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PALEOSOLS AND THEIR REFLECTION OF THE ENVIRONMENTAL CHANGES IN THE NORTHEAST REGION OF THE QINGHAI-XIZANG PLATEAU

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ABSTRACT: Based on field investigations, laboratory analyses and ^{14}C dating, this paper discusses the laws of the formation and development of the paleosols in the northeast region of the Qinghai-Xizang Plateau since Late Pleistocene. The authors reconstruct basic conditions of climate, vegetation, soil and natural zones during the three periods in which the paleosols were formed, i.e. the last interglacial of the Late Pleistocene, warm stage of Late Glacial and the Optimum of Holocene. Finally, this paper discusses the relationship between the paleosols and the uplift of the Qinghai-Xizang Plateau.
KEY WORDS: Paleosol, environmental change, the uplift of the Qinghai-Xizang Plateau

The northeastern Qinghai-Xizang Plateau, being a transitional region between the high-cold zone of the Qinghai-Xizang, the arid zone of the Northwest China and the monsoon zone of the Eastern China, is very sensitive to the environmental changes. Environmental changes in the last geological period have important influences on paleosol development. Based on the field investigations, laboratory analysis and dating of the samples collected from more than 30 paleosol sections, this paper try to discuss the formation and development of paleosols, basic characteristics of the natural environment during the periods of paleosol development in late Quaternary and the relationship between paleosol development and tectonic uplift in the northeast Qinghai-Xizang

Plateau.

I. THE DISTRIBUTION CHARACTERISTICS OF PALEOSOLS IN TIME AND SPATIAL SCALE

The geomorphic frame of the northeast Qinghai-Xizang Plateau is composed of a series of mountains and basins (or plateaus), being parallel each other. The paleosols, various of ages and types, are widely distributed on pediments of mountains, basins and plateau surface (Fig. 1, Table 1).

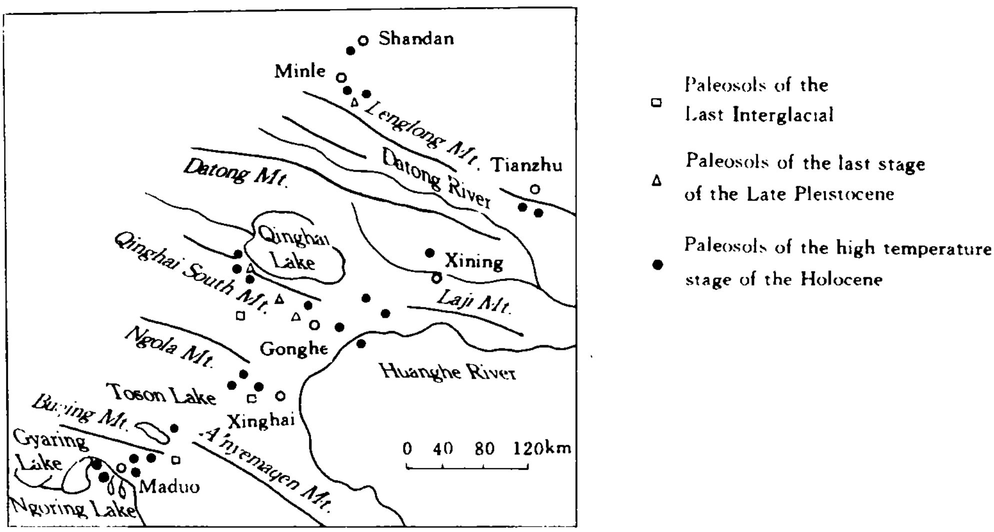

Fig. 1 Distributions of the paleosols in the northeast region of the Qinghai-Xizang Plateau

Table 1 shows that the altitudes of paleosols range from 2,000 m to more than 4,000 m in the study region. The paleosols can be found not only on passes of mountain, pediment plains, fluvial fans, alluvial and lacustrine terraces, but also at top of inactive dunes and till hills. Most of paleosols are buried relics of soils, their parent material is very complex, various from alluvial, pluvial, glaciofluvial, lacustrine, aeolian deposits to till, but mainly sandy sediment.

