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ON THE INFORMATION OF MIRE DEPOSITIONAL ENVIRONMENT

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ABSTRACT: Mire is the product of the Quaternary. It mostly formed, developed and declined after the postglacial age. Therefore the chemical element analysis, spore–pollen analysis, ^{14}C dating, mire plant determination for mire sediment, and the study on hierarchy relation of mire sediment, can provide a lot of information for restoring paleogeography, paleoclimate and environmental change. So some people called mire sediment—peat as "database of environment".

KEY WORDS: mire sediment, chemical elements analysis, spore–pollen analysis, ^{14}C dating, environmental information

I. THE ENVIRONMENTAL INFORMATION OF SOME CHEMICAL ELEMENTS IN MIRE SEDIMENT

Through analyzing some chemical element contents and their ratios in mire sediment—peat, and mire plant residues, the environment of marine facies and continental facies sedimentation can be reconstructed.

1. Cl and F Contents and Cl / F Ratios

As every one knows, Cl content in marine–facies muds tone is very high, generally 2,000–3,000mg / kg, 15–20 times higher than that of continental–facies fresh–water depositional mudstone. Peat preserved Cl, which reflects that sodium salt and sylvite in ancient water body had an influence on mire formation. The formation and development of seashore type of peat mire in ancient sea bay lagoon, estuary bay lagoon, depressions between sand bars in seashore were influenced by sea water to a certain extent. Because sea water medium contains high salinity, peat accumulated in this environment has high Cl content. Based on the statistics of data in Literature 1, the mean Cl content of seashore type of peat in east China is 2,248 mg/ kg ($n=10$); while Cl content in continental facies fresh-water type of peat mire sediment is very low, only 306 mg/ kg ($n=44$). On the contrary, F content in the crust is 660 mg/ kg, the mean F content in soils is 42 mg/ kg, that of sea water less than 3 mg/ kg. In the above-mentioned mire sediment, F content in seashore type of peat is 262 mg/ kg ($n=10$); that of continental facies fresh-water type of peat is 621 mg/ kg ($n=44$). As for F/ Cl ratio, because seashore type of peat contains high Cl and low F, F/ Cl ratio in the peat is much lower than that of continental facies fresh-water type of peat, the mean ratio is 0.12; while the mean F/ Cl ratio of continental facies fresh-water type of peat is up to 2.13.

To sum up, according to Cl and F contents in mire sediment—peat and their ratio, one can restore the water source feed of mire in historical periods, the hydraulic connection of the seashore type of mire with the sea, and determine marine facies and continental facies sedimentation environment of mire.

2. Sr and Ba Contents and Sr / Ba Ratios

Sr and Ba are combined with SO_4 in carrier medium into $SrSO_4$ and $BaSO_4$ in the migration process. The solubility of $SrSO_4$ is 0.11 g/ L, it can be carried into sea with running water. $BaSO_4$ belongs to the compound which is difficultly soluble in water, its solubility is extremely small, only 2.33×10^{-3} g/ L, so it was precipitated with sediment. Therefore in marine facies sediment, Sr content is high, Ba content is low, and Sr/ Ba ratio is larger than that of continental facies fresh-water sediment. Seashore type of peat mire sediment has a comparatively high Sr content due to the influence of sea water in its formation process. For example, Lidao peat at Rongcheng County of Shandong Province belongs to peat mire formed by closed lagoon, Sr content in the sediment can reach 355 mg/ kg, Ba content 260 mg/ kg, Sr/ Ba ratio is 1.37. Jianbi peat at Dantu County, Jiangsu Province belongs to floodplain type of peat mire sediment, Sr content in the peat is 142 mg/ kg, Ba content 797 mg/ kg, Sr/ Ba ratio is smaller than that of Lidao peat (Table 1)[1].

Table 1 Sr and Ba contents in mire sediment and Sr / Ba ratios

Depositional facies	Sr (mg/ kg)	Ba (mg/ kg)	Sr/ Ba	Sampling sites
Closed lagoon type of mire	355	260	1.37	Lidao at Rongcheng, Shandong
Semi-closed lagoon type of mire	260	450	0.57	Chengou at Lianshui, Jiangsu
Fresh-water lake type of mire	169	690	0.25	Gaoqiao at Zongyang, Anhui
Floodplain type of mire	142	797	0.18	Jianbi at Dantu, Jiangsu

3. S and Cu Contents

In the crust, generally S content is very low, only 0.26 g / kg, but S content in sea water is 0.89 g / kg, two times higher than the crust. Generally speaking, element S is a comparatively sensitive environmental index.

