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Analysis of sedimentary environment of core AB-67 at Barrow

Wang Guo (王　国), Zhang Qingsong (张青松) and Li Yuanfang (李元芳)
Institute of Geography, Chinese Academy of Sciences, Beijing 100101, China

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Abstract A total of 48 samples from the core AB-67 at Barrow are analyzed for 25 grain size items and 44 geochemical items. Q-mode factor analysis applied to these data yielded 4 factors. Mapping of there factor showed their close affinity to sedimentary environment; these core sedimentary rate, precipitation, sea level change, annual temperature. Paleoenvironmentary transfer functions were defined to estimate mean annual temperature and annual precipitation from corelationship between 5 samples at core-top and observation record from Barrow Meteorology Observatory. Sedimentary rate was determinated from dating by ^{210}Pb and several environment events, and sea level from changes of sedimentary phase. The reconstructed temperature and precipitation curves show that Barrow climate is colder and drier in the 16th and the 17th century, temperature rose up and precipitation fluctuated sharply in the 18th and the 19th century, these two changes are greater in the 20th century. The reconstructed temperature curves agree with the variation of assemblages of micropaleontology.

Key words Barrow, drilling core, sedimentary environment, Q-mode factor analysis, transfer function.

1 Introduction

The purpose of this study is, by inversely deducing sedimentary environment from sedimentary result, to recover the record of recent environmental change at Barrow. In this field of study, the traditional method is qualitative, it takes grain size, its statistics feature, geochemical composition and the combination as environment change index. In recent years, the developing Q-mode factor analysis and transfer function techniques expedite the quantification of paleoenvironment research (Shrader and Kockarpuz 1990; Imbrie and Kipp 1971; Klovan and Imbrie 1971; Andrews *et al*. 1981; Bernabo 1981; Guiot 1987; Wang *et al*. 1982; Wang *et al*. 1991).

Q-mode factor analysis is used to study the linear model of several undetermined causes and their mostly known results. Changes of sea level, sedimentary rate, temperature and precipitation must bring about the changes of sedimentary grain size and chemical composition in the lagoon sedimentary environment. There relationship may not be strictly linear, but before using nonlinear technique, we will analyze grain size and geochemical composition by Q-mode factor analysis technique, to extract sedimentary environment factors. Factor identification is the key of Q-mode factor analysis. Here, the identification was done according to: (1) the relationship of cause and result on sedimentary modeling; (2) known mapping of environment changes; (3) relative degree between recent meteorological data and factor. In this paper, we will identify temperature factor, precipitation factor, sedimentary factor and sea level factor.

Defining transfer function is important in paleoenvironment quantitative research. The temperature and precipitation transfer function is obtained from linear transform of these factors, and two unknown constants are got by linear regress of 11 a running mean climatic data from Barrow Meteorological observatory. Determining sedimentary rate is very important for establishing sedimentary time model. The transfer function of sedimentary rate is from a linear transform of its factors, two constants was determined by ^{210}Pb dating and recognition of several environment events. The transfer function of sea level change is got from linear transform of sea level factor, and the two constants are determined by the time when marine sediment began and the present water depth. Research on sea level change is only an attempt here, this is because, first, there are no recent observed sea level data to compare with, and second, it must be further studied which effect sea level change had on inshorn zone sediment prior to marine fransgression.