Absolute ages has shown that the paleosols were mainly formed in the following three periods in the northeast Qinghai-Xizang Plateau.

(1) The periods of the Late Pleistocene-before the Last Glacial Maximum (LGM), including the last interglacial (140—80 ka B. P.) and interstitial of the Last Glacial (50—30 ka B. P.).

(2) Warm period of the Late Glacial (14—10 ka B. P.) between LGM and

Table 1 The schedule of distribution of the paleosols in the Northeast Qinghai-Xizang Plateau

No.	Sites	Altitude (m)	Position	Parent material	Age (a B. P.)
1	Ngoring L.	4265	Sandy dam	Lacustrine sand	^{14}C 5735±75
2	Xingxinghai	4275	Lake terrace	Lacustrine silt	^{14}C 5540±65
3	Maduo	4215	Inactive dune	Aeolian sand	^{14}C 8800±100
4	Tosou L.	4080	Lake terrace	Lacustrine silt	^{14}C 7534±80
5	Huashixia	4200	Till hill	Sand gravel	TL 135,700±10,500 (below)
6	Maqu	3470	pediment plain	alluvial sand	^{14}C 6500±100
7	Maqu	3480	T_2 of Yellow River	Alluvial sand	^{14}C 2485±85
8	Gonghe	2890	Inactive sand dune	Aeolian sand	^{14}C 6180±80
9	Gonghe	2885	Fluvial terrace	Alluvial sand	^{14}C 7530±84
10	Gonghe	2990	Fluvial terrace	Alluvial sand	^{14}C 3420±72
11	Gonghe	2880	Fluvial terrace	Alluvial clay	^{14}C 4605±58
12	Gonghe	3100	Pediment plain	Fluvial sand	^{14}C 11210±150
13	Guinan	3180	Fluvial pediment plain	Fluvial silt	^{14}C 1341±67
14	Gonghe	2905	Fluvial terrace	Alluvial sand	^{14}C 14200±180
15	Xinghai	3440	Fluvial plain	Alluvial sand	^{14}C 30,100±2600(up) TL 135,700±500(below)
16	Xinghai	3595	Inactive sand dune	Aeolian sand	^{14}C 6220±66
17	Gonghe	2950	Pediment plain	Fluvial sand	^{14}C 27.6±75
18	Daotang R.	3280	Inactive sand dune	Aeolian sand	^{14}C 3960±100
19	Jiermeng	3325	Terrace of Buha R.	Alluvial sand	^{14}C 3300±130
20	Heima R.	3400	Fluvial plain	Alluvial sand	^{14}C 10290±120
21	Heima R.	3400	Fluvial plain	Alluvial sand	^{14}C 4730±50
22	Heima R.	3400	Fluvial Plain	Alluvial sand	^{14}C 840±50
23	Tianzhu	2990	Fluvial fan	Fluvial sand	^{14}C 3520±70
24	Tianzhu	2990	Fluvial fan	Fluvial fan	^{14}C 6350±140
25	Minle	2800	Fluvial plain	Alluvial sand	^{14}C 11280±110
26	Minle	2800	Fluvial plain	Alluvial sand	^{14}C 6210±90
27	Minle	2800	Fluvial plain	Alluvial sand	^{14}C 2480±60
28	Shandan	2650	Fluvial fan	Fluvial sand	^{14}C 4000±80
29	Riyue Mt.	3650	Mountain pass	Slope sand	^{14}C 4920±80
30	Xiangpi Mt.	3950	Mountain pass	Slope sand	^{14}C 3590±90
31	Ela Mt.	4220	Fluvioglacial plain	Fluvioglacial sand	^{14}C 7134±65
32	Ela Mt.	4210	End moraine	Loess	^{14}C 5030±70

Holocene.

