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PALEOSOLS OF SANDY LANDS AND ENVIRONMENTAL CHANGES IN THE WESTERN PART OF NORTHEAST PLAIN OF CHINA WESTERN DURING HOLOCENE

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ABSTRACT: Two-three paleosol layers were formed in the western part of the Northeast Plain, China during Holocene. These paleosol layers interlaid with eolian fine sand layers. Dated by ^{14}C dating, archeology and TL and analyzed by statistics, the formation periods of paleosols are divided from the results. The periods are 11,000—7000 5500—4500, 3500—2800 and 1400—1000 a B. P. respectively.

According to the spore-pollen compositions in more than ten sand dune paleosol profiles, it is discovered that there is little spore-pollen in the sand layers and a little spore-pollen in the paleosol layers. The spore-pollen compositions in the paleosols are simple, mainly *Artemisia* (50%—70%) and Chenopodiaceae. In the paleosols of 11,000 — 7000 a B. P., the spore-pollen composition is *Artemisia*-Rubiaceae-chenopodiaceae. The contents of *Ephedra* pollen in the lower and upper parts of the layer are less than that in the middle part. In the paleosols of 5500—4500 a B. P., the spore-pollen composition is *Artemisia*-Chenopodiaceae-*Melilotus*. There is some *Salix* sp. and *Betula* sp. pollen in the lower part of the layer and some *Ephedra* pollen in the upper part. In the paleosols of 3500—2800 a B. P., the spore-pollen composition is *Artemisia*-Chenopodiaceae—Rubiaceae. There are some *Kochia* and Baryaceae. In the paleosols of 1400—1000 a B. P., the spore-pollen composition is also *Artemisia*-Chjenopodiaceae-Rubiaceae. There is a little pine pollen.

The grain size of paleosol is relatively coarse, but still finer than that of eolian sand and becomes coarser from the bottom to the top of the profile. This fact reflects that the weathering environments during the paleosol formation periods were wetter than that during the eolian periods and became dryer from middle to late Holocene.
Key Words: Northeast Plain, sandy land, paleosol, Holocene Environment

The sandy lands in the western part of the Northeast Plain of China, include

Horqin Sandy Land and Songnen Sandy Land. Their administrative areas include Jirem League and Chifeng City in Inner Mongolia, Tieling City in Liaoning Province, Siping City and Baicheng District in Jilin Province and Qiqihar City in Heilongjiang Province. Its climate is semi-arid and semi-humid. It is the most sensitive zone to environmental changes. Here the paleosol layers existed widely in sandy lands and conserved a great amout of information about the environmental changes such as paleo-climate and paleo-vegetation changes during the Holocene. This kind of information provided important scientific evidences for the recovering of paleo-climate and paleo-environment and the prediction of the future environments.

I. THE PROFILE CHARACTERISTIC OF THE PALEOSOLS IN SANDY LANDS

During the Quaternary period, this region subsided continuously and deposited middle, fine grain sand with the thickness of tens meters or even several hundred metres. These fluvid sands were eroded by the strong wind during the arid periods and then accumulated locally and formed the sandy lands because of the alternative changes of the humid and arid climate[1-2]. In the sand dune profiles, 2—3 paleosol layers existed widely and interlaid with the eolian light-yellow fine sand layers. Their thickness is 0. 3, 1. 0 and 2. 0m respectively. They were located in the whole sandy land, specially the paleosol layers with the thickness of 1. 0 and 2. 0m were distributed as north as Qiqihar, as south as Chifeng, Zhangwu and as east as Qianguo. Some paleosols existed directly on the terraces or flood plains and were covered by eolian sand; some were exposed with large area because of the wind erosion. Their contact relationships with eolian sand were: unconformed with the overlying fine sand layer and transited gradually to the underlying fine sand layer. The bedding in the eolian sand was not very obvious. The strike-dip of the paleosol on flat sandy land was horizontal.