Mire is in anaerobic environment, under the influence of sea water rich in sulphate, sulphide will be easily formed. If sea water contacts with partly decomposed mire plant residues to be reduced, through decomposition by microbes, hydrogen sulphide will be formed, further forming sulphide. So in seashore peat mire sediment, S content is comparatively high, mostly over 10 mg / kg. In continental facies fresh—water type of peat mire sediment, S content is commonly less than 10 mg / kg. For example, Futian peat in Hainan Island belongs to estuary bay lagoon type of mire sediment facies, S content is very high, 61.9 mg / kg. As for Zhenzhuwan peat mire at Xialu, Suixi County in Guangdong Province, due to many times of intrusion of sea water in its formation process, S content is comparatively high, 10.1 mg / kg, while its adjacent Xialu (Quanshui) peat sediment, not influenced by sea water, belongs to continental facies fresh—water type of mire sediment, S content is only 5.6 mg / kg[1].

But in some continental facies fresh—water lake type of mire sediment, S content is also high. The reason is that some hydrophytes contain rich protein, under still—water reduction condition, the peat with high S content is also easily formed. It must be differentiated from seashore type of peat mire sediment.

Element Cu in peat mire plant residues can be also as an indicator for marine facies and continental facies sedimentation environment. Generally, in rocks, Cu content is 55 mg / kg, that of soils 22 mg / kg, that of sea water only 3 mg / kg. Cu has great migration capacity, so in chemical and biological deposits Cu content is comparatively high. According to the determination of Cu content of plant residues in continental facies fresh—water type of mire sediment is very high, can reach 177 mg / kg; that of seashore type of mire sediment is low, 81 mg / kg[1]. Therefore, Cu content of plant residues in mire sediment can be used to indicate the hydraulic connection of mire formation process with sea water.

II. THE INDICATION OF SPORE—POLLEN COMPOSITION IN MIRE SEDIMENT ON POST—GLACIAL ENVIRONMENT

The spore—pollen analysis of mire sediment can reconstruct regional plant association in the post—glacial age and reflect climatic change. Now we take the spore—pollen analysis of Qindeli peat mire at Tongjiang County, Heilongjiang Province as an example, to restore the plant community succession, climatic change and mire evolution in north Sanjiang Plain since 12,000 yr B.P. (Table 2). Through the investigation on mire sediment—peat in main mire distribution regions of China and spore—pollen analysis, we can approach mire evolution and environmental change in regions of China since the post—glacial age.

Table 2 Spore–pollen assemblage in mire sediment and environment analysis
(Qindeli peat mire profile at Tongjiang County, Heilongjiang Province)

Age (yr B.P.)	Pollen assemblage	Plant group	Comparison with present climate	Mire change
12,000–95,00	*Betula humilis, Alnus japonica, Carex*		–2℃—–3℃	Waters of rivers and lakes enlarge
9,500–5,000	*Ulmus pumila, Artemisia, Quercus*		3℃—4℃	Local mires development
5,000–2,500	Fir, pine, *Betula*		About –1℃	Mires enlarge
2,500 to present	Pine *Carex*	Red pine forest	–1℃—–2℃	Mires shrink

1. Northeast Region

In the Early Holocene (10,000–7,500 yr B.P.), the global climate got warm. Based on the spore–pollen analysis of mire sediment profiles[2,3], it can be seen that in northeast region, except the Songnen Plain, *Betula* pollen was chief, or *Betula* and *Pinus* pollen was dominant. At that time, along south coastal area and in some plains and mountains, there was small area of mire developing. In the middle period of the Holocene (7,500–2,500 yr B.P.), broadleaf trees pollen was dominant, or *Pinus* and broadleaf trees pollen was chief. Climate in the whole region became warm, there was plentiful precipitation, not only in mountains but also plains, peat mire commonly developed. Particularly since 4,000 yr B.P. mire developed luxuriantly. From 2,500 yr B.P. to present, *Pinus* pollen and herb pollen increased obviously, while broadleaf trees pollen evidently decreased. In the plains, climate was cold and slightly dry, and fluctuated greatly, most of mires stopped developing and was covered by silt and sand. In the Da and Xiao Hinggan Mountains, the Changbai Mountain and northeast Sanjiang Plain, climate was cold and slightly humid, which was still favorable to mire development and peat accumulation; many mires continuously developed since the Early Holocene.

