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Lagoon sediments geochemistry and its significance in study of climatic and environmental changes in Barrow, Alaska

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Abstract This paper deals with the features and distribution of chemical elements in the Borecore AB-67 (60 cm long, it covered a time span of past 450 a) from Elson Lagoon in Barrow, Arctic Alaska. The analysing data show that concentration of major elements, trace elements, rare and rare-earth elements are quite different between the upper part (0 - 20 cm) and the lower part (20 - 60 cm). And the correlation between contents of clay and organic material and concentration of chemical elements are discussed. Based on the characters of sediment geochemistry of Borecore AB-67, the history of climatic and environmental changes in Barrow in the past 450 a can be reconstracted as follows: 1) Relatively cold and dry with low sea level stage occurred prior to 1740 A. D.; 2) It was becoming warm accompanied by transgression from 1740 A. D. to 1827 A. D.; 3) From 1827 A. D. to 1994 A. D. (0 - 20 cm), it was fluctuated warming accompanied by continuous transgression, in this period relatively cold appeared around 1935 A. D. and 1969 A. D..

Key words Arctic, Barrow, Lagoon, geochemistry, climate.

1 Introduction

Chemical compositions of lagoon sediments originated mainly from weathering rocks and soils in the catchment area. Chemical elements are released due to solution, ion exchangeble process and leaching process, etc. and then to be transported and deposited into lakes. The distribution, transportation and accumulation of chemical elements or especially the trace elements not only depend on chemical properties themselves but also are closely correlated to local and global climate, and bioecological environmental condition. Therefore a research on geochemistry in lake core not only can provide information about weathering degree, source and migration of elements, but also reconstract the history of paleoclimate and environmental changes in the area. This study deals with the sediment geochemistry of Elson Lagoon in Barrow of Alaska. We believe the results of the research are of some benefits for the study of global climatic and environmental changes. The Barrow is located in the low-lying Arctic Coastal Plain on the northeast Alaska (71°20′N, 156°40′W), facing the Chukchi Sea to the west and the Beaufort Sea to the north (Fig. 1). The climate is extremely cold in Barrow of Alaska. The mean annual temperature is −12.4℃. The summer and winter mean temperatures are of 2℃ and −29℃ respectively, but the variation of annual temperature is large. According to the record of NOAA Station in Barrow, Alaska during 1977 – 1993, the highest annual temperature in 1989 is 2.1℃ higher than the average temperature of 17 a, the lowest annual temperature in 1984 is 4.6℃ lower than that of 17 a.

As a general rule, physical weathering, mechanical transportation are dominant in Barrow, Alaska, most of sediments are debris and sands. But chemical weathering is obvious in summer. The content of silty-clay and the enrichement of chemical elements with clay and organic matter in lake sediments reflecte climatic change in the region.

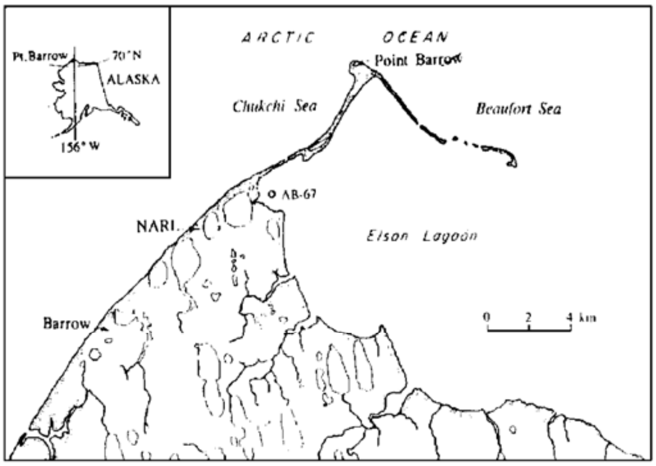

Fig. 1. The map of Barrow, Alaska and the location of sediment core AB-67 in the Elson Lagoon.

Prof. Zhang Qingsong and Mr. Hou Shugui made an investigation in Barrow between mid August and early September, 1994, and took the Borecore sample AB-67 by drilling, which provided the record data in the past 450 a.