The grain composition of the paleosol is coarse. The clay content is less than 2. 5% and most of the grain is fine sand and silt-fine sand, that is between 0. 25—0. 1mm. The grain composition of the eolian sand is also mainly fine sand which takes up more than 50%. In Songnen Sandy Land, there are more middle sand or silt-fine sand in the eolian sand and its sorting is ordinary[3]. In Horqin Sandy Land the sorting of eolian sand is relatively fine and most of the sand is fine sand[4]. The paleosols are hard and belong to calcic concrete, and generally have calcic actions, some of them even have white calcic mycelium. Their mineral contents are mainly quartz and felspar. The quartz content takes up more than 80%. The content of heavy mineral is less than 0. 6%. Their organic matter content is also less than

1%[2].

II. THE DATES OF PALEOSOLS IN SANDY LANDS

According to the ^{14}C, archaeological and TL (thermoluminescence) dating of the paleosols and eolian sand in sandy lands, we discovered that a great bill of paleosol layers were formed from early Holocene (11,000 a B. P.) to late Holocene (12,000 a B. P.) (Table 1). The results of the statistical dating data and structure analysis of stratum profiles reflect four periods of paleosol formation (Fig. 1): (1) The first paleosol formation period is 11,000—7000 a B. P. (2) The second period is 5500—4500 a B. P. The paleosol samples of this period take up 33.3% of the total samples. This paleosol layer was exposed widely. (3) The third period is 3500— 2800 a B. P. (4) The fourth period is 1400—1000 a B. P.

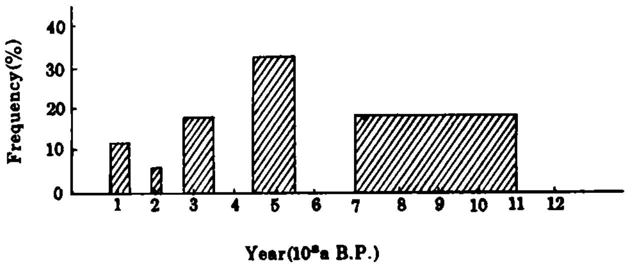

Fig. 1 Sketch of the paleosol dates statistics of sandy land

When the paleosol formed, the desertification action was weakened. The environment was suitable to the human activity and the cultural relic layer was formed. So the locations and ages of the cultural relic layer could be considered as the evidences of the environmental changes. All the cultural relics dated 7000 a B. P. in Qiqihar and Durbet, 5000 a B. P. in Tailai and Baicheng and 3000 a B. P. in Zhaoyuan reflect that the natural environment was appropriate and fit to the soil formation[6-8], also provide the basis for the division of environmental changes. The TL dating to eolian sand samples from Xinmiao and Shenjingzi in Qianguo County is 6590 ± 330, 6810 ± 340 a B. P. respectively and reflects that the desertification occurred and the paleosol formation stopped[1].

III. THE GRAIN CHARACTERISTIC OF THE PALEOSOL PROFILE IN SANDY LANDS

The environmental change in sandy lands was reflected not only by the paleosol profile structures, but also by the physical and chemical characteristic of the profiles such as grain characteristic.

The grain analysis result (Table 2) of Hongsheng Sand Dune Profile in Tailai County reflects that the grain distribution of the whole profile is similar and mainly concentrated in 0.250—0.100mm, that is, fine sand and silt—fine sand. The grain size of paleosol is similar to that of matrix eolian sand. Its clay content is very little and no more than 1.5%. These facts indicate that the soil did not develop well and the development period was short. Meanwhile the environment was relative arid, and there could be some eolian sands accumulating gradually on the soil surface. So the soil grain composition was coarse and the paleosol profile developed poorly. On the other hand, there are differences in the grain characteristic between eolian sand and paleosol. Table 2 shows obviously that the grain content between 0.125—0.100mm of paleosol is more than that of eolian sand. But between 0.250—0.200mm and 0.180—0.154mm, the grain content of paleosols is obviously less than that of eolian sand. The middle grain sizes of the paleosol are also smaller than those of eolian sand, respectively 0.133mm, 0.148mm and 0.152mm, 0.162mm. This shows the weathering action of paleosol was stronger than that of eolian sand and the climate during its development period was more humid than that during desertification period. At the same time, the grain size of sample Tailai-3 is smaller than that of Tailai-5, and Tailai-4 smaller than Tailai-6, that is, the grain compositions of paleosol and eolian sand become coarser respectively from the lower part of profile to the upper part. This indicates the climate became drier and the weathering action became weaker and the desertification became stronger not only during paleosol development periods but also during desertification periods.