(3) The Optimum of Holocene (75—3 ka B. P.) before Neoglacial.

Up to now, paleosols developed before the Late Pleistocene have not been found in the study region, which indicates that remaining of paleosols were firmly controlled by landform and time. The older the age of paleosol is, the more seriously paleosol was destroyed, and it is difficult to remain. Therefore, a few of paleosols of the Last Interglacial were found. The younger the age of paleosol is, the more complete the remnant of paleosol is. So the most of paleosols, found in the study region, were formed in the Optimum of Holocene. Under the effects of plateau uplift, intense erosion made above trend more obvious.

II. THE TYPES AND EVOLUTION OF PALEOSOLS

1. Paleosols Formed before LGM

The Paleosol in Dahebatan of Xinghai Basin, developed in fluvial plain of foothills, is an example of this type (Fig. 2). The strata at the bottom of the profile is sandy gravel bed of Gonghe Formation deposited in early and middle Pleistocene, in which ice wedge casts were developed. A TL date of fine sand in a wedge is 135.7±10 ka B. P. A 20 cm thick brown-red paleosol, overlying on the erosion surface at Gonghe Formation, is mainly consisted of fine sand with 10% clay and tense structure and experienced intense pedogenic processes. According to the data of chemical analysis, its ratios of SiO_2/Al_2O_3 and FeO/Fe_2O_3 are 3.19 and 0.27, respectively. A 30.1±2.6 ka B. P. TL date of loess overlying the paleosol indicates that the paleosol formed in the last interglacial before Malan Loess deposited. The ratios of SiO_2/Al_2O_3 and FeO/Fe_2O_3 of Malan Loess, being 5.33 and 0.51 respectively, are higher than that of the brown\red of paleosol. It shows the paleosol was formed under the climate being warmer and wetter than that of Malan Loess. Another dark paleosol, overlying on the Malan Loess, was formed in the Optimum of Holocene according to its ^{14}C date of 4460±60 a B. P.

The brown-red paleosol, mentioned above, can be also found in Gonghe Basin. It is 20 to 50 cm thick and always located between Gonghe Formation and Malan Loess. Based on the study of magnetic stratigraphy and ^{14}C dating, Gonghe Formation completed 100—140 ka ago, and Malan Loess began to deposit 20—30 ka ago[1]. Table 2 is chemical compositions of the Late Pleistocene brown-red paleosols in several sites of Gonghe Basin. According to

Table 2, it can be inferred that the paleosol belongs to the middle stage of chemical weathering or stage of concentrating silicon and aluminum (ratio of $SiO_2/Al_2O_3>4$). Compared with that of Malan Loess, the climate of the paleosol was warmer and moister (Malan Loess, of which ratio of SiO_2/Al_2O_3 is higher than 5, belongs to the early stage of chemical weathering or stage of concentrating calcium). The paleosol in Gonghe Basin, being as same as that in Xinghai Basin on basic feature, can be regarded as drub one formed under the forest-steppe environment.

Table 2 Chemical compositions of brown-red paleosol in Gonghe Basin

Sites	SiO_2	Al_2O_3	FeO	Fe_2O_3	CaO	MgO	TiO_2	$CaCO_3$	SiO_2/Al_2O_3	FeO/Fe_2O_3	CaO/MgO	(CaO+MgO)/Al_2O_3
Yitala	55.85	14.47	1.39	4.37	6.56	1.81	0.48	7.01	3.85	0.31	3.62	0.57
Ertala	56.09	15.2	1.39	4.46	6.22	1.59	0.55	6.76	3.69	0.31	3.91	0.51
Gahai	50.39	16.18	0.92	5.32	7.01	2.54	0.44	8.72	3.11	0.17	2.75	0.59
Gamaoyang	52,76	15.26	1.34	4.24	7.61	2.15	0.44	10.75	3.45	0.31	3.53	0.63