2 Elson lagoon sedimentary model and Q-mode factor analysis

Elson lagoon is at the northmost of Barrow, Alaska, USA, to the northwest is the Beaufort Sea, and to the west is the Chukchi Sea. The mean depth of the lake is 7 m, with a maximum depth of 12 m at Plover Point. The core AB-67 is got at the southwest corner of this lake, 1 km apart from coast line, where the water depth is 2 m. The geochemical composition of the core is show in Fig. 1. The top of the core (20 cm) represents marine sedimentary environment, the middle part (20 – 32 cm) transition facies sediment, and the bottom (32 – 60 cm) continental facies sedimentary environment. According to micropoleontological study (Li and Zhang 1996), the lower part of the core contains many non-marine shellfish ostracods, such as *Candona*, *Potamocypris* sp., *Limuocythere* sp. (31 – 60 cm), and low salt environmental foraminiferal fauna, such as *Elphidium albiumbilicatum*, *Elphidium elavatum* and *Elphidium orbiculare* (35 – 60 cm). In the upper part, non-marine shellfish ostracods vanish, with in eurythermal and euryhalinous foraminiferal fauna in low-salt environment. Instead the shellfish ostracods is *Cytleromorpha macchesneyi*, and the foraminiferal fauna includes *Ammotium cassis* (19 – 35 cm layer), *Elpliolium excavatum alba* and *E. askundi* (0 – 19 cm). The diatoms occur at the depth of 30 cm; the combination in the lower part consists of *Caloneis bacilhum*, *Cacconeis scufellum*, *Eanotia praeruptavar*, *Navioula rhynchocephala*, *Navicnla semen* and *Pinnularia isostauron*, these are all freshwater diatoms, with no fragments of marine plankton diatom, indicating an environment of estuary delta. The diatoms in the upper part include *Melosiro sulcata*, *Melosiva sulcata* var, *crenulata*, *Melosira arctica*, *Amphoraproteus* var. *laevistriata*, *Diploneis entomon* and *Diploneis bombonides*; there are also several spesies of marine plankton diatom, such as *Chaetoceros*, *Actinocylus* and *Coscinodiscus*, which are badly damaged and were carried here by storm surge and ocean current; the diatom combination represents an offshore neritic zone environment.

According to the record from Barrow Meteorological Observatory, mean monthly temperature is only higher than 0 ℃ in summer. Elson Lagoon keeps melt in summer, and frozen in other three seasons. East wind is prevailing in unfrozen period,

