Soilscape of the west-central Taiwan — the footprints on soil pedogenesis and geomorphic environment

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Abstract
There are five different types of soils including Entisols, Inceptisols, Arfisols, Ultisols, and Oxisols, distributed in west-central Taiwan. They cover the surfaces belonging to three major geologic terrains namely the Pleistocene anticline, the Holocene coastal plain, and the modern alluvial fan. This study demonstrates the mosaic pattern of the soil distribution may help to identify the extents and boundaries between geologic terrains, and to resolve the environmental changes due to complex fluvial migration. The informative soil mapping is achieved by properly grouping certain soil units based on genetic relationship between soil properties and the geomorphic environment. Moreover, the chronological data from archaeological and geological studies in the area is used as time constraints to envisage the progressive development in soil pedogenesis through time.

Key Words
Entisols, Inceptisols, Arfisols, Ultisols, Oxisols.

Introduction
Soil is earth material subject to the formation processes that involves the factors of climate, organism, topography, parent material, and time (Jenny 1941), which leads to a wide variety of compound in composition and structure from place to place. Among the total of 12 soil orders in *Soil Taxonomy*, the island of Taiwan contains 11 of them distributed on the surfaces of various landforms developed by active tectonics since Plio-Pleistocenc. The wide diversities on both soil and landform in Taiwan provide an excellent environment and opportunity to the inter-discipline study of pedology and geomorphology (eg., Tsai *et al.* 2006, 2007a, b, c, 2008; Hseu *et al.* 2007). The goals of this study is to (i) establish an up to date soil database, (ii) identify the extent and boundary in each terrain, (iii) reconstruct the fluvial environment on the Choshui alluvial fan, and (iv) envisage the progressive development of pedogenesis.

Geology and soil distribution
There are five soil types, including Entisols, Inceptisols, Arfisols, Ultisols, and Oxisols, developed in west-central Taiwan. They cover the surfaces belonging to three geologic terrains namely Pleistocene anticlines, Holocene coastal plain and modern alluvial fan (Lin 1957; Ho 1986; CGS 2004) (Figure 1). The alluvial fan was developed on the coastal plain with frequently floods and river migration resulting in ambiguous terrain boundaries (Chang 1983,1985). Moreover, there are river terraces developed on these anticlines, where surface soils forms a typical post-incisive type of soil chronosequence.

Geomorphic expression and time constraints
The fundamental unit of the soil database in this study was based on taxonomic class of soil series, which allows different levels of map units in soil mapping. However, the soils mapped with the unit of low hierarchical classes show detail fabrics in a very complex mosaic. With properly grouping of the soil units based on the genetic relationship between soil properties and geomorphic environments, the geomorphic expression for each grouped soil variety provides a useful tool to locate the position or landform of the environment. In this study, the pattern of the fabrics based on taxonomic class of great group is adequate in detail for the geomorphologic purpose, and is therefore used in our soil mapping. The geomorphic interpretation for the soil varieties distributed in the study area was based on Buol *et al.* (1997) (Table 1) (Figure 2). Moreover, there are chronological data in the geological and archaeological studies, which can be used as age or time constraints in studying both the pedogenic process during soil development and the geomorphic evolution.

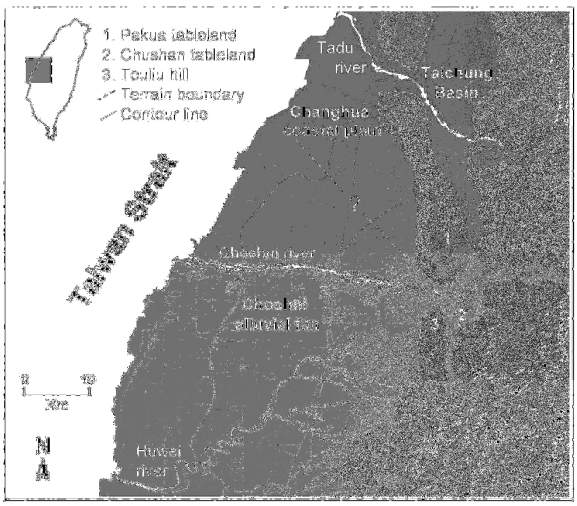

Figure 1. The shaded relief map of the study area.

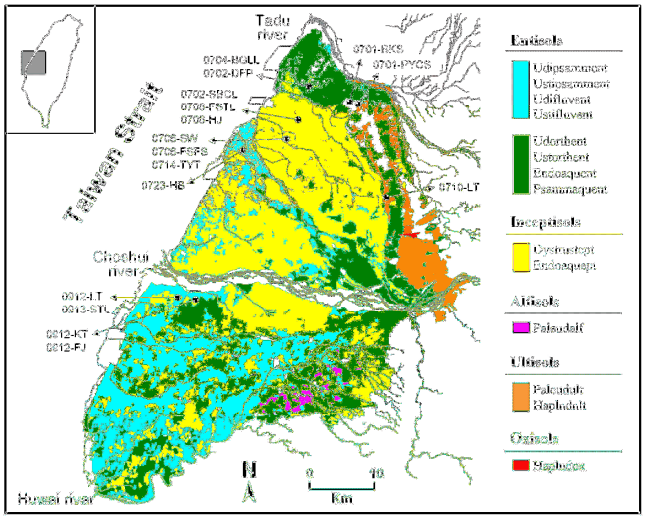

Figure 2 The soil map of the study area. The solid circles with arrow indicate the excavated archaeological sites.

