J. Mt. Sci. (2009) 6: 205–210
DOI: 10.1007/s11629-009-1038-y

Tillage Pedogenesis of Purple Soils in Southwestern China

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Abstract: Land cultivation and tillage process, and their consequent impacts on soil erosion, have been criticized as the main cause of degradation of land or soil quality. However, purple soils, classified as Regosols in FAO Taxonomy or Entisols in USDA Taxonomy, are formed from purple rocks of the Trias-Cretaceous system, have been developed or at least accelerated the development due to continual tillage operation, especially digging and ridging. The present study took micromorphological investigation on the sedimentary rocks and the soils under different operations of tillage. Results show that the purple rock of Feixiangguan Formation of the Trias system (T1f) is the easiest to physical weathering and the most fertile soil material enriched in nutrients, and it has been, therefore, mostly cultivated and intensively tilled around the year. It has the fastest soil formation rate. Soil formation rate in the cropland with conventional tillage is higher than that in the forestland and the grassland. It implies that the artificial brokenness and tillage disturbance play a great role in physical weathering and initiating soil formation processes.

Keywords: Tillage impact; pedogenesis; purple soil; micromorphology; southwestern China

Introduction

Soil tillage practices can influentially manipulate or alterate soil properties and processes dynamically in space and time, especially in the regosol areas with long agricultural history (Strudley et al. 2008, Gao et al. 2008). Land cultivation and tillage process, and their consequent impacts on soil erosion, have been criticized as the main cause of degradation of land or soil quality (e.g., Pennock et al. 1994, Lal 2001). However, purple soils in China have been developed or at least accelerated the development due to continual tillage operation, especially digging and ridging. And in this way, the soil fertility and quality are maintained as nutrients are released in the weathering process of purple rock fragments (Li 1991). The purple soils cover an area about twenty million hectares in China, mainly in southwestern China. Due to their rapid weathering, complexity of mineral composition, richness of nutrients and loam in texture, the purple soils are valuable soil resource with high fertility and suitability to various crops. At the same time, poor capability of anti-drought, severe soil erosion and serious land degradations are also predominant in the purple soil region (He 2003). However, a little is known about the pedogenesis and classification of those significant purple soils (Li 1991, He 2003). The present paper gives a brief introduction on those soils and presents micromorphological investigations on the sedimentary rocks and soils under different operations and durations of tillage.

Received: 29 January 2009
Accepted: 14 March 2009

1 Geology of Purple Rocks and Purple Soils

The purple rocks are sedimentary material with purple color, and they had been developed from the Triassic to the Tertiary. Its thickness reaches to 1.2 thousand km, but only half of those sedimentary strata is exposed in southwestern China (Table 1). They consist of the dark purple shale of Feixiangguan Formation of the Trias system (T1f), brown purple sandy mudstone of Penglai Formation (J3p), red brown purple mudstone of Suining Formation (J3s), and gray brown purple sandy mudstone of Shaximiao Formation (J2s) of the Jurassic system. The dark purple shale of Feixiangguan Formation of the Trias system (T1f) is genetically marine sediment, while the others are lacustrine ones (Li 1991). Those sedimentary rocks are very prone to physical weathering, and the most fertile soil material enriched in nutrients. Therefore, they have been mostly cultivated and intensively tilled around year. Plants could directly grow in the rock fragments and one season is enough to make the fragments changed into soil. The long-term and well-developed soils hold sound texture and structure for nutrient release and water infiltration (Li 1991, Zhu et al. 1999, Liu et al. 2009)

The purple soils developed from the Trias-Cretaceous system of sedimentary rocks are characterized by lithologic soils without distinct pedogenic horizons. They have been classified as Orthic Entisols in the Chinese Soil Taxonomic System, Regosols in FAO Taxonomy or Entisols in USDA Taxonomy. A well weathered purple soil usually contains about 15 % clay with 1.7 % organic matter, 0.07 % total nitrogen and 0.06 % total phosphorus (He 2003).