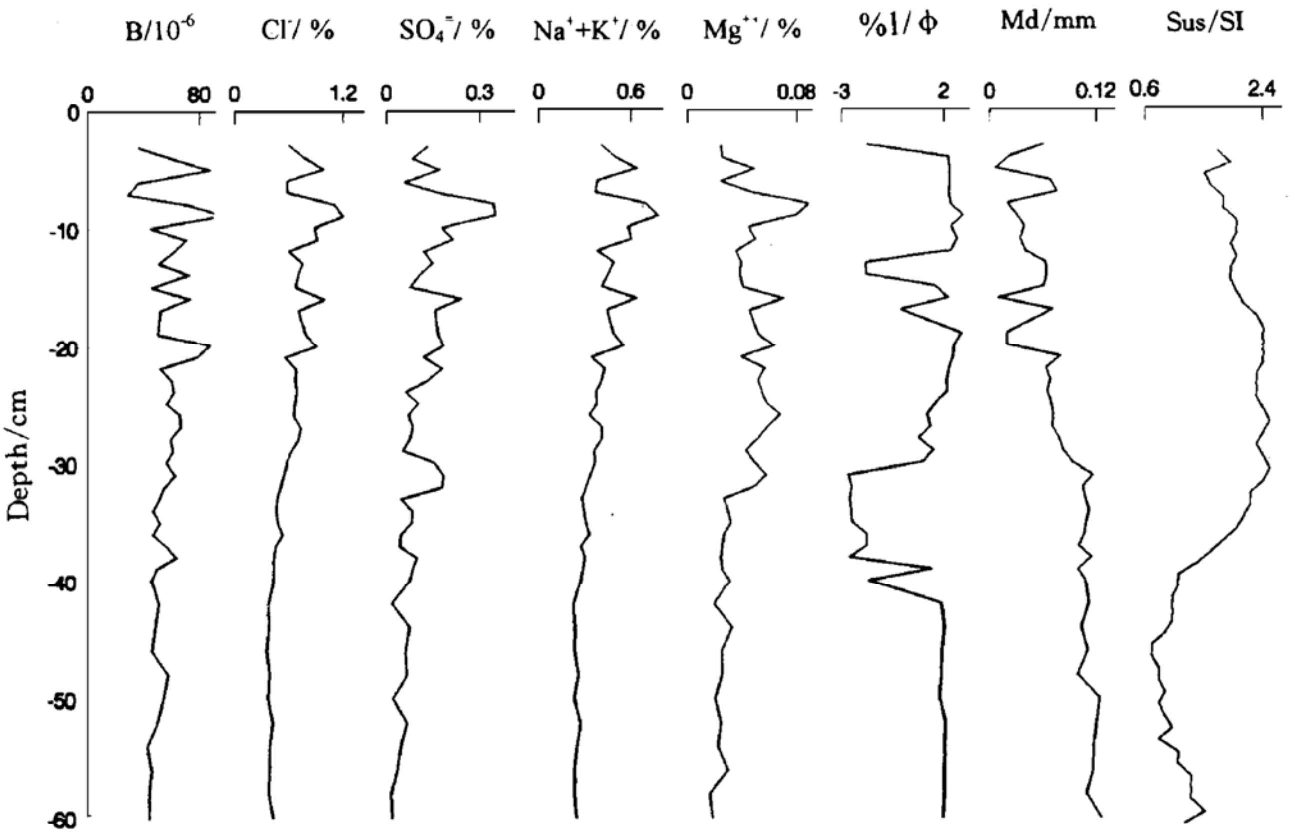

Fig. 1. Variation of Cl^-, Na^+, SO_4^{2-}, Mg^{2+}, B, Md, φ_1 in core AB-67.

the mean wind speed is 5 – 6 m/s. Thanks to wind force, Beaufort Sea water may flow into and out of the channels between Plover Islands, and the sea and lake exchange water frequently. Strong wind is sometimes from southwest with a wind speed of 20 m/s; coarse continental material may be blow onto the lake surface. For marine sedimentary system of Elson Lagoon, temperature have affect on lake frozen period and the grown of living things in water; thus temperature exerts influence on the change of the geochemical composition of the core AB-67; while the speed and direction of wind affect sedimentary dynamic environment, namely, the changes of sedimentary rate and sea level; in addition, the change of global sea level also affect sedimentary dynamic environment. Change of dynamic environment certainly leads to the change of grain size composition in core AB-67. In the continental deposit system prior to transgression temperature had an effect on the process of weathering and leaching and thus on the change of geochemical composition in core AB-67; precipitation had an effect on sedimentary dynamic environment. Though sea level change didn't directly influence the core AB-67, it may cause the change of grain size composition in the core AB-67 by changing runoff dynamic condition. To sum up, environment temperature will control the change of geochemical composition in the core AB-67. Sedimentary rate, sea level change and precipitation will control changes of its grain size composition. On this basis, a Q-mode factor analysis is made of grain size composition and geochemical composition, respectively, in with a purpose to extract temperature factor, sedimentary rate factor, sea level factor and precipitation factor.

As a result of Q-mode analysis of grain size and geochemical composition (Table 2), three varimax factors of grain size have explained 94.9% of the varimax contained in the data set. This shows that the sedimentary factor, sea level factor and

Table 1. The items and samples of Q-mode analysis

Items		Samples
Grain size	Geochemical data	
5 - 10 mm, 3 - 5 mm, 1 - 3 mm, <1.00 mm, <0.80 mm, <0.50 mm, <0.35 mm, <0.25 mm, <0.20 mm, <0.15 mm, <0.125 mm, <0.10 mm, <0.07 mm, <0.05 mm, <0.035 mm, <0.025 mm, <0.02 mm, <0.016 mm, <0.01 mm, <0.008 mm, <0.005 mm, <0.002 mm, <0.001 mm, <0.0005 mm	P, Ba, Sr, V, Ni, Cu, Co, Cr, Mo, Zn, Ga, Nb, Sc, Sn, Ta, Y, Yb, Be, Ce, Pb, Zr, La, Lu, W, Rb, Organism, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, $K^+ + Na^+$, $CaCO_3$, pH, SiO_2, P_2O_5, Fe_2O_3, Al_2O_3, CaO, MgO, K_2O, Na_2O, MnO, TiO_2	AB67-3, AB67-4, AB67-5, AB67-6, AB67-7, AB67-8, AB67-9, AB67-10, AB67-11, AB67-12, AB67-13, AB67-14, AB67-15, AB67-16, AB67-17, AB67-19, AB67-20, AB67-21, AB67-22, AB67-23, AB67-24, AB67-25, AB67-26, AB67-27, AB67-28, AB67-29, AB67-30, AB67-31, AB67-32, AB67-33, AB67-34, AB67-35, AB67-36, AB67-37, AB67-38, AB67-39, AB67-40, AB67-41, AB67-42, AB67-43, AB67-44, AB67-45, AB67-46, AB67-47, AB67-48, AB67-49, AB67-50

Table 2. The eigenvalue of Q-mode varimax factor from core AB-67

Number	Grain size composition			Geochemical composition		
	Eigenvalue	Contribution	Add up/%	Eigenvalue	Contribution	Add up/%
1	36.8	78.3	78.3	46.8	99.5	99.5
2	5.8	12.4	90.7	0.14	0.3	99.8
3	1.9	4.2	94.9	0.04	0.1	99.9

precipitation factor are decisive to the grain size composition. The first main factor has a contribution of 99.5% in geochemical composition, showing that temperature factor plays a decisive role on the change of geochemical composition.