2. The North China Plain

The spore–pollen analysis[4] of the North China Plain shows that during 13,100–11,770 yr B.P. in the plain areas the rivers overflew, lakes and mires commonly developed, but climate was still cold, so fir, spruce and pine forests expanded. During

11,770—10,120 yr B.P. the climate in the first half period turned warm and got dry, the area of lakes and mires shrank, in the second half period, precipitation increased, *Typha* and Umbelliferae plants flourished and peat began to accumulate. In this region, from the Early Holocene (10,100—7,700 yr B.P.) *Artemisia* and *Chrysanthemum* pollen was dominant, climate turned dry, lakes and mires shrank again. In the early period of the Middle Holocene (7,700—5,800 yr B.P.) *Pinus* and *Quercus* pollen was dominant, climate got warm, with plentiful rainfall, mires enlarged again. During 5,800—4,900 yr B.P. a cold period appeared. In the late period of the Middle Holocene (4,900—3,400 yr B.P.) *Pinus* pollen decreased, *Betula* and *Quercus* pollen increased, temperature rose up again and 2—3℃ higher than present, precipitation increased, there appeared many peat mires dominated by reed. From 3,000 yr B.P. to present *Pinus* pollen was dominant, climate was mild, cool and slightly dry, and fluctuated greatly. After 2,000 yr B.P. mires in this region were successively covered by silt and sand.

3. East Coastal Plains

During the post—glacial age, global climate got warm, continent glaciers thawed, causing large—scale transgression, sea level rose approaching present sea level. At that time, along seaside areas, peat mire developed, and accumulated peat under present sea level 10—30 m[5], for example, Maojiagou peat at Changli County, Nanpaihe peat at Huanghua County, the peat under ground 8 m in the Changjiang (Yangtze) River delta, they were all formed at that time. In the middle period of the Holocene (8,000—6,000 yr B.P.), the sea level continued rising, and up to the highest by 6,000 yr B.P.. During that period, climate in this region was mild and humid, river level and ground water level along the coast was stood up and blocked by the rising of the sea level, mire area expanded, accumulated 7—15 m thick of peat[5], for example, under ground 15 meter at Jinghai County, Wuwei peat of the Changjiang River floodplain. In the late period of the Middle Holocene (6,000—2,500 yr B.P.), the sea level began to drop, to the east of the highest coast line, many depressions and lagoon types of peat mires were formed, accumulated peat under ground 1—6 m[5], such as upper layer peat at Maojiahe, Changli County, Shagang peat at Haian County, Tuanjie peat at Wujiang County, etc. In the Late Holocene (2,500 yr B.P.), the sea level continued to drop, seashore plain increasingly expanded. During 2,500—1,500 yr B.P., some peatlands were also formed, but after 1,500 yr B.P., due to dry climate and the interference of human activities, most mires had stopped developing.

4. The Qinghai—Xizang Plateau

The Himalaya movement since the Tertiary caused the crust of this region to rise, forming the huge Qinghai—Xizang Plateau. Since the Quaternary, in the mountains and basins of the eastern part of the Qinghai—Xizang Plateau, the middle and upper reaches of the

Yarlung Zangbo River and its valleys, the head area of the Changjiang River, a large area of peat mires developed, forming a certain scale peat mires.

The Zoige Plateau is a relative subsidence area of the Qinghai–Xizang Plateau since the Quaternary, many stretches, and a large area of lakes and mires were formed. Based on spore–pollen analysis of peat mire sediment, since the Holocene, vegetation types in this region have the following change: in the Early Holocene, alpine meadow, block dark conifer forests; in the middle period of the Middle Holocene, spruce and fir conifer forests and subalpine brush meadow, in the late period evergreen conifer forests, subalpine shrub meadow; in the Late Holocene, subalpine shrub meadow. Since the Holocene there was not great climatic change of cold / warm and dry / humid on basin valleys and glacial depressions 3,400–3,600 m above sea level, meadow paludification and lake paludification commonly occurred, forming a large area of thick and deep continuous accumulated peat basins.

In the valleys of the upper and middle reaches of the Yarlung Zangbo River in the southern part of the Qinghai–Xizang Plateau, piedmont diluvial fan, glacial depressions, intermontane basins and river terraces 4,300–4,600 m above sea level, mires developed. According to spore–pollen analysis[7], since the Holocene, vegetation types of this region had an alternative change of alpine bush meadow, bush steppe and meadow steppe. From the early period of the Holocene, mires began to develop, in the middle period, mires enlarged in area, in the late period, due to glaciers fluctuation there were once three times of ice advance, climate became cold and slightly dry, unfavorable to mire development; only in peat mires with stable water source feed, peat still continuously accumulated.