2 The method of study

The Borecore AB-67 was drilled by a piston sampler in the Elson Lagoon at a depth of 2 m and about 2 km away from the coast (Fig. 1). The total length of the core is 60 cm. The upper part of core (0 – 40 cm) was divided at an interval of 1 cm slices, the lower part (40 – 60 cm) at an interval of 2 cm for chemical, microfossil, sediment, isotope analysis. The samples were air-dried, then processed through a 0.1 mm mesh screen after pulverizing with an agate mortaer for analysis of major elements and trace elements, rare and rare-earth elements.

Following the melting of samples with HNO_3-$HCLO_4$-HF, the concentration of trace elements, rare and rare-earth elements were determined by ICAP-9000. For B the samples were melted by H_3PO_4-HNO_3-$HClO_4$-HF, for major elements, by $LiBO_2$. The limits of the precision (mg/kg) are: K-0.1220, Na-0.238, Ca-0.0081, Mg-0.0246, Fe-0.006, Cu-0.005, Co-0.004, Zn-0.0035, Mn-0.0025, Ni-0.0064, V-0.003, Ba-0.0026, Sr-0.0014, B-0.024, P-0.116, Li-0.0028, Pb-0.023, Cr-0.0092 (Chen 1988).

The data of chemical analysis were treated by statistical technique, e.g. multivariable statistical analysis including cluster, factor, major component, etc..

3 The results and discussion

3.1 Sediment environmental parameters

3.1.1 Salinity

Elson Lagoon is the open water area, connecting with the Beaufort Sea. The salinity is 31.13 g/l.

3. 1. 2 pH

pH is used to measure of the acidity and moisture capacity of sediment environment. Here pH decreases gradually from the lower part to the upper part of the Borecore AB-67. Below 33 cm, the range of the pH is from 8. 18 to 8. 86, the mean value is 8. 54. Above 33 cm, the pH is less than 8 with the exception of a few layers, which reflected that below 33 cm, the sediment environment was terrestrial with alkalinity when it was arid continental climate in Barrow; but above 33 cm, pH is similar with that of modern shallow sea or shore deposits with intermediate to alkalinity, suggesting it was moist climate in Barrow.

3. 1. 3 Organic matter

Contents of organic matter increased from lower to upper section in AB-67 sediment core. Contents are generally less than 2. 0%, the mean value is 1. 09% below 32 cm depth, the mean rose to 2. 56% between 32 cm and 20 cm depth. Upper 20 cm section, the contents of organic matter are higher, average is 2. 56%, the maximum value of organic contents are as high as 7. 48% – 10. 76% at 16, 9, 3 cm layers. According to the description of lithological characters of the core, dark grey silt and clay are dominant from belove 20 cm, suggesting the temperature and moisture was rising, aquatic plants luxuriated in the Lagoon, there are a large number of organic debris in the sediment layers. Because Barrow is located in Arctic tundra, annual mean temperature was very low, the decomposing velocity of plants was relatively low.

3. 1. 4 Boron

B is the important element which is used to distinguish marine deposits from terrestrial deposits. In general, if concentration of B is more than 50 mg/kg in sediments, it would be marine deposits, <50 mg/kg, it would be terrestrial (Ren and Wang 1981). Below 50 cm of the Borecore AB-67. the mean content of B is 46. 5 mg/kg, suggesting that terrestrial deposits are dominant. At a depth of 50 – 31 cm, B is 53. 5 mg/kg, at a depth of 30 – 20 cm, B is 65 mg/kg, showing that it was interim stage from terrestrial to marine facies. Upper 20 cm, the mean content of B is 63 mg/kg, suggesting a shallow sea or lagoon environment. In partial layer, the content of B is 45 mg/kg at 7 cm probably showing marine regression.

3. 2 Distribution characters of chemical element assemblages in the Borecore AB-67

Major elements SiO_2, Fe_2O_3, Al_2O_3, etc. are mainly components of sediments, which account for 80% – 99% of total amount. The frost, physical-weathering and mechanical transportation are dominant in the Barrow region, the contents of SiO_2 are very high, the average in the Borecore AB-67 is 85. 24% high. In the lower part (20 – 60 cm), SiO_2, Fe_2O_3, and Al_2O_3 account for 83. 60%, 2. 52%, 5. 13% respectively, while in the upper part (0 – 20 cm), SiO_2 decreases by 76. 24%, Fe_2O_3 and Al_2O_3 are opposite to SiO_2, increase up to 3. 39 and 7. 21%, indicating a strengthening of chemical weathering which resulted in leaching of SiO_2 and enrichment of Al_2O_3 and Fe_2O_3 (Fig. 2) was significantly increased.