3 Identification factors

From the sedimentary model of the core AB-67, the three deciding varimax factor of grain size are sedimentary factor, sea level factor and precipitation successively. According to traditional sedimentology, middle grain size has a proportional relationship with sedimentary rate in end-sediment. Comparing with Md curve in Figure 1, we may find that the first factor (Fig. 2a) has a good positive correlation relationship with Md. Thus, we can call the first factor sedimentary rate factor. From sedimentary facies of the core, it is obvious that its lower part is continental, sea level is lower; its higher part (0 - 20 cm) is marine, sea level is higher, the sea level can't rise and fall extravagantly on the scale of decades. Thus, the second main factor (Fig. 2b) is sea level factor; the remainder is precipitation factor (Fig. 2c). It is well related with sedimentary rate in a short period.

In the sedimentary model of the core AB-67, the first main factor of geochemical composition is temperature factor. Its second main factor is actually the negative correlation function of the first main factor. This two varimax factors explained 99.8% of the total variance in geochemical composition. It is thus clear that this is temperature factor. On tendency of the first main factor (Fig. 2d), the lowest is at 10 cm depth, the highest is at 30 cm depth. Calculated by ^{210}Pb dating, the former is of the initial stage of the 20th century, the latter is the 18th century, called as "Little Ice Age". According to research on globe change (Yao *et al.* 1990), temperature in initial stage of the 20th century is higher than that in the 18th century. Thus, temperature factor is negative relation with temperature record. The second main factor is in agreement with temperature influence. The tendency of temperature change in whole core AB-67 is that temperature is lower before invasion of sea water, the lowest temperature is at 30 – 40 cm depth, called as "Maximum of Little Ice Age"; temperature is higher after transgression by ^{210}Pb dating, higher temperature is the 1950s, lower one in the 1960s and the 1910s. It closely agrees with 11-year running average temperature from Barrow Meteorological Observatory.

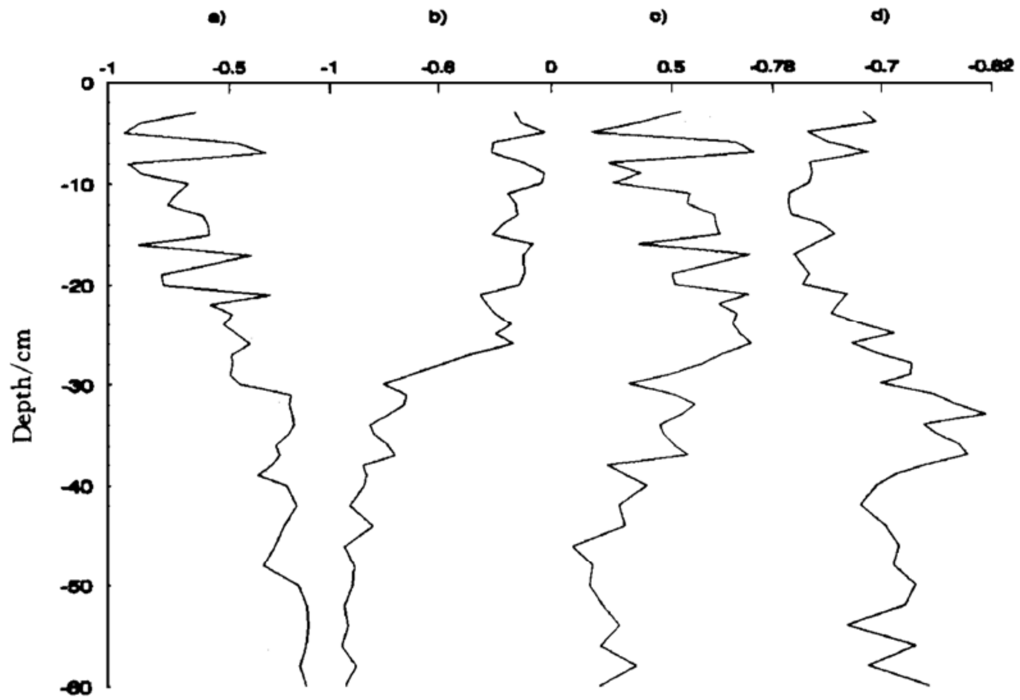

Fig. 2. The Q-mode factor identification of grain size and geochemical composition in core AB-67.

