Strontium and neodymium isotopic compositions of detrital sediment of NS90-103 from South China Sea: Variations and their paleoclimate implication

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Abstract Strontium, neodymium isotopic compositions and trace elements of the detrital sediments of Core NS90-103 from South China Sea were analyzed. The results show that the $^{87}Sr/^{86}Sr$ ratios of the detritus during the last glacial range from 0.722 4 to 0.723 0. They are significantly higher than those during the Holocene and the maximum of the last interglacial, which range from 0.721 0 to 0.721 7. This indicates stronger continental weathering during the last glacial. On the other hand, the $^{143}Nd/^{144}Nd$ ratios of these detritus are higher during the last glacial too, similar to the variation of the $^{87}Sr/^{86}Sr$ ratios. The trace element geochemistry of these detritus indicates that more authigenic sediments, such as ferromanganese, during the last glacial may partly contribute to the increase of $^{143}Nd/^{144}Nd$ ratios. Furthermore, much more detritus from continent of South China to the north of the South China Sea may probably contribute to $^{143}Nd/^{144}Nd$ ratios increase during the last glacial, which was the result of the enhancement of northeast monsoon.

Keywords: Nansha Islands, detrital sediments, strontium and neodymium isotopes, paleoclimate.

The geochemical records of deep-sea sediments are part of the major subjects of the studies of the past climate change. For instance, the rhythmic change of global climate can be reconstructed by oxygen and carbon isotopes of foraminifer shells, and the past sea surface temperature records can be established by long train unsaturation alkenones, and the nutrient circulation in the sea water can be tracked from N, P and Cd elements. All the studied materials above are biological-derived, such as microfossil. On the other hand, in addition to biological-derived materials, the detrital sediments also contain plenty of paleoclimatic information. For example, the strontium and neodymium isotopes mark the source of the detritus, from which the change of eolian flux and marine currents can be tracked[1—4]. Also, detrital strontium isotope is one of the indexes of continental weathering intensity and it can link the paleoclimate records in sea and on land[5, 6].

The South China Sea (SCS) is the largest marginal sea at the west Pacific. The major part of the sediments in SCS are made up of detritus from continent carried by rivers[7]. Eolian and volcanic materials may also contribute to these detrital sediments. Changes of the contribution proportion of these sources may indicate the change of monsoon and marine currents. In former study by Gui et al., strontium and oxygen isotope were used to track the sources of the surface sediments of Nansha Islands, the south part of the SCS, and some discussion on paleoclimate implication had been made[8].

In this study, we measured the variation of the strontium and neodymium isotopes of the detrital sediments of Core NS90-103 from Nansha Islands. Trace element contents of some of the detritus were also included to further understand the paleoclimate information of the SCS and surrounded continents, embodied within these detritus.

1 Samples and experiment

The piston core NS90-103 was collected at the west slope of the southern SCS under water depth of 1584 m. Age model of this core was determined by disequilibrium uranium series method and oxygen isotope stratigraphy of plankton foraminifer *Globigerinoides sacculifer*. Details of the age model refer to Wei et al.[9].

All the experiments of strontium and neodymium isotopes and trace elements were taken in Isotope Geochemistry Laboratory, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences. The sediments were first wet sieved through 100 mesh to get rid of the big grains, then soaked in 5% acetic acid for 24 hours to dissolve carbonate. Leachate was removed by centrifugal, and sediments were washed by de-ionized water for 5 times before they were gathered. Finally, the sediments were fused at 670℃ for 30 minutes to destroy organic materials.

The samples for Sr isotope measurement were digested by mixed acids of HF, HNO_3 and HCl. Sr was purified and gathered through Dowex 50 cation resin column. Sr isotopes were measured on VG 354 mass spectrometry. They were all calibrated according to $^{86}Sr/^{88}Sr$=0.119 4, and NBS SRM987 was used to check the accuracy of the measurement, yielding the $^{87}Sr/^{86}Sr$ ratio as 0.710 346±10(2σ). Sr isotope compositions of the sediments are list in table 1, and the Sr blank of the whole procedure was less than 10^{-9}g.

Table 1 Sr isotopic composition of the detrital sediments of Core NS90-103

Sample No.	Depth /cm	$^{87}Sr/^{86}Sr$ a)	Sample No.	Depth /cm	$^{87}Sr/^{86}Sr$ a)	Sample No.	Depth /cm	$^{87}Sr/^{86}Sr$ a)
Si-1	1	0.721 220±14	Si-73	181	0.722 160±18	Si-163	406	0.722 115±7
Si-5	11	0.721 785± 9	Si-79	196	0.722 888±10	Si-167	416	0.721 739±11
Si-11	26	0.722 897±21	Si-91	226	0.722 454±10	Si-175	436	0.721 840± 8
Si-17	41	0.722 999±14	Si-103	256	0.723 151±12	Si-179	446	0.722 356± 8
Si-21	51	0.723 026± 8	Si-107	266	0.721 956± 6	Si-187	466	0.721 852± 5
Si-25	61	0.722 421±12	Si-111	276	0.722 039±10	Si-193	481	0.721 946±13
Si-29	71	0.722 882± 9	Si-119	296	0.722 015± 9	Si-199	496	0.721 858±13
Si-35	86	0.722 635±11	Si-125	311	0.721 217± 8	Si-205	511	0.721 694±11
Si-41	101	0.723 003±10	Si-133	331	0.721 486±33	Si-209	521	0.721 884±10
Si-49	121	0.722 421± 9	Si-137	341	0.721 772± 9	Si-215	536	0.721 844±10
Si-57	141	0.722 648±11	Si-143	356	0.721 549± 9	Si-219	546	0.721 088± 6
Si-61	151	0.723 128±11	Si-147	366	0.721 440± 8			
Si-65	161	0.722 872±13	Si-157	391	0.721 080± 7			

a) Calibrated according to $^{86}Sr/^{88}Sr$ = 0.119 4, and errors are 2σ.