IV. SPORE-POLLEN CHARACTERISTICS OF SANDY LAND PALEOSOL PROFILE

Information about environmental change of the Holocene in the region can been obtained from spore-pollen characteristic of sandy land paleosol profile. The result of spore-pollen analyses from tens of profiles shows that spore-pollen is lack in eolian sand, spore-pollen content is also less in paleosol and their kinds are single, which are dominated mainly by herbaceous pollen accounting for over 90%, pollen of xylophyta and spores of pteridophyte and algae are fewer.

1. Paleosol Profile of Hongsheng Sandy Land in Tailai County

The profile, typical paleosol profile since the Middle Holocene, develops on the dune of the first terrace of the Nenjiang River and is situated at Dongsheng, Hongsheng in Tailai County, called Dongwenggen hill by local people. The profile

Table 1 Dates of sandy land paleosol in the western part of Northeast Plain

Locations	Strata	Date (a B. P. Calibrated by tree Ring)	Sources of Data
Wonutu, Qiqihar	The third layer paleosol	1280±100	Author
Chaohaimiao, Horqin	Sand dune paleosol	1265±100	Wu Honglin
Chaohaimiao, Horqin	Buried ash in sand dune	1200±80	Wu Honglin
Manggetu, Qiqihar	Bottom of paleosol	1200±63	Author
Daqinggou, Zhangwu	The third layer paleosol	2030±70	[5]
Sanjiazi, Zhangwu	the second layer paleosol	2135±46	[5]
Wonutu, Qiqihar	the second layer paleosol	3440±110	Auther
Hongsheng, Tailai	The second layer paleosol	2970±110	Auther
Yixin, Dumeng	Sand dune paleosel	2975±115	Auther
Zhennan, Zhenlai	The second layer paleosol	3170±155	[6]
Baijingbao, Zhaoyuan	Ash hole in soil	2900±100	Auther
Chaohaimiao, Horqin	The low layer paleosol	3045±70	Auther
Taipingchuan, Changling	Sand dune paleosol	3600±75	Auther
Manggetu, Qiqihar	Sand dune paleosol	4585±113	Auther
Manggetu, Qiqihar	Sand dune paleosol	4615±115	Auther
Hongsheng, Tailai	The first layer paleosol	4940±175	Auther
Zhennan, Zhenlai	The first layer paleosol	4630±130	Auther
Sheli, Da'an	Middle part of paleosol layer	5140±145	Auther
Sanjiazi, Zhangwu	The first layer paleosol	5180±70	[5]
Yiaolinmaodu, Horqin	Sand dune paleosol	4620±65	Auther

Locations	Strata	Date (a B. P. Calibrated by tree Ring)	Sources of Data
Hotuoqitun, Dumeng	Cultural relics in sand dune	5420±75	[7]
Baicheng	Tomb in the paleosol	5460±110, 5175±130	[8]
Xinmiao, Qianguo	Eaolian sand	6590±330	Auther
Shejingzi, Qianguo	Eaolian sand	6810±340	Auther
Machang, Dumeng	Upper part of paleosol	7645±170	Auther
Tongyu, Qianguo	Low part of paleosol	9130±110	Auther
Jingxing, Longjiang	Bottom of soil	9630±160	Auther
Nanshan, Chifeng	Top of the first layer paleosol	7340±90	Zhang Wenshan et al.
Nanshan, Chifeng	Bottom of the first layer paleosol	9835±301	Zhang Wenshan et al.
Kaitong, Tongyu	Top of paleosol	7220±130	Auther
Tengjiagang, Qiqihar	Cultural layer	8200±85	[7]
Daxingtun, Qiqihar	The second cultural layer	10500±80	[7]
Daqinggou, Zhangwu	The bottom layer paleosol	12000±220	[5]