4 Transfer function

The transfer function of sedimentary rate is:

$$Y_1 = K_1X_1 + C_1 \quad (1)$$

here, Y_1 is sedimentary rate, X_1 is sedimentary rate factor, K_1 and C_1 are unknown constants. From change tendency of temperature factor, temperature is the lowest in 32 – 33 cm depth (AB67-33) of the core. In globe change, it corresponds to about AD 1694 (Schneider and Mass 1975); 6 – 7 cm depth of the core (AB67-7 sample) is also the cold period. In high latitude zone, temperature drop down strongly, and the higher latitude is, the greater temperature drop down. Its period is about 1917 (Vinnikov *et al.* 1980). So, we get $K_1 = 0.2811$, $C_1 = 0.3009$. Substituting into equation (1), it is obtained that the mean sedimentary rate of the core is 0.9 mm/a, this is in agreement with 1.2 mm/a of mean sedimentary rate by ^{210}Pb dating. It shows that the transfer function of sedimentary rate is accurate.

The transfer function of sea level is:

$$Y_2 = K_2X_2 + C_2 \quad (2)$$

here, Y_2 is sea level height (based on invasion), X_2 is sea level factor, K_2 and C_2 are unknown constants. Sea level height at present is 2.2 m, its sea level factor is at 2 - 3 m depth (because top 0 - 2 cm is absent). Sea level height is 0 m on transgression, its sea level factor is at 31 - 32 cm depth. Thus, we get $K_2=5.4175$, $C_2=3.9129$.

The transfer function of precipitation is:

$$Y_3 = K_3X_3 + C_3 \quad (3)$$

here, Y_3 is annual precipitation, X_3 is precipitation factor, K_3 and C_3 are unknown constants. 11-year running average precipitation was calculated for 1921 - 1994 precipitation data from Barrow Meteorological Observatory. According to sedimentary rate transfer function, to determine the samples in this period, to calculate linear interpolation, and to evaluate its correlation coefficient, we get: $R=0.912$, regress coefficient $K_3=208.48$, $C_3=43.3276$. Precipitation factor lags behind the precipitation for 8 a.

The transfer function of temperature is:

$$Y_4 = K_4X_4 + C_4 \quad (4)$$

here, Y_4 is mean annual temperature, X_4 is temperature factor, K_4 and C_4 are unknown constants. 11-year running average temperature was calculated for 1921 - 1994 temperature data from Barrow Meteorological Observatory. According to sedimentary rate transfer function, to determine the samples in this period, to calculate linear interpolation, to evaluate its correlation coefficient, we get $R = -0.878$, regress coefficient $K_4=-19.3228$, $C_4=-26.5489$.

5 Reconstruction of sedimentary environment of core AB-67

According to these transfer function, to substitute their factor data, we reconstruct sedimentary rate, sea level, precipitation and temperature record (Table 3). In micropoleontology, *Elphidium asklundi* and *Elphidium excavatum alba* are not seen in lower part of the core (29 - 60 cm), but they are extensively distributed in upper part of the core (0 - 29 cm).

According to study of McDougall *et al*. (1986), these two foraminifers in Alaska, show warmer marine environment. From temperature record in this paper, the temperature is obviously different around 1917. It was cold before that year, and it was warm afterwards. It is clearly in good agreement with environment change of foraminiferal fauna indicators.

6 Conclusions

(1) In the reconstruction of sedimentary rate curve, we determine the sedimentary period of each layer in core AB-67. Bottom sediment period begins in the latter half of the 16th century.

(2) In the research of sea level change, we clarify the sea level change curve of Elson Lagoon. According to grain size, geochemical composition and micropoleontology combination, marine deposit begins in 20 cm depth, its period is the latter half of the 18th century. It is earlier than one by ^{210}Pb dating. Mean uplift speed of sea level is 10 mm/a over the last 200 a.