Table. 1 show the concentration of trace elements, rare and rare-earth elements, dispersed elements in sediments of the Borecore AB-67. Overlapping the curves of trace elements Cu, Pb, Zn, Ni in Fig. 2, it is found that 20 cm depth can be seen as a significant limit of the distribution of trace elements. The concentration of Cu, Pb, Zn, Ni are low below 20 cm, the average of Cu is 13.58 mg/kg; Pb: 11.94 mg/kg, Zn: 55.36 mg/kg; Ni: 17.58 mg/kg; while above 20 cm, they are doubled. In general, these trace elements are apt to be bound to <63 μm, <2 μm silty-clay fraction in sediments and are carried by the silty-caly partion (Forstner 1981). The variation of trace elements, organic matter together with silty and clay is shown in Fig. 3, the correlation coefficient is 0.80 ($n=50, p=0.01, r=0.354$). The results of cluster analysis of chemical elements indicate that the trace elements (Cu, Zn, Pb, Se, Y, Zr, Li, Yb, Sr, etc.) belong to same assemblage, bearing an close positive linear relationship with a coefficient of $R=0.95$ ($n=50$, $p=0.01, r=0.354$). Light rare-earth element and rare elements (Nb, Ce, Rb) belong to another assemblage, $R=0.70$, which are almost in thick debris containing residue weathering minerals. These trace elements, rare and rare-earth elements and dispersed elements with quite different chemical properties may appear in the assemblage with similar distribution patterns in the sediment core due to be linked to the same type of "carrier particles" and similar transportation and sediment process. A comprehensive analysis of chemical elements and environment parameters show that the first factor is the organic matter, the eigenvalue is 19.3334, the accumulation rate is 40.2730. It is obvious that organic matter is the most important factor in the distribution and migration of trace elements, rare and rare-earth elements in the Barrow region. The contents of chemical element assemblages including Y, Ni, Cu, Co, Mo, Zn, Ga, Sc, Sn, Ta, V, Yb, Be, Zr, Li, W in upper part of 20 cm are more than those below 20 cm, suggesting that the catchment has been apparently affected by chemical and biological weathering which resulted in crumbling and breaking down of bedrock into smaller pieces, such as clay and colloid. Chemical elements are released from the bedrock, bound to the clay and colloid and transported with these suspended sediments.

