushanding Mud Volcano Nature Reserve from 23 January, 2007 to 7 December, 2011(Figure 7). The height and volume of the Mud volcanoes were estimated as much as 27 cm and 49.6 m^3 during the typhoon Fanapi, an erosion rate surpassing the annual average rate.

CONCLUSION

This study estimates the erosion rate of the Gutingkeng mudstone with about 39 mm/yr in the last 60 years , which conforms the erosion rate estimated by other geologic methods. The bald mudstone area has extended at a rate of 2.5 km^2/yr in the last 7 years estimated from satellite image analysis and encroaches on the vegetated lands in an outward and backward fashion. Using a 3D ground-based Laser Scanner to monitor the mud volcanoes changes, the results showed a high erosion rate in the Gutingkeng mudstone of at least 9.8 cm yearly, especially when attacked by the typhoons or/and torrential rainfalls. This study also confirms the application of geospatial techniques to such issues as regional erosion rate and denudation pattern is feasible and more effective.

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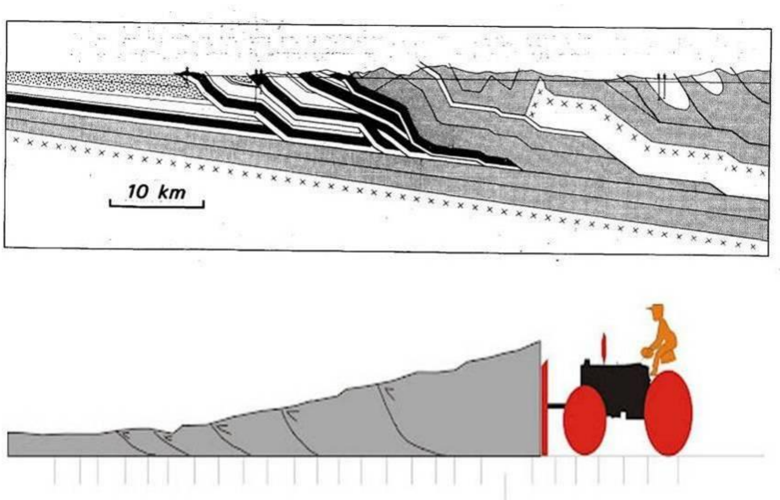

Figure 1: the fold-and-thrust belt was development above décollement in the western foothills (Suppe, 1981).

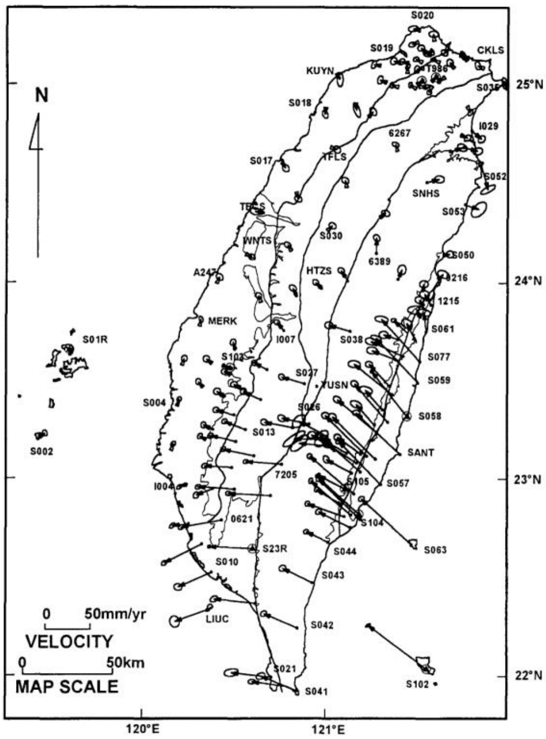

Figure 2: The horizontal GPS velocity field relative to Baisha, Penghu (S01R) of Taiwan (Yu et al., 1997).