Table 3. Reconstruction of sedimentary environment of Core AB-67

Number of sample	Sedimentary rate /(mma^{-1})	Sedimentary time /(AD)	Sea level height /m	Annual precipitation /mm**	Mean annual temperature /℃
AB67-3	1.223823	1972.995	2.200	156.543	−12.7496
AB67-4	0.561233	1960.000	2.326	119.123	−12.939
AB67-5	0.388934	1938.235	2.795	78.3508	−11.9757
AB67-6	1.690295	1922.422	1.761	202.735	−12.252
AB67-7	2.029561	1917.000	1.753	218.963	−12.82
AB67-8	0.429572	1902.897	2.395	93.3622	−11.9938
AB67-9	0.582910	1882.680	2.791	121.136	−12.0368
AB67-10	1.134267	1869.694	2.731	97.0675	−11.9918
AB67-11	0.992732	1860.249	2.058	163.403	−11.7094
AB67-12	0.886092	1849.570	2.224	161.29	−11.7002
AB67-13	1.295670	1840.068	2.251	184.953	−11.7406
AB67-14	1.354765	1832.519	1.969	186.336	−12.1641
AB67-15	1.377904	1825.199	1.769	189.81	−12.3542
AB67-16	0.539017	1812.294	2.572	119.1	−12.0767
AB67-17	1.872914	1799.014	2.378	215.588	−11.791
AB67-19	0.817760	1785.838	2.392	148.311	−12.0084
AB67-20	0.838253	1770.702	2.308	150.965	−11.9008
AB67-21	2.087130	1762.341	1.503	214.88	−12.5317
AB67-22	1.386121	1756.338	1.656	188.461	−12.4057
AB67-23	1.651606	1749.704	1.820	204.586	−12.3164
AB67-24	1.540311	1743.430	2.130	200.992	−12.7269
AB67-25	1.698526	1737.241	1.824	206.898	−13.203
AB67-26	1.843229	1731.584	2.183	216.505	−12.5996
AB67-27	1.638717	1725.820	1.326	192.073	−12.974
AB67-28	1.649107	1719.737	0.754	175.252	−13.4552
AB67-29	1.621594	1713.622	0.119	146.083	−13.438
AB67-30	1.724251	1707.639	−0.422	110.852	−13.0071
AB67-31	2.336538	1702.599	0.031	149.663	−13.7461
AB67-32	2.310859	1698.296	0.000	168.996	−14.0558
AB67-33	2.345843	1694.000	−0.344	156.595	−14.4907
AB67-34	2.368422	1689.758	−0.699	138.331	−13.6126
AB67-35	2.300432	1685.473	−0.592	141.64	−13.798
AB67-36	2.154996	1680.979	−0.312	150.4	−14.1171
AB67-37	2.201385	1676.388	−0.183	162.627	−14.2355
AB67-38	2.103168	1671.739	−0.825	92.595	−13.6636
AB67-39	1.950119	1666.798	−0.749	108.59	−13.2201
AB67-40	2.294093	1662.055	−0.801	127.454	−12.9616
AB67-41	2.402600	1655.713	−1.093	103.213	−12.7304
AB67-42	2.251516	1647.109	−0.626	108.355	−13.0897
AB67-43	2.146805	1638.010	−1.186	62.623	−13.277
AB67-44	2.017555	1628.395	−1.005	80.7116	−13.2057
AB67-45	2.421848	1619.310	−1.030	77.5636	−13.5122
AB67-46	2.525401	1611.221	−1.187	88.9701	−13.3599
AB67-47	2.541298	1603.326	−1.124	103.5	−12.5507
AB67-48	2.515101	1595.415	−1.245	87.4918	−13.5238
AB67-49	2.442400	1587.345	−0.946	118.72	−12.8499
AB67-50	2.519000	1579.281	−1.174	86.4131	−13.745

*: The numeric bit of data in the table is not the precision of data; **: Its time is littler (earlier) 8 a than the age of sample.

(3) The tendency of temperature and precipitation shows that environment in the 16th – 17th century is colder and drier than today, temperature rose and precipitation fluctuated in the 18th – 19th century, or especially greatly in the 20th century. The frame of temperature fluctuation is verified by microponotoly assemblage in core AB-67.

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