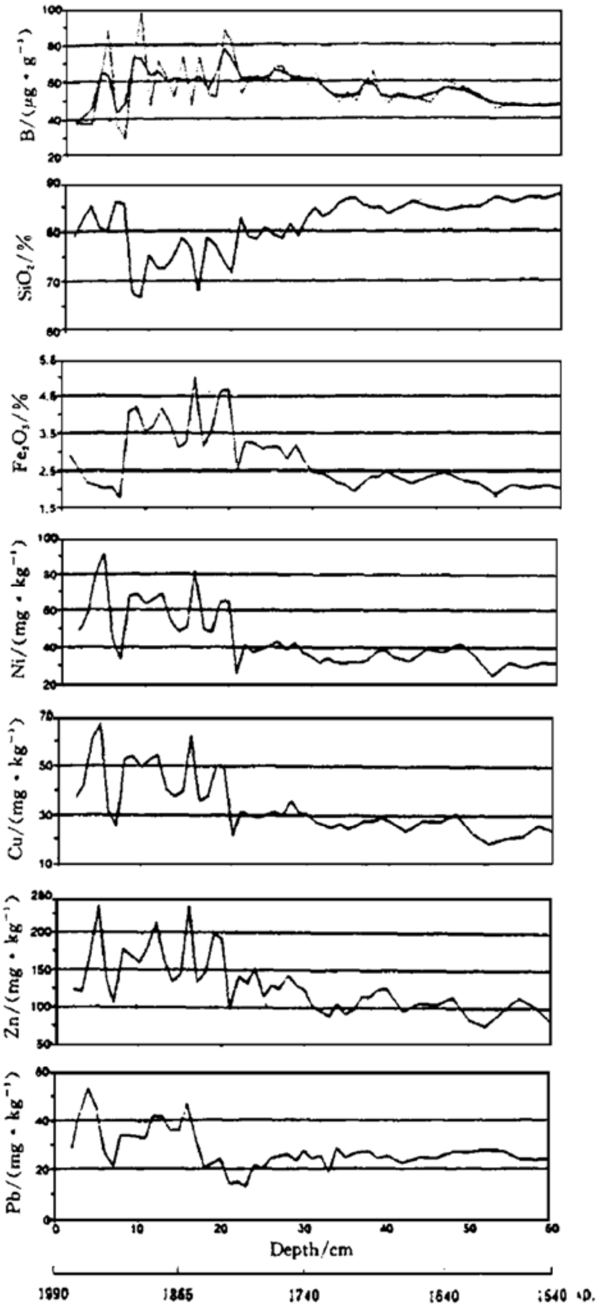

Fig. 2. Concentration variation of B, SiO_2, Fe_2O_3, Ni, Cu, Zn, Pb through Borecore AB-67 in the Elson Lagoon in Barrow, Alaska.

Geochemical zones are established by the cluster analysis of chemiclal element data and ^{210}Pb radiation and sedimentology dating (Fig. 4):

Table 1. Contents of chemical elements of AB-67 sediment core in the Elson Lagoon of Barrow, Alaska (* Unit: mg/kg)