Table 2 The grain contents of Hongsheng sand dune paleosol profile in Tailai County (%)

Degree	>0.315	0.315—0.250	0.250—0.200	0.200—0.180	0.180—0.154	0.154—0.125	0.125—0.100	0.100—0.080	0.080—0.063	<0.063	Middle size
Tailai-8 modern soil	1.05	3.3	16.5	9.1	23.4	16.3	20.9	6.0	2.95	0.5	0.16
Tailai-6 eaolian sand	1.5	4.4	17.3	8.3	21.5	16.6	19.9	6.8	2.8	0.9	0.162
Tailai-5paleosol	0.8	3.1	11.9	8.0	16.4	16.0	25.5	9.7	4.5	2.1	0.148
Tailai-4 eaolian sand	0.9	2.9	13.8	8.9	18.8	17.7	22.7	8.7	4.9	0.7	0.152
Tailai-3 paleosol	0.42	1.2	6.48	6.0	15.5	18.2	28.6	12.6	9.0	2.0	0.133

emerged due to wind erosion. The characteristic of profile structure is illustrated as Fig. 2:

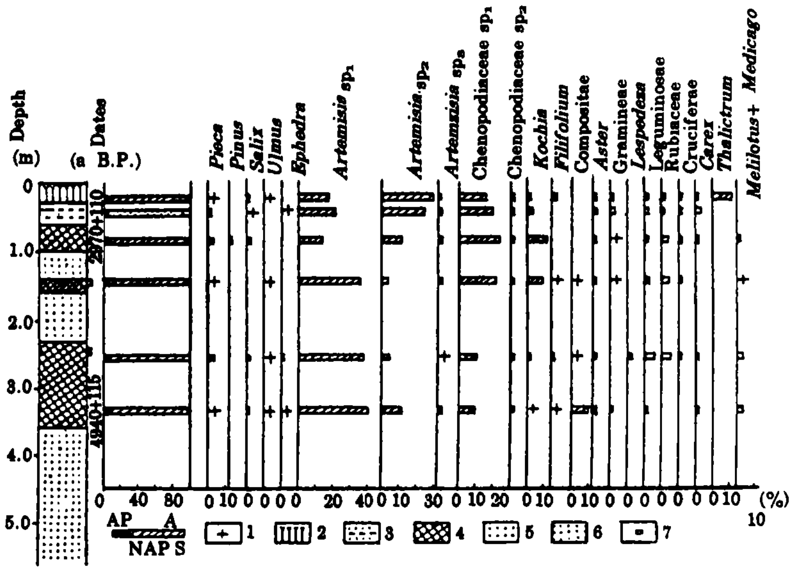

Fig. 2 Structure and spore-pollen spectrum of sandy land paleosol profile at Hongsheng village in Tailai County

1. spore-pollen content<1% 2. surface soil 3. sandy soil 4. paleosol 5. fine sand 6. clayey sand 7. sample of ^{14}C dating 8. AP. xylophyta pollen NAP. herbaceous pollen A. water algae spore S. pteridophyte spore

8. Sandy chernozem, with clay-grain content of 0.25% and sparse *Artemisia* grassland vegetation, 0.3m thick.

7. Light black sand, with low content of organic material and Ca, 0.3m thick.

6. Paleosol, contacts with overlying layer by unconformity and is in state of gradual change with underlying layer by regional stratum comparison, whose age is about 1200 a B.P., 0.4m thick.