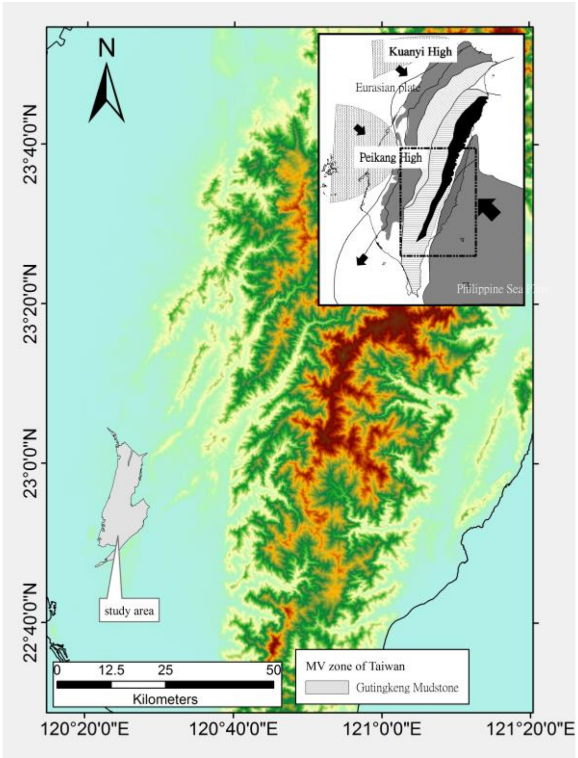

Figure 3: The study area is Gutingkeng mudstone where located in southwest Taiwan.

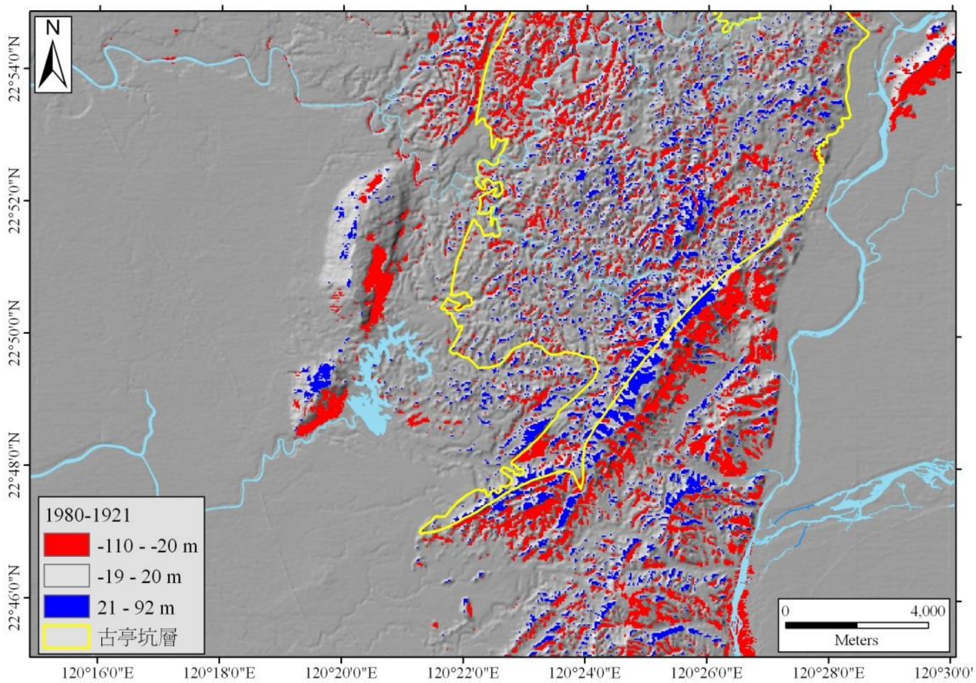

Figure 4: Subtract from 1980 and 1921's DTM, red and blue polygons represent decrease and increase mass volumes respectively.