In the hinterland of the Qinghai–Xizang Plateau—the head area of the Changjiang River 4,500–5,200 m above sea level, peat mires commonly developed, but peat was thin, only 0.2–0.5 m. The mire here were mostly formed in the middle and late period of the Holocene.

III. THE ANALYSIS OF ^{14}C DATING OF MIRE SEDIMENT REVEALING REGIONAL CHANGE OF MIRES IN THE POST–GLACIAL AGE

On the basis of ^{14}C dating of peat samples from 376 pieces of mire sediment, according to the statistics of 1,000–year interval of the Holocene (10,000 yr B.P.) and climatic zone statistics, we formulated Table 3[2], and combined with the statistics of latitude (5°) formulated Table 4[2]. From Table 3 and Table 4 the following conclusions can be drawn.

1) Since 50,000 yr B.P., ^{14}C dating sample number of 56.5–97.8% of various climatic zones, and 56.5–97.8% of various latitude section all concentrated in the Holocene (10,000 yr B.P.), indicating that the Holocene was the main formation period of peat mires in different regions of China.

Table 3 Statistics of ^{14}C dating of peat in various climatic zones (frequency %)

Age (yr B.P.)	Climatic zones				
	Frigid and middle temperate zone	Warm temperate zone	Tropic and subtropic zone	Qinghai–Xizang Plateau	Whole country
Less 1,000	14.5	2.5	3.1	17.6	7.2
1,000–2,000	18.5	12.5	3.1	9.8	10.1
2,000–3,000	25.0	13.3	5.5	13.7	13.0
3,000–4,000	9.2	10.8	7.8	21.6	10.9
4,000–5,000	7.9	14.2	10.2	7.8	10.6
5,000–6,000	5.3	8.3	11.7	2.0	8.0
6,000–7,000	3.9	2.5	13.3	7.8	7.2
7,000–8,000	5.3	6.6	4.7	7.8	5.9
8,000–9,000		5.8	2.3	3.9	3.2
9,000–1,0000	3.9	6.6	1.6	5.9	4.2
Less 10,000	93.4	82.6	63.3	97.9	80.3
10,000–20,000	1.3	11.7	22.7	2.0	12.0
20,000–50,000	5.2	5.8	14.0		7.8

Table 4 Statistics of ^{14}C dating of peat in various latitude sections (frequency %)

Age (yr B.P.)	Latitude (° N)					
	45–50	40–45	35–40	30–35	25–30	20–25
Less 1,000	16.3	5.3		8.4	4.8	18.8
1,000–2,000	18.6	14.5	10.5	3.6	8.3	6.3
2,000–3,000	20.9	19.7	13.5	8.4	8.3	6.3
3,000–4,000	11.6	14.5	5.4	10.8	13.1	6.3
4,000–5,000	4.7	18.4	10.8	8.4	9.5	6.3
5,000–6,000	7.0	7.9	6.8	14.5	4.7	
6,000–7,000	4.7	1.3	2.7	15.7	10.7	12.5
7,000–8,000	7.0	9.2	2.7	8.4	3.6	
8,000–9,000		2.6	6.8	1.2	4.8	
9,000–10,000	7.0	3.9	6.8	3.6	2.4	
Less 10,000	97.8	97.3	66.8	83.0	70.2	56.5
10,000–20,000	2.3		21.6	10.8	16.7	31.2
20,000–30,000			5.4	1.2	3.6	
30,000–40,000		2.6	6.8	2.4	7.1	12.5
40,000–50,000				2.4	2.4	
Sample number	43	76	74	83	84	16

2) Since 10,000 yr B.P., mire development in various climatic zones and latitude sections was quite unbalanced, frigid temperate zone, middle temperate zone and the Qinghai–Xizang Plateau in China. Since 3,000 yr B.P. or 4,000 yr B.P.; warm temperate zone 5,000–1,000 yr B.P.; tropical and subtropical zones 7,000–4,000 yr B.P. had the highest ^{14}C dating sample number, showing that these periods were the luxuriant periods of peat mire development of various climatic zones since the Holocene, and there was a trend extending from south to north. At present in the Qinghai–Zizang Plateau and the northeast mountains, there is still a large area of mires. Based on the statistics of ^{14}C dating of various latitude sections, 45–50° N since 7,000–6,000 yr B.P. and 1,000 yr B.P. had the highest ^{14}C dating sample numbers; peat mire development was luxuriant. At the same time, we can find that peat mires of China were concentratedly distributed 40–45° N, and mainly developed after the Middle Holocene.