2 Agriculture System and Tillage Operation

The purple soil regions are mostly characterized by hilly or low-mountain landscape (Figure 1), mainly in the Sichuan Basin. The

Figure 1 Geomorphologic features of purple soils (a, horizontal strata of the sedimentary rock; b, slant strata of the sedimentary rock; c, agricultural landscape of purple soils)

Table 1 Geological rock system of the purple soil parental material (Li 1991, Sichuan Soil Survey Group 1997, He 2003)

Era & Periods		Stratum (Formation)	Profile Description
Cenozoic	Tertiary	Yuguangpo (E_3^3)	Reddish-brown mudstone interbedded with reddish-brown pelitic, dark purple,ash black mud shale mudstone
		Jiaguan (E_3^2)	Reddish-brown mudstone interbedded with 3-4 layers argillaceous and micropsammite siltstone
		Lushan (E_2^1)	Salmon pink calcareous siltstoneinterbedded with orange red and olivine siltstone and pelitic siltstone
		Lumeiyi ($E_2$1)	Reddish-brown arenaceous mudstone interbedded with conglomeratic gritstone
		Xiaotun (E_1x)	Reddish-brown argillaceous sandstone interbedded with arenaceous mudstone
Mesozoic	Cretaceous	Jiangdihe (K_3j)	Fuchsia calcareous-silty mudstone interbedded with variable thickness of calcareous siltstone, pelitic fine sandstone
		Guankou (K_3g)	Reddish-brown calcareous-pelitic siltstone and arenaceous mudstone interbedded with mottled mudstone and thin seam of marlite
		Matoushan (K_2m)	Lumpy of reddish-brown mudstone and calcareous interbedded with zebraic purplish grey arenaceous shale and layers of reddish-brown siltstone and purplish grey feldspathic arenaceous quartz rock
		Jiaguan (K_2j)	Grayish yellow purple clumpy calcium sandstone interbedded with lamella mudstone
		Jiange (K_1j)	Pale-violet-red hoariness sandstone interbedded with pelitic siltstone and mudstone
		Puchanghe (K_1p)	Fuchsia mudstone and calcareous interbedded mixed with fine sandstone and marlite
		Jianmenguan(K_1j)	Thick seam of fuchsia sandstone interbedded with arenaceous mudstone and mudstone
	Jurassic	Lianhuakou ($J_3$1)	Brick-red mudstone interbedded with variable thickness seam of conglomerate and calcific sandstone
		Penglaizhen (J_3p)	Purplish grey quartzitic sandstone and brown-purple calcific sandstone interbedded with brown-purple mudstone
		Suining (J_3s)	Thin microlayered of brick-red calcareous-clayey siltstone interbedded with silty claystone
		Tuodian (J_3t)	Fuchsia arenaceous mudstone interbedded with sandstone and fine sandstone
		Guangou (J_3g)	Fuchsia calciferous-arenaceous mudstone interweaved with yellow mudstone, offwhite calcareous siltstone and quartzitic siltstone
		Shaximiao (J_2s)	Grayish-purple marlaceous and feldspar-quartz sandstone interbedded with fuchsia arenaceous mudstone
		Shaximiao (J_2s)	Purple arenaceous shale in the upside, black petroliferous shale in the middle, yellow-green shale and arenaceous shale in the underside
		Shanglufeng ($J_2$1)	Interbedding of brown siltstone, mudstone and marlite in the upside, interbedding of siltstone and mudstone in the underside
		Xialufeng ($J_1$1)	Dark-purple and dark-brown mudstone interweaved with siltstone
		Ziliujing (J_{1-2}z)	Mudstone (maroon, cadmium-red, grey-purple) interbedded with quartz sandstone (grayish-brown, gray)
	Triassic	Feixianguan (T_2f)	Purple mudstone interweaved with lamella green-grey marlite, or interbedded with calcareous mudstone
		Dongchuan (T_1d)	Thick seam of yellow fine sandstone and arenaceous shale