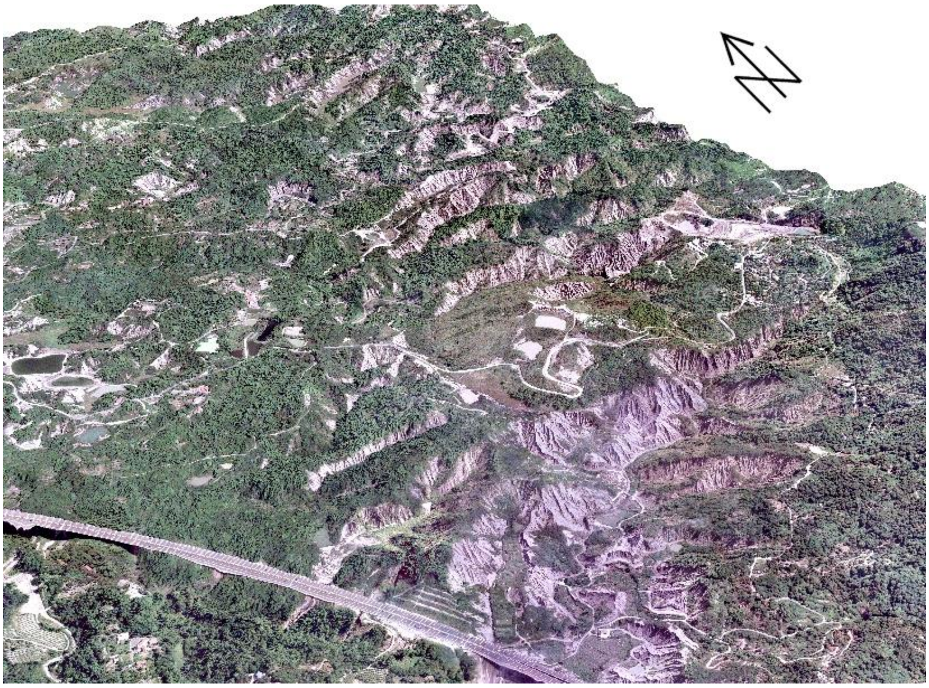

Figure 5: The virtual 3D map of the Gutingkeng mudstone, the bald area mainly occupied in south facing slope. (view direction from southwest to northeast)

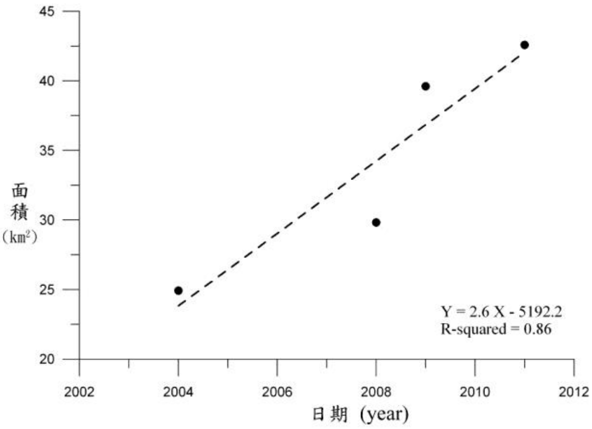

Figure 6: The bald area in Gutingkeng mudstone from 2004 to 2011.

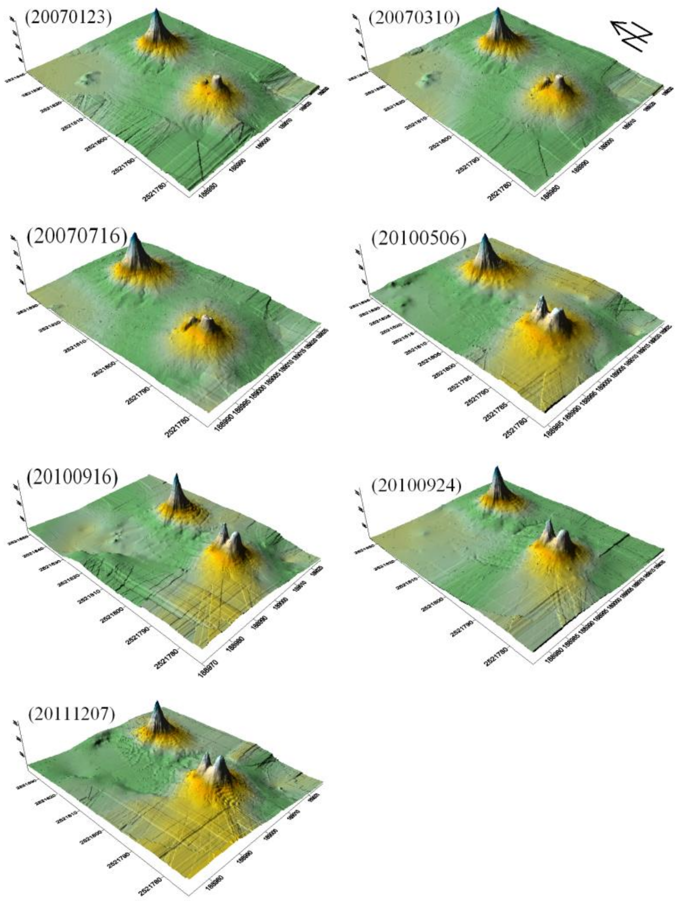

Figure 7: The results of 3D ground-based scan in Wushanding Mud Volcano Nature Reserve. (in order to enhance the landform characterize, the vertical component were increased three times)