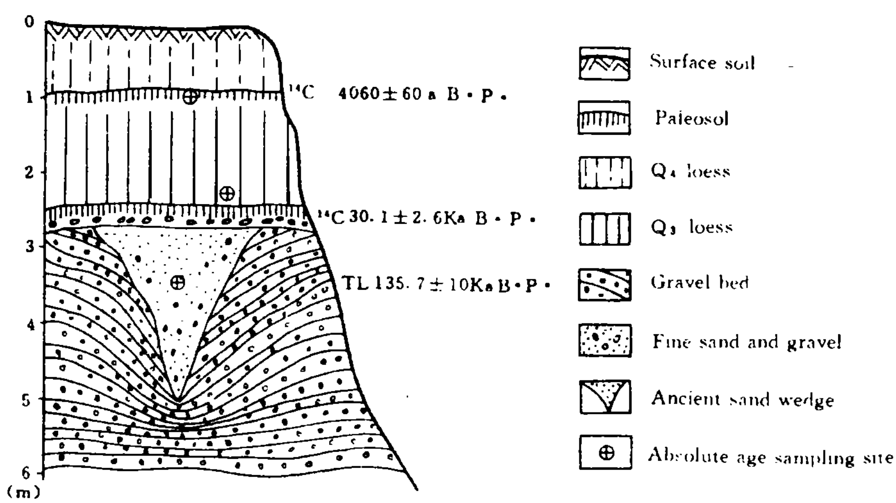

Fig. 2 A stratigraphic profile of paleosols in Dahebatan, Xinghai Basin

2. Paleosol in Warm Period of Late Glacial

Late Glacial between 14 ka B. P. and 10 ka B. P. is a transitional period from the Last

Glacial to Holocene postglacial after LGM, in which gradually warming climate was favorable to develop paleosol. The section of the paleosol, formed in warm period of the Late Glacial, consists of maroon humus layer, gray-white calcic horizon and parent materials from up to down in Gonghe Basin, Qinghai Lake Basin and foothills of the Qilian Mountains. Humus layer of the paleosol is thick (over 50 cm) in centers of basins and thin (below 20 cm) in foothills of mountains. Accumulating of carbonate is very obvious in the paleosol. The sporo-pollen assemblage of paleosol[2] was analyzed as Table 3.

Table 3 Sporo-pollen assemblage of the paleosol in warm period of Late Glacial (%)

Sites	Shazhuyu, Gonghe	Biandukou, Minle	Heima R., Qinghai Lake	North margin of Gonghe Basin
Depth (m)	0.75	3.0	1.9	1.5
Age (a B.P.)	14,220±180	11,280±110	10,290±120	11,210±150
Artemisia sp.	79.66	45.19	34.42	64.78
Compositae	2.91		11.64	12.20
Gramineae	5.08		10.06	
Polygonum sp.	7.21		6.17	
Ranunculaceae	4.25		3.96	
Leguminusae			2.27	
Convolvulaceae			10.39	
Plantagiceae			1.41	
Chenopadiaceae	21.15			
Ephedra sp.	14.42			
Betula sp.		0.32		

The sporo-pollen assemblage demonstrates that the paleosol formed under the semi-arid herbaceous vegetation with few trees. Appearance of *Ephrdra* indicated arid environment in the northern foot of the Qilian Mountains. While, there was a *Artemisia* steppe in Gonghe Basin. The properties and sporo-pollen assemblages of the paleosol have shown that the paleosol in the Late Glacial is chestnut soil in Gonghe Basin, Qinghai Lake Basin and foothill of the Qilian Mountains.

3. The Paleosol in the Optimum of Holocene

The paleosol in the Optimum is widespread in the study region, of which ages concentrated in 7—5 ka B. P. It is mountainous or submountainous meadow soil in the source area of the Yellow River, black loam in Gonghe Basin and Qinghai Lake Basin, sierozem on fluvial platforms in the northern foothills of the Qilian Mountains. Parent materials of the paleosol is loess or loessal silt, and located at 1—2 m depth below the earth surface.