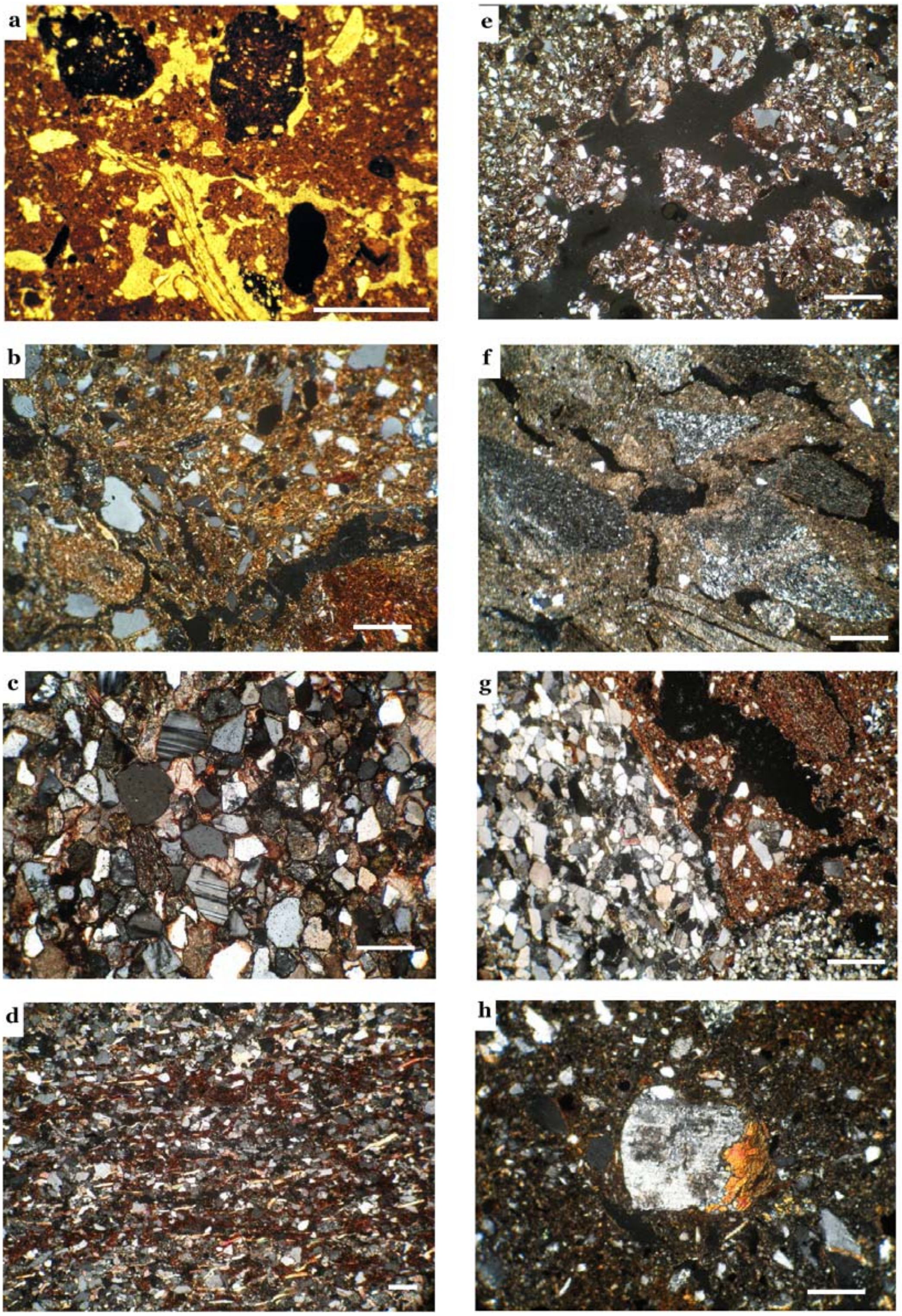

Figure 2 Micromorphological features of different weathering stages of the purple soils (a, the organic residue (black-brown) granules of amorphous material and living plant roots; b, quartz and feldspar grains surrounded by opaque matrix of iron and manganese oxides; c, fresh sandy rock of parental material; d, reddish-brown mudstone of parental material; e, strongly weathered and very fine angular blocky structure; f, rock fragments by physically broken or weathering; g, half weathered rock fragments; h, strongly weathered quartz grains) (scale bar 500 μm).