3) During 50,000–10,000 yr B.P. in various climatic zones and most latitude sections the highest ^{14}C dating sample numbers occurred in 20,000–10,000 yr B.P., indicating that from the post–glacial age to the Holocene, mires of some areas also developed.

IV. ENVIRONMENTAL INFORMATION REFLECTED IN THE COMPOSITION OF MIRE SEDIMENT AND HIERARCHY SEQUENCE RELATIONS

The composition, type and evolution series of plant residues of mire sediment—peat can reveal the development stage and the original plant community composition of mires, the nutrition status and hydrological regime of mire body, and mire formation ways.

Take Gengxinshan peat mire sediment profile at Tanghongling Forest Center, Heilongjiang Province as an example, the whole profile can be divided into three hierarchies[8]: 120–80 cm is herb residues; according to the analysis of physio–chemical properties, the mire remained in eutrophic development stage, fed by groundwater and surface water. 80–20 cm is wood–herb–moss peat, reflecting that mires had entered mesotrophic development stage, fed by groundwater and precipitation. 20 cm to surface is wood–moss peat, showing that mires had entered oligotrophic development stage, mainly fed by precipitation. From the evolution of plant residues of the profile, we can see that the mires were formed through forest paludification, now they have evolved into less wood *Sphagnum* bog, as the mires develop further, they will become treeless *Sphagnum* bog.

Mire sediment hierarchy sequence can reveal mire genesis and environmental change. If the bottom of mire sediment is muck layer, it is shown that the mire was evolved from water body paludification. This is due to that under the inundation reduction condition, mire was formed by aquatic plant and animal residues. If the lower part of mire sediment is humus layer, it is revealed that the mire began from meadow paludification. Some moss peat layers directly developed on bedrock weathering crust or sand gravel layer. This is the depositional process formed by frozen earth paludification. If the bottom of the sediment is wood layer, it is shown that the mire evolved from forest paludification.

Environmental change is judged based on the interruption, reverse or anomaly of peat hierarchy sequence.

In normal peat hierarchy sequence, if the interruption or reverse of peat sediment appeared, it means that its nutrition was from external, such as river flooding, dust from volcano eruption and precipitation containing a great amount of salt. Ore (1933) reported that in the profile of a peat mire at Grande de Tierra del Fuego three interlaces of volcanic ash were found, which reflected that in the mire formation process, three times of volcano eruption happened. We can estimate the time of volcano eruption according to the accumulation rate of peat. Not only in Grande de Tierra del Fuego, but also in Japan, Kamchatka along the coast of the Pacific in North America, South America, Iceland, Faeroe Is., Norway, Sweden there are all reports about peat mires. After volcano eruption, the dust entered peat layers, increased nutrient components of the peat layers, the aeration status was improved, accelerated the decomposition of organic residues, sometimes oligotrophic bogs could reverse into eutrophic fens. Therefore, the hierarchy sequence of peat layers, the peat interruption or reverse accumulation, and the appearance of anomaly layers all have certain indication effect on environment.

REFERENCES

[1] 王锯谷等，不同沉积类型泥炭的研究，陕西人民出版社，1987.

[2] 马学慧等，我国泥炭形成时期的探讨，地理研究，6 (1)，1987.

[3] 中国科学院贵阳地球化学研究所^{14}C、孢粉组：辽宁南部一万年来自然环境的变化，中国科学，(6)，1977.

[4] 张子斌等：北京地区一万三千年来自然环境的演变，地质科学，6 (3)，1981.

[5] 钟金岳等：我国沿海地区的埋藏泥炭及其形成的古地理，海洋与湖沼，12 (5)，1987.

[6] 王曼华：若尔盖高原区泥炭地的孢粉组合及古植被与古气候，地理科学，7 (2)，1987.

[7] 汪佩芳等：西藏南部全新世泥炭孢粉组合及自然环境演化的探讨，地理科学，1 (2)，1981.

[8] 尹怀宁：关于小兴安岭东段沼泽形成问题，植物生态学与地植物学丛刊，8 (2)，1984.

[9] 阪口丰(刘哲明等译)：泥炭地学对环境变化的探讨，科学出版社，北京，1983.