Sampling depth /cm	Ni*	Co*	Cu*	Zn*	V*	Mo*	Ga*	Ta*	Li*	Nb*	Rb*	Fe /%	Al /%
AB-67 0 - 2	25.18	11.93	23.63	63.20	83.50	0.33	11.15	0.80	24.14	9.93	42.32	2.89	6.81
AB-67 2 - 3	29.17	14.61	21.03	60.35	93.05	0.41	11.46	0.78	25.80	20.21	103.10	2.17	3.92
AB-67 3 - 4	41.20	18.74	30.30	86.40	129.10	0.59	15.44	1.04	37.07	21.97	139.90	2.10	3.89
AB-67 4 - 5	45.50	19.14	33.45	118.10	165.05	0.66	19.26	1.27	46.76	14.96	66.25	2.02	3.80
AB-67 5 - 6	22.48	11.21	16.05	68.35	80.25	0.33	9.78	0.65	23.73	6.54	45.41	2.07	3.75
AB-67 6 - 7	16.63	9.81	12.74	52.50	66.15	0.30	8.17	0.55	19.48	2.34	31.91	1.73	4.41
AB-67 7 - 8	33.60	14.83	26.40	88.50	114.35	0.55	14.53	0.99	32.92	9.45	36.81	4.06	8.70
AB-67 8 - 9	34.27	15.11	26.88	84.75	115.20	0.54	14.75	0.99	32.13	9.20	61.35	4.21	8.81
AB-67 9 - 10	31.56	14.85	24.75	79.95	102.50	0.47	13.16	0.89	30.55	11.29	50.30	3.54	8.11
AB-67 10 - 11	32.94	15.14	26.37	90.40	101.45	0.39	13.15	0.91	31.44	9.63	55.25	3.70	8.36
AB-67 11 - 12	34.36	17.07	27.14	106.95	127.45	0.52	15.36	1.01	34.80	14.30	76.10	4.18	9.26
AB-67 12 - 13	27.34	13.26	20.29	81.75	101.55	0.47	12.95	0.86	27.68	9.65	69.95	3.77	8.19
AB-67 13 - 14	24.09	12.11	18.73	66.70	91.55	0.43	11.69	0.78	24.71	11.74	79.75	3.08	7.00
AB-67 14 - 15	25.36	13.53	19.85	72.50	88.70	0.43	11.96	0.81	26.20	8.74	72.40	3.28	7.41
AB-67 15 - 16	41.28	18.16	31.22	118.00	133.00	0.60	18.16	1.21	40.43	10.57	101.8	5.03	10.20
AB-67 16 - 17	24.64	13.61	17.90	67.00	83.00	0.35	10.83	0.74	24.12	9.37	76.10	3.12	7.15
AB-67 17 - 18	23.86	12.21	18.88	73.90	101.15	0.44	12.85	0.84	27.98	9.96	50.30	3.59	7.73
AB-67 18 - 19	32.24	15.27	25.03	99.10	136.90	0.60	17.15	1.10	38.06	10.43	62.60	4.66	9.59
AB-67 19 - 20	32.46	15.35	24.83	95.40	133.20	0.57	16.97	1.08	37.07	9.02	65.05	4.68	9.48
AB-67 20 - 21	12.85	9.03	10.65	48.38	62.90	0.29	8.05	0.53	17.50	7.87	42.96	2.51	5.91
AB-67 21 - 22	20.63	11.53	15.98	71.10	89.00	0.34	11.12	0.72	23.53	8.64	50.30	3.28	6.98
AB-67 22 - 23	18.50	10.39	15.03	65.90	80.80	0.31	10.31	0.67	21.95	8.03	42.96	3.23	6.99
AB-67 23 - 24	19.30	13.76	14.67	76.50	81.70	0.40	10.89	0.71	22.14	10.45	45.41	3.08	6.46
AB-67 24 - 25	20.50	10.89	15.15	57.20	80.30	0.31	10.43	0.68	21.07	9.48	38.05	3.12	6.63
AB-67 25 - 26	21.53	11.26	15.80	64.50	80.05	0.36	10.62	0.70	20.86	8.50	58.90	3.12	6.52
AB-67 26 - 27	19.25	11.04	15.10	62.60	75.80	0.35	10.01	0.64	19.38	12.89	54.00	2.77	5.91
AB-67 27 - 28	21.19	12.13	18.09	72.10	83.10	0.36	10.91	0.71	20.96	12.11	66.25	3.20	6.41
AB-67 28 - 29	18.53	11.16	15.61	64.80	75.50	0.31	9.86	0.63	18.19	12.72	60.15	2.76	5.72
AB-67 29 - 30	17.42	11.31	15.25	62.15	71.50	0.31	9.16	0.60	17.30	12.64	72.40	2.46	5.12
AB-67 30 - 31	15.78	10.70	13.71	50.60	66.95	0.25	8.24	0.53	15.03	10.48	66.25	2.44	5.25
AB-67 31 - 32	17.14	10.80	13.02	47.42	64.25	0.24	7.95	0.52	15.42	12.06	65.05	2.34	5.08
AB-67 32 - 33	15.92	10.22	12.55	44.11	63.10	0.20	7.83	0.50	14.24	10.11	70.10	2.15	4.88
AB-67 33 - 34	15.83	10.60	13.44	53.50	63.20	0.27	8.14	0.53	14.53	11.18	58.90	2.13	4.67
AB-67 34 - 35	16.00	10.30	12.20	45.21	57.65	0.26	7.36	0.49	14.04	11.85	85.90	1.92	4.27
AB-67 35 - 36	15.82	10.57	13.06	49.07	62.10	0.26	7.67	0.50	14.43	13.26	81.00	2.12	4.73
AB-67 36 - 37	16.72	10.67	14.03	57.60	67.25	0.29	8.47	0.54	15.13	9.93	62.60	2.34	4.97
AB-67 37 - 38	18.80	11.41	14.02	57.05	64.35	0.29	8.47	0.55	15.03	12.91	73.65	2.33	4.81
AB-67 38 - 39	19.21	12.35	14.67	62.30	67.80	0.31	8.94	0.58	10.21	11.66	66.25	2.49	5.10
AB-67 39 - 40	17.37	11.37	13.84	62.85	62.20	0.26	8.03	0.53	14.83	10.96	82.20	2.33	4.73
AB-67 40 - 42	16.28	9.64	11.80	47.55	54.95	0.25	7.29	0.48	12.66	10.64	78.55	2.35	4.80
AB-67 42 - 44	19.51	10.97	13.98	53.50	65.20	0.26	8.45	0.54	15.23	11.72	88.35	2.24	4.96
AB-67 44 - 46	18.53	10.65	13.77	51.95	64.50	0.26	8.43	0.56	15.13	12.77	103.10	1.86	3.86
AB-67 46 - 48	21.14	11.71	15.42	57.20	73.85	0.29	9.68	0.62	17.40	12.86	82.20	2.03	4.05
AB-67 48 - 50	17.36	9.05	11.40	42.04	59.10	0.26	8.10	0.52	13.94	11.55	95.70	2.02	4.23
AB-67 50 - 52	12.16	8.05	9.35	37.63	47.89	0.19	6.66	0.44	11.66	11.03	93.25		
AB-67 52 - 54	15.98	9.53	10.47	47.97	57.05	0.25	8.00	0.53	12.75	13.78	98.20		
AB-67 54 - 56	14.26	9.22	10.70	56.90	54.05	0.19	7.49	0.49	12.06	12.13	90.80		
AB-67 56 - 58	16.15	9.25	13.01	50.70	56.55	0.24	7.94	0.52	13.05	12.42	90.80		
AB-67 58 - 60	15.54	9.49	11.67	40.25	53.35	0.21	7.61	0.50	11.86	12.75	95.70		