climate is subtropical with annual mean temperature of 17-18 °C and annual mean precipitation of 1000-1400 mm. Most of the rainfalls occur during the raining season from May to August (Li 1991). Due to the fertile purple soils and favorable subtropical climate, the purple soil region in the Sichuan Basin, is one of populous agricultural regions in China. But slope land in the basin accounts for more than 60 % of the cultivated land, about 20 % of which is steep slope land of > 25°. Because of high population density, cropland shortage, high cropping intensity and the purple soil prone to erosion, the basin is also one of severest eroded regions in the Upper Yangtze River Basin (He et al. 2007, Zheng et al. 2007, Ni and Zhang 2007). There has been a long history of agriculture operating with both animal-drawn and manual tillage, such as hoeing. The main crops are rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), rape (*Brassica napus* L.), and sweet potato (*Ipomoea batatus* Lam.) (Sichuan Soil Survey Group 1997).

3 Impact of Tillage on Pedogenesis of the Purple Soils

According to long-term observation data (Zhu et al. 1999; Liu et al. 2009; Li et al. 2009), the cropland with conventional tillage, forestland and grassland have soil formation rates of 3005, 2497, and 2036 $t \cdot km^{-2} \cdot a^{-1}$, respectively. As to the exposed parent materials of the rock fragments, the soil formation rates range from 8300 $t \cdot km^{-2} \cdot a^{-1}$ to 15,800 $t \cdot km^{-2} \cdot a^{-1}$. It implies that artificially brokenness and tillage disturbance play a great role in physical weathering and initiating soil formation processes (Figure 2), although the roots of trees and grasses in the bedrock also could accelerate both the physical and bio-chemical weathering processes. But parent materials have a significant impact on soil formation rate due to their different characteristics, such as the water absorption rate, Si/Al element ratio of the clay, and the eluviation coefficient (the ratio of Silica-oxide) (Li 1991; Liu et al. 2009). Under the similar weathering condition and water regime (Controlled by micro-plots), the soil formation rates of the different parent materials were in the order of J2s > J3p > J3s (Liu et al. 2009). Figure 2 shows the micro-morphological features of different weathering stages of the soils.

It seems that farmers know those phenomena better. They prepare the land with level trenches at each distance of 4 to 7 meters. The distance depends on the slope gradient, that is, the steeper slope with shorter distance. The trenches are general 30 cm deep and connected with one end or both ends to the hill-side ditches or to runoff tanks. The trenches can also be become deeper and serviced as level ditch channels (He et al. 2007). Those operations generally form the grids of trenches and ditches, serving as to (1) expose the deep bedrock and enlarge the exposing surface; (2) divide a slope land into relatively homogenous units for an appropriate crop; (3) intercept surface runoff and lead it to hill-side ditches, water tanks or stream gullies; (4) stop rill erosion by shortening the slope length and reducing velocity of runoff; and (5) temporarily trap sediment in rainy season. The ditches sometimes were dug for near one meter deep and filled with manures or bio-residue such as straws.

4 Conclusions

A range of studies by both field and micromorphological investigations have indicated that long-term tillage effects result in a modification of soil profiles and spatial patterns. The purple soils in southwestern China formed from purple sedimentary rocks of the Trias-Cretaceous system which are very prone to physical weathering, have been developed or at least accelerated the development due to continual tillage operation, especially digging and ridging. Local farmers even prepare their land with the grids of deep trenches and ditches to get faster physical weathering of the rock fragments. With the long history of agriculture, tillage practice has been an important driving force on pedogenesis of the purple soils in Southwestern China.

Acknowledgements

This study was supported by the CAS West-Developing Initiative (Grant No. KZCX2-XB2-07) and the Key Technologies R & D Program of China (Grant No. 2008BAD98B04).

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