5. Yellow fine sand, no bedding, 0.4m thick.

4. Paleosol, the ^{14}C age is 2970±110 a B.P., 0.2m thick.

3. Grey yellow fine sand, 0.7m thick.

2. Paleosol, a great deal of ancient twig, pressing-made stone artifact and pottery found in this layer. The age from ancient twig at upper is 4940±175 a B.P. and age at bottom is about 5500 a B.P., 1.3m thick.

1. Grey yellow sand, no bedding, 2.0m thick.

The spore-pollen composition characteristics of paleosol in profile are: the first layer is paleosol and the depth of sampling is 3.5m and 2.6m. Spore-pollen composition at the bottom of paleosol is mainly *Artemisia*, accounting for 54.8%, Chenopodiaceae is 9.2%, Melilotus is 2.6%, *Salix* and *Betula* are 3.3%, the content of other spore-pollen less, which reflects paleo-climate characteristics, warmer and semi-arid. Main composition of spore-pollen at the middle upper part of paleosol is also *Artemisia*, accounting for 43%, Chenopodiaceae is 12.2%, Melilotus is 3.3%, Rubiaceae is 6%, *Ephedra* is 3% and the content of other spore-pollen is much less. The increase of content of these durable dry plant pollen shows that during 5500 — 4500 a B. P. when paleosol developed there was a tendency of gradually becoming dry although the period was semi-arid. In the second layer, the spore-pollen composition is that *Artemisia* is 44.2%, Chenopodiaceae 23%, Rubiaceae 4%, Kochia 8%, Bryaceae 3%, which reflects that climate is semi-arid and semi-humid in 3000 a B. P. spore-pollen composition of the third paleosol is *Artemisia* 29.3%, Chenopodiaceae 25.3%, Kochia 13.4%, Rubiaceae 6%, *Pinus* 4% and some Asters are included, which reflects warmer-drier paleo-climate characteristic.

2. **Sandy Land Paleosol Profile at Kaitong in Tongyu County**

The profile, more typical profile formed in the early period of the Holocene, is situated on sands 5km far from north of Kaitong village. Dropout of profile is 8m, paleosol develops at depth of 4—6m, still higher than circumstance relief, which shows that paleosol was formed on the sand not on the erosion low-lying land. White-grey find-sand overlies paleosol layer. spore-pollen analyses of samples from bottom, middle and top have been made. Ages on top is 7220 ± 130 a B. P. According to thickness conclusion and regional stratum composition, we can draw a conclusion that age on bottom of paleosol may be 9000 a B. P. spore-pollen composition characteristic is shown is Fig. 3.

Artemisia is main accounting for 49.3%, Rubiaceae 12%, Chenopodiaceae 12%, *Ephedra* 6%, which reflects environment of semi-arid *Artemisia* grass. Age in the middle of paleosol is about 8000 a B. P., *Artemisia* is still main in its spore-pollen composition accounting for 60.9%, Chenopodiaceae 5.3%, Rubiaceae 7.5%, *Ephedra* 2.2%, Concentricystes 3%, Botrychium and Selaginella are 3%, content of algae and pteridophyte spore increases, which shows that although climate in the period was drier, more humid than that in the early period and is in transitional state from semi-arid to semi-humid. Spore-ollen composition at the top of paleosol is: *Artemisia* 55.4%, Chenopodiaceae 14%, Rubiaceae 7.6%, *Ephedra* 16%, contents of algae and pteridophyte spores decrease to 2.5%, which show that climate began to become dry and content of saline alkali soil increased, plants of Chenopodiaceae increased.