Table 1. Taxonomic definition and corresponding geomorphic interpretation for the soils distributed in west-central Taiwan.

Soil taxa	Brief definition*[1]	Geomorphic interpretation*[2]
Entisols		
Udipsamment Ustipsamment	Soils have textures of loamy fine sand or coarser and are better drained than Aquent.	The islands, bars and river banks positions in the floodplains of rivers.
Udifluvent Ustifluvent	Soils are loamy and clayey (fine in texture than loamy fine sand) alluvial soils with very simple profiles. Irregularity of content of organic matter with depth is diagnostic. Stratification is common in alluvium and in soils derived from it.	The natural levee positions in the floodplains of rivers.
Udorthent Ustorthent	Soils are loamy and clayey Entisols with a regular decrease in content of organic matter with depth.	The higher dryland positions in the floodplains of rivers.
Endoaquent	Soils are permanently or seasonally wet (saturated) and even if artificially drained, which display bluish gray redoximorphic features.	The backwater lowland in the floodplains of rivers.
Psammaquent	Soils that have less 35% rock fragments and a texture of loamy fine sand or coarser are permanently or seasonally wet (saturated) and even if artificially drained, which display bluish gray redoximorphic features.	The backwater lowland in the floodplains of rivers.
Inceptisols		
Dystrudept	Soils have ochric epipedons.	The upland positions on young geomorphic surface.
Endoaquept	Soils have redoximorphic features and are saturated with water at some period in the year unless artificially drained.	The lowland positions on young geomorphic surface.
Arfisols		
Paleudalf	The depth of mineral soils with fine texture is greater than 150 cm, and soils have an argillic horizon with hue of 7.5YR or redder and chroma of 5 or more.	Landform surface was abandoned and has not been disturbed by fluvial processes for the past thousands of years.
Ultisols		
Hapludult	Soils with base saturation of less than 35% have argillic horizon.	Terrain of alluvial terraces in a steady state system of weathering, erosion, and isostatic uplift over a time span of ten or hundred thousand years.
Paleudult	Soils with base saturation of less than 35% have argillic horizon. And, relative clay content decreases less than 20% within 150 cm of the surface.	Terrain of alluvial terraces in a steady state system of weathering, erosion, and isostatic uplift over a time span of ten or hundred thousand years.
Oxisols		
Hapludox	A soil pedon with udic moisture regime contains 40% or more clay in the surface 18cm and CEC over clay is 16 cmol/kg or less.	Relatively stable upland summit positions, relict from a previous regional erosion surface, or on preserved remnants of an oldest alluvial terrace or pediment.

*1: based on Soil Survey Staff (2006)
*2: from Buol *et al.* (1997)

Progressive pedogenic development

The effective time interval for forming each soil in taxonomic class of soil is critical, information for estimating soil age. For instance, soil ages of ≧1300 and 19000 years for the Inceptisols distributed on the Changhua coastal plain and the Pakua tableland suggest the required time for development of Inceptisols. A longer period of time is required for Inceptisols to develop into Ultisols, and the soil age of more than 300 ka for Oxisols give a maximum time constraint for Ultisols. The minimum age of the Ultisols lies between 1.9 and 30 ka. As a result, the developmental sequence of soil pedogenesis based on time constraints is established for soils ranging through from Entisols, Inceptisols, Ultisols, to Oxisols (Figure 3).

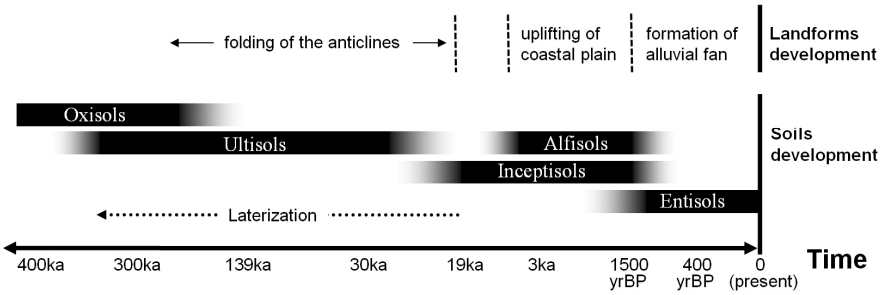

Figure 3. Soil development through time in Taiwan. Note that the timeline is not linearly indicated.

Concluding remarks

A landform with Inceptisols is expected to be older than that with Entisols formed during geomorphic evolution. The boundary between Inceptisols and Entisols observed in this study area distinguishes the geologic terrains between the Changhua coastal plain and the Choshui alluvial fan, which supports the idea that the alluvial fan was built on and above the coastal plain. The sediments discharged by the Choshui River covered most of the coastal area. However, this area may have been exposed by tides until its uplift in the middle Holocene. The coastal area received a massive deposition of alluvium from the Choshui River, which built a massive alluvial fan on the coastal plain. The pedogenic intensity of the reddish soils developed on the anticlines grades from Inceptisols, Ultisols, to Oxisols depending on the increasing altitude of the terrace surfaces on the anticlines. This study demonstrates soil varieties and their mosaic distribution may help to identify not only the extent of each geologic terrain but also the Paleo-environment of the west-central Taiwan. With chronological constraints, the genetic relationship between soils and landforms may reveal the progressive development of pedogenesis through time.

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