Zone 1, below 32 cm in the Borecore AB-67 (before 1740 A. D.): it was comparatively cold and dry with low sea level in Barrow, Alaska. Terrestrial deposits were dominant containing many coarse grain particles with less component of clay and organic matter. B < 50 mg/kg, the contents of SiO_2, Fe_2O_3, and Al_2O_3 were relatively high, but trace elements, rare and rare-earth elements were apparently low. Light rare-earth elements bound to SiO_2 were higher.

Zone 2, 20 - 30 cm (from 1740 A. D. to 1827 A. D.): it was becoming warm gradually and transgression commenced. The contents of trace elements, rare and rare-earth elements and major elements Fe_2O_3, Al_2O_3 were increased, but the contents of SiO_2 was decreased.

Zone 3, about 20 cm (from 1827 A. D. to 1994 A. D.): it was fluctuated warming accompanied by continuous transgression. The contents of B was 79.66 – 88.29 mg/kg, organic matter was greatly enrichmented, the maximum amounted to 10.76%. Major elements Fe_2O_3, Al_2O_3, trace elements, rare and rare-earth elements were enrichemented by finer particles and colloid, transported and deposited in the Lagoon and shore environment marked with Cl^-, $K^+ + Na^+$, suggesting that warm climate leads to strengthening of chemical weathering process in the catchment and multiplying of vegetation. The reconstruction indicates that cool condition appeared around 1935 A. D. (7 cm depth) and 1969 A. D. (3 cm depth).

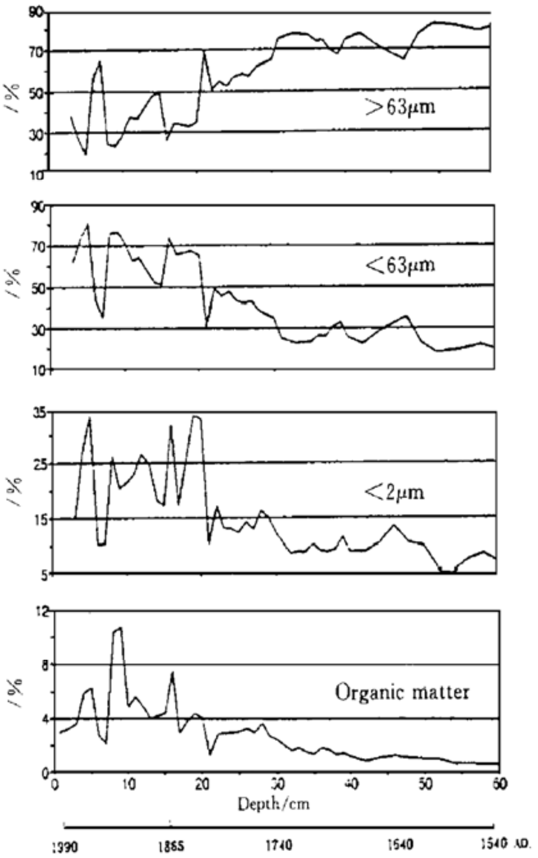

Fig. 3. Variation of depositional component (>63 μm, <63 μm, <2 μm) and organic concentration through Borecore AB-67 in the Elson Lagoon in Barrow, Alaska.