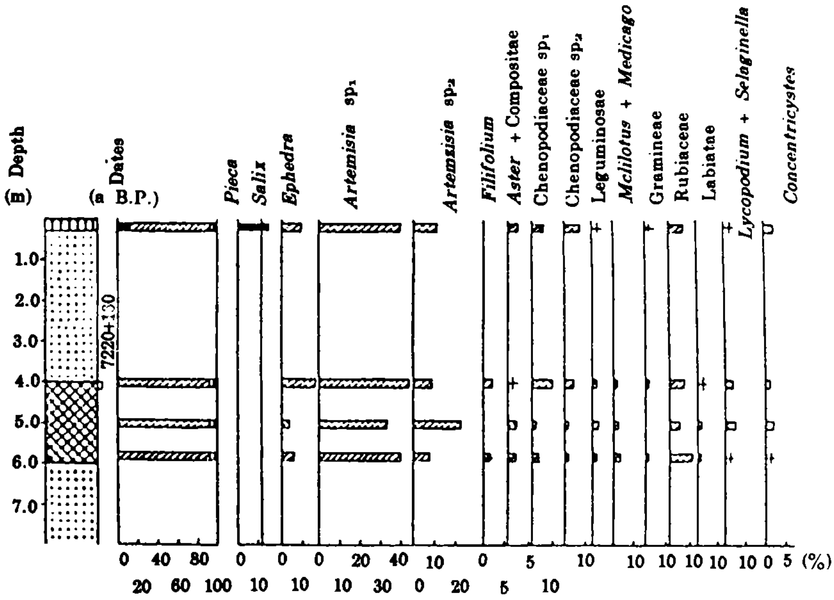

Fig. 3 Spore-pollen spectrum of dune paleosol profile at Kaitong of Tongyu County (the legends are the same as those in Fig. 2)

In a word, not only content of spore-pollen composition of paleosol in sandy land in the west of Northeast Plain, but also variety is single and *Artemisia* is dominant type, which shows vegetation cover-degree was low in developmental process of paleosol and was grassland landscape of *Artemisia* or Savanna grassland. Change is little within layers of paleosol, especially drought-enduring plant pollen increases from bottom to top of paleosol stratum, which reflects climate condition of soil-forming is a bit different, the climate of the late period became dry until sand-layer was formed.

V. ENVIRONMENTAL CHANGES OF HOLOCENE

According to the above-mentioned structure characteristic, quality and state change of physics and chemistry, characteristics of spore-pollen composition and dating data of sandy land paleosol, it can been seen that environmental changes of the Holocene in this region experienced 4 cycles from dry to humid, namely, 12,000—11,000—7000, 7000—5500—4500, 4500—3500—2800 and 2800—1400—1000 a B. P..

1. 12,000—11,000—7000 a B. P.

Global climate began to become warm and humid at the beginning of the

Holocene, but climate of the western part of the Northeast Plain was still dry and sand action was stronger. Until 11,000 a B. P. or so, with climate getting warm and humid, sand action began to weaken, drift sand began to fix, sandy grassland landscape was formed, in which *Artemisia* is constructive-community with Chenopodiaceae, Rudiaceae, *Ephedra* etc., sandy chernozem developed, but weaker sand action existed and sand accumulated on soil and accumulated got thick. Environment getting good was fit for human activities and historical remains which became later cultural relics layers. Until 8000 a B. P., climate became humid. Drought-enduring plants like *Ephedra* increased, but, hydrophilic algae and Pteridophyte decreased. Meanwhile, peat began to develop on the eastern edge of sandy, for example, ^{14}C age of peat profile at Xiaonan in Changchun is 7820±110 a B. P. After 7200 a B. P., climate began to get dry again, drought-enduring plants increased, hydrophilic plants decreased. After 7, 000 a B. P. , climate further got dry, grassland began to degenerate, wind action enforced and drift sand buried soil, so paleosol was formed. Paleosol developing in the period appeared at Kaitong of Tongyu County, Nanshan of Chifeng County and Tongyu of Qianguo County, ^{14}C ages were respectively 7220±130, 8809±301, 7340±90, 8500±110 and 7645±170 a B. P. [2]