The basic features of mountainous meadow soil and submountainous meadow soil are gray-brown, high organic content (10%—15%), developed humus layer, coarse materials and low content of clay (5%—10%) on the bank of Ngoring Lake, Xingxing Lake and Tuosu Lake in the source of the Yellow River. The differences of submountainous meadow soil from mountainous meadow soil are of intense pedogenic processes and with thick humus layer (15—30 cm).

The dark gray paleosols in Gonghe Basin and Qinghai Lake Basin are mainly black loam soil with loose structure and thick humus layer. Since the parent materials is loess, carbonate leaching and accumulating are two principal processes to have operated within the paleosol, but the boundaries of calcic horizon are not clear in section of the paleosol. The form of carbonate accumulating is mainly of pseudo-mycelium. The paleosol mainly consists of a lot of coarse silt (over 50%) and a little of clay (below 20%), being sandy or silty. In summary, the pedogenetic processes of the paleosol are ones of steppe soil.

In the northern foothills of the Qilian Mountain, the gray-yellow paleosols of sierozem contain little of organic materials (1%—3%). Content of organic materials is often less than 0. 5% in sandy paleosol. Leaching of the paleosols is little obvious, there is usually accumulations of gypsum and salt at the bottom of the paleosol section. Grain compositions of the paleosol are coarse, content of clay is often below 10%. In a word, the paleosol has features of the soil formed under desert steppe vegetation.

The results of sporo-pollen analysis of several paleosols were shown in Table 4[2]. They clearly indicate the semi-arid steppe in the region around Qinghai Lake and desert steppe in the foothills of the Qilian Mountains in the Optimum of Holocene.

Table 4 Sporo-pollen assemblage of the paleosols in the Optimum of Holocene(%)

Sites	Heima R., Qinghai Lake	Biandukou, Minle	Biandukou, Minle	Junmachang, Shandan
Depth (m)	1.4	1.2	0.6	1.5
Age (a B.P.)	4730±50	6210±90	2480±60	4000±80
Artemisia sp.	24.39	79.76	21.13	86.67
Compositae	6.5	11.04		
Ephedra sp.		0.61	3.02	8.42
Gramineae	12.20			
Chenopadiaceae	6.10		12.45	
Polygounm sp.			46.79	
Labiate			7.17	
Cupressaceae	7.01			
Betula sp.	0.53			
Pinus sp.				0.69

According to what mentioned above, we can summarized evolution of soils during the late Pleistocene in the northeast Qinghai-Xizang Plateau in Table 5.

Table 5 The sequences of soil genesis in the Northeast Qinghai-Xizang Plateau

Epoch	The source of the Yellow River	Gonghe Basin	Qinghai Lake basin	The north slope/foothill of Qilian Mts.
Present	Mountain or submountain meadow soil	Castanozems (east) brown soil (west)	Chernozem (south) castanozem (north)	Castanozems (east) brown/gray desert soil (west)
The Optimum of Holocene	Mountain or submountain meadow soil	Black loam	Black loam	Black loam
Warm period of Late Glacial	?	Castanozems	Castanozems	Castanozems
Last interglacial	Drab soils	Drab soils	Drab soils	Drab soils

III. THE REFLECTIONS OF PALEOSOLS TO ENVIRONMENTAL CHANGES

Paleosols, formed under certain biological and climatic conditions, indicate changes of natural zones. As a part of vertical natural zones, paleosols and their evolution in the Qinghai-Xizang Plateau were strongly effected by the plateau uplift and reflected height changes of land surface[3]. We chose several principal types of paleosols and compared them with the same types of soil in present so as to reveal evolution processes of natural environments.