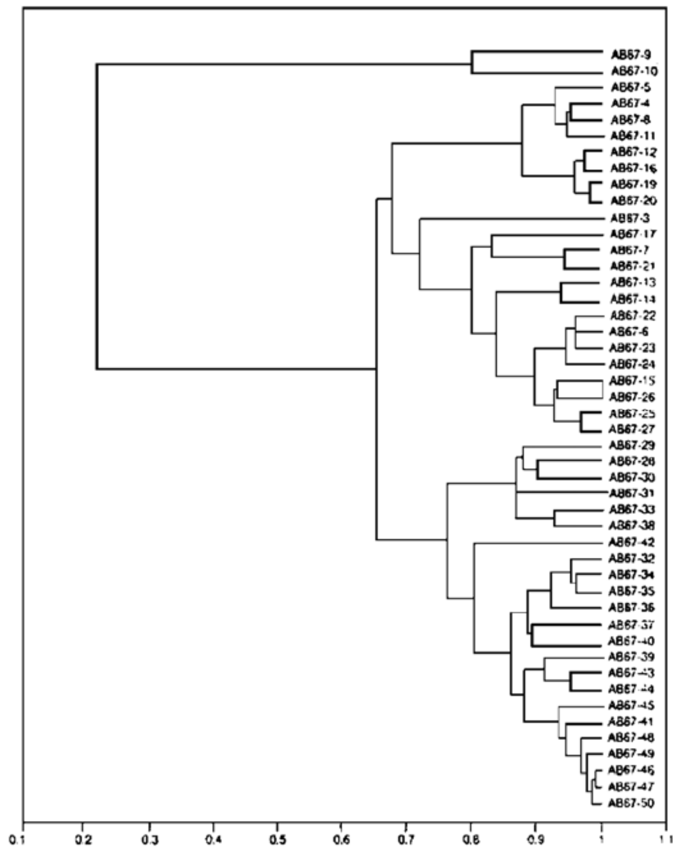

Fig. 4. The stratigraphic cluster of geochemistry though the Borecore AB-67 in the Elson Lagoon in Barrow, Alaska.

As compared with the researches of tree-ring in the Northern Fennoscandinavia and ice core to the Qinghai-Tibetan Plateau and Greenland (Briffa *et al.* 1988; Dlaz *et al.* 1989; Jones *et al.* 1986; Yao and Thompson 1992; Johnsen *et al.* 1970), it is found that the climatic change recorded in the Borecore AB-67 of Elsoon Lagoon is similar with the results, such as the data of ice core in Greenland, which indicated relatively warm period between 1700 A. D. and 1800 A. D. and obviously cool condition from 1850 A. D. to 1860 A. D. , the record in AB-67 Borecore showed it was fluctuated warming from 1736 A. D. in the Barrow area and relatively cool period around 1852 – 1861 A. D. . The study of tree ring in Northern Fennoscandianavia indicates that the particularly warm period is from 1826 A. D. to 1831 A. D. . The reconstruction using geochemistry of chemical elements in the Borecore AB-67 shows that the beginning of a clear warm period is about 1827 A. D. ,the results are completely identical with those done in the Northern Fennoscandinavia.

4 Conclusion

The reconstruction of paleoenvironment and paleoclimate in the Barrow region, Arctic Alaska by using the geochemical characteristics of the chemical element assemblages in the sediments core is a new subject. At a depth of 20 cm of the Borecore AB-67(about 1827 A. D.), it is the important limit. Above 20 cm, the contents of trace elements, rare and rare-earth elements increased obviously, and the major elements Fe_2O_3, Al_2O_3 as well as, but SiO_2 decreased; the contents of B is more than 50 mg/kg, organic matter and fraction of $< 63\ \mu m$ and $< 2\ \mu m$ are increased which is closely correlated with trace elements and rare, rare-earth elements suggesting that it was particularly warm periods with continuous transgression around 1827 A. D. , which leads to multiplying of vegitation and strengtheing of chemical biological weathering processes, cold period aroung 1935 A. D. and 1969 A. D. . The results are similar with the study of the reconstructing summer temperatures in the Northern Fennoscadinavia, etc. , which provides scientific basis for global climatic and environmental changes.

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