2. 7000—5500—4500 **a B. P.**

After 7000 a B. P., climate got dry, sandy land expanded. A large area of windy sand developed. TL ages of honeycomb-like dune at Shenjingzi and sand ridge at Xinmiao of Qianguo County is respectively 6810±340 and 6590±330 a B. P. [1]. After 5500 a B. P., climate began to become transitional state from semi-arid to semi-humid, sandy land vegetation began to develop, dominated by *Artemisia* and Xylophyta such as *Salix* and *Betula* began to grow and sandy land chernozem developed. Under more humid climate condition, physical weathering of sand enforced, which caused highest clay grain content and it could reach 1.5% in the period. Grain size of middle value of soil is 0.133mm, which is the smallest value of paleosol of every period. Soil developing in the period distributes from Manggetu of Qiqihar on the northern edge of the sand to Zhangwu on the south and still to Daan on the east. Peat developed in some low-lying land on the eastern edge of the sand, for example, ^{14}C age at the bottom of peat profile at Sanxianbao of Changling County is 4500±250 a B. P., rectified age by tree ring is 5120±155 a B. P. [9]. Up to 5000 a B. P., climate became a bit dry, drought-enduring vegetation increased, indicating arrival of new desertification.

3. 4500—3500—2800 **a B. P.**

After 4500 a B. P., sand action enforced increasingly, soil was covered with drift sand and buried soil was formed. Spore-pollen of peat profile in the valley of Sanxianbao of Changling County shows that *Pinus* decreased, *Artermisia* and *Ephera* increased, which indicated that climate had been becoming warm and dry. After 3500 a B. P., climate became semi-humid and semi-arid again. Drift sand was fixed, plants such as *Artemisia* and Chenopodiaceae developed again. *Ephera* pollen vanished and *Artemisia* pollen decreased on the peat profile of Changling. Because the humid period was shorter, only 700 years, climate was drier and physical weathering was not strong, clay grain in the soil was only 1.2%, grain size of middle value was 0.148mm, soil thickness was only about 30cm. For example, paleosol were all 30cm thick distributing at Hongsheng of Tailai County, Yixing of Dumeng County and Zhengnan of Zhenlai County, the ^{14}C ages were respectively 2970±110, 2975±115, 3170±155 a B. P.

4. 2800—1400—1000 **a B. P.**

The period was alternate stage from arid (2800—1400 a B. P.) to semi-arid (1400—1000 a B. P.) and layers of eolian and paleosol developed. Since 1, 000 a B. P., climate became dry again, meanwhile, due to human activities such as excessive reclamation, herb and lumbering soil desertification enforced progressively and regional environment worsened. The information from paleosol shows that sandy land of the Holocene in the region experienced 4 processes of developing and reversing. The extending of paleosol from southeast to northwest and alternate appearing of paleosol and eolian sand for many times was result of advancing and retreating of southeast monsoon for many times and moving of climate zone of semi-arid and semi-humid for many times, longitude which advanced and retreated were about 5—8. Due to climate alternate change from dry to wet, semi-arid zone moved toward southeast and vegetation was desert grassland and area of drift sand enlarged during period when drift sand expanded. During recovering period of sandy land, semi-humid zone moved toward northwest of the plain, vegetation was sparse *Artemisia* grassland, drift sand was fixed and paleosol and swamp wetland developed.

VI. CONCLUSION

1. There were 4 developing periods of paleosol on the west of sandy lands in Northeast Plain since the Holocene.

2. Environment change experienced 4 cycles from arid to semi-arid and semi-humid since the Holocene, namely, 12,000 — 11,000 — 7000, 7000 — 5500 — 4500, 4500—3500—2800 and 2800—1400—1000 a B. P.. Since 1000 a B. P., climate tended to get dry. Vegetation in the period of semi-arid and semi-humid was *Artemisia* grassland or sparse *Artemiasia* grassland and swamp wetland landscape.

3. The information from sandy paleosol showed that monsoon of the Holocene in the region advanced and retreated, semi-arid and semi-humid zone expanded and shrank for many times. Width of advancing and retreating was about 5 — 8 of longitude.

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