1. Drab Paleosols and Environmental Changes

Drab soil is zonal one in warm temperate monsoon climatic province in the eastern Eurasia, and is distributed widespread in semi-humid warm temperate belt of China. There mean annual temperature and precipitation are 11—14℃ and 500—700 mm respectively, the aridity is 1. 0—1. 5, and natural vegetation is mainly forest-steppe. The altitude of the limit of modern drab soil is 3,500 m a. s. l. in the upper reaches of the Jinsha River (its latitude is close to that of the source of the Yellow River). Mean annual temperature and precipitation are respectively 0—4 ℃ and 300—500 mm in the region of drab paleosol of last interglacial in present, the highest altitude of drab paleosol is 4,200 m a. s. l. in present. Therefore, in the study region, the temperature has dropped down about 10 ℃ and the precipitation decreased about 200 mm and the earth surface has uplifted 700 m since the last interglacial around 100 ka ago. Taken account of vertical temperature gradient as 0. 6℃/100m, 4℃ of temperature decreasing of 10℃ is due to the uplift of land surface, and other 6℃ is due to climatic fluctuations.

2. Castanozem Paleosols and Environmental Changes

Castanozem is formed in temperate sub-arid steppe zone. The modern soils in the eastern Gonghe Basin, the northern Qinghai Lake Basin and foothills platforms of the Qilian Mountains are castanozems. In the region of the modern castanozem, mean annual temperature and precipitation are 2—5 ℃ and 250—450 mm respectively, and aridity is 1—2. The upper limit of the modern castanozem is about 3200 m a. s. l.. The paleosols of warm period of Late Glacial in the study region is chiefly castanozem. In Xinghai Basin where highest altitude of castanozem paleosols is 3,500 m a. s. l. , mean annual temperature and precipitation are 0℃ and 300—400 mm respectively. Compared the modern climate in the region of castanozem paleosol with that in the region of modern castanozems, temperature decreased about 3. 5 ℃, precipitation has little changes, the earth surface uplifted around 300 m. Therefore, 1. 8 ℃ of decreasing temperature was due to uplift of landforms, and other 1. 7 ℃ was the result of climatic variation. We suggested that 300 m uplift had happened in Gonghe Basin since LGM, based of the study on periglacial phenomena[4]. The evolution of paleosols demonstrate it is correct.

3. Black loam paleosols and Environmental Changes

Paleosols in the Optimum of Holocene belong to black loam in the study region, except for in the upper reaches of the Yellow River. They are similar to S_0 in the Loess Plateau. Black loam, being a natural soil of warm temperate steppe, is widespread in the northern Shaanxi, northwest Shanxi and eastern and central Gansu in the Loess Plateau. Mean annual temperature and precipitation are 8—10 ℃ and 300—500 mm respectively in the region of modern black loam. The mean annual temperature and precipitation are 2—8 ℃ and 200—400 mm respectively in the region of black loam paleosols. Compared with them, in the study region, temperature has dropped down around 4 ℃ and precipitation has decreased about 100 mm since the Optimum of Holocene. The Optimum is the period with high temperature in global. In the period, mean annual temperature is 2—3 ℃ higher than present, precipitation is 100—200 mm more and the sea level is 2—3 m higher in eastern China[5]. Compared temperature decreasing in the study region with in eastern China, temperature decreasing of 1—2 ℃ can be on account of the uplift of Tibetan Plateau, and the earth surface has uplifted at least 200 m in the study region since the Optimum of Holocene.

According to what mentioned above, we have summarized environmental changes of three periods of paleosols during the Late Quaternary in Table 6.

Table 6 Environmental changes in the Northeast Qinghai-Xizang Plateau since the last interglacial

Epoch	Climate (compared with present)		Vegetation	Soil type	Natural zone	Uplift (m)
	Mean annual temp. (℃)	Mean annual rainfall (mm)				
Optimum	+4	+100	Steppe	Black loam	Warm-temperate sub-arid zone	200
Warm period of Late Glacial	+3.5	Mild	Steppe	Castanozem	Temperate sub-arid zone	300
Last interglacial	+10	+200	Forest steppe	Drab soil	Warm-temperate sub-humid zone	700

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