Samples for Sm and Nd isotope measurement were precisely weighted, and well mixed with $^{149}Sm+^{145}Nd$ spike before they were digested by mix acids. Sm and Nd were also purified and collected by ion exchange method and measure on VG 354 mass spectrometry. Nd isotopes were calibrated according to $^{146}Nd/^{144}Nd=0.721\ 9$, and the measurement of La Jolla, a USGS standard Nd solution yielded the $^{143}Nd/^{144}Nd$ as 0.511 850±6(2σ). The results of these sediments are listed in table 2, and the Sm, Nd blank were less than 10^{-10} g.

Trace elements were measured on PE Elan 6000 ICP-MS by external standard calibration method. Details of the analysis refer to Liu et al.[10], and the results are listed in table 3.

Table 2 Sm and Nd isotopic composition of the detrital sediments of Core NS90-103

Sample No.	Depth /cm	Sm /μg • g^{-1}	Nd /μg • g^{-1}	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ a)	T_{DM} b)/Ga	ε^{0}_{CHUR} c)
Si-5	11	6.058	33.96	0.102 4	0.512 212±12	1.28	−8.31
Si-21	51	5.889	33.42	0.106 5	0.512 223±16	1.32	−8.10
Si-25	61	6.986	33.69	0.125 2	0.512 221±17	1.60	−8.13
Si-41	101	5.755	32.76	0.106 2	0.512 197±16	1.35	−8.60
Si-49	121	5.963	33.37	0.108 0	0.512 218±14	1.34	−8.19
Si-61	151	5.831	33.12	0.106 4	0.512 189±13	1.36	−8.76
Si-73	181	6.027	33.17	0.109 8	0.512 244±21	1.33	−7.69
Si-103	256	5.945	25.34	0.141 8	0.512 080±14	–	−10.88
Si-107	266	4.807	27.07	0.107 3	0.512 083±11	1.53	−10.83
Si-125	311	5.883	31.98	0.112 2	0.512 098±15	1.58	−10.53
Si-157	391	5.493	30.47	0.103 8	0.512 138±10	1.40	−9.75
Si-163	406	5.187	29.40	0.106 7	0.512 072±15	1.53	−11.04
Si-199	496	5.647	31.89	0.107 0	0.512 147±16	1.43	−9.58
Si-219	546	5.505	30.82	0.107 9	0.512 135± 7	1.46	−9.81

a) Calibrated according to $^{146}Nd/^{144}Nd = 0.721\ 9$, and errors are 2σ. b) Present values for depleted mantle are $^{143}Nd/^{144}Nd = 0.513\ 15$, $^{147}Sm/^{144}Nd = 0.213\ 7$. c) Present value for CHUR reservoir is $^{143}Nd/^{144}Nd = 0.512\ 638$.

Table 3 Trace element composition of the detrital sediments of Core NS90-103 (unit: μg/g)

Element	Si-17	Si-45	Si-91	Si-107	Si-157	Si-205	Element	Si-17	Si-45	Si-91	Si-107	Si-157	Si-205
Li	72.86	80.31	77.12	76.37	73.95	63.79	Ba	661	727	827	722	749	754
Be	2.54	2.80	2.68	2.59	2.85	2.51	La	40.08	43.54	44.70	42.17	42.65	42.63
P	486	524	538	567	531	591	Ce	76.36	83.39	85.19	80.52	80.49	80.14
Sc	16.89	18.63	17.85	17.73	17.62	16.99	Pr	8.97	10.01	10.19	9.62	9.44	9.76
Ti	5135	5507	5746	5338	5571	5582	Nd	33.09	36.87	37.49	35.70	35.30	36.18
V	134.9	155.4	147.7	145.5	145.3	138.4	Sm	5.89	6.56	6.68	6.45	6.32	6.44
Cr	101.9	110.4	107.9	102.5	108.2	101.5	Eu	1.08	1.21	1.26	1.17	1.17	1.17
Mn	721	808	815	541	561	517	Gd	5.42	5.87	6.21	5.86	5.77	5.78
Co	20.44	21.15	20.16	18.28	17.89	16.79	Tb	0.85	0.93	0.95	0.90	0.90	0.89
Ni	65.01	59.46	58.36	53.31	53.73	50.48	Dy	4.53	4.93	5.10	4.75	4.79	4.66
Cu	53.61	51.16	61.57	58.43	49.29	59.27	Ho	0.96	1.04	1.07	0.99	1.02	0.98
Zn	251	175	258	216	174	233	Er	2.81	2.97	3.04	2.92	2.94	2.80
Ga	24.7	27.0	26.1	24.7	25.2	23.6	Tm	0.42	0.45	0.46	0.43	0.44	0.43
Ge	2.17	2.25	2.21	2.11	2.17	2.08	Yb	2.73	2.90	2.97	2.83	2.84	2.74
Rb	160.4	169.0	162.6	156.8	158.7	152.1	Lu	0.42	0.44	0.44	0.42	0.42	0.41
Sr	70.84	73.45	75.25	74.34	76.92	77.93	Hf	3.32	3.43	3.25	3.35	3.30	3.20
Y	25.87	28.28	28.60	26.61	27.58	26.25	Ta	1.37	1.39	1.45	1.35	1.39	1.37

(To be continued on the next page)

(*Continued*)

Element	Si-17	Si-45	Si-91	Si-107	Si-157	Si-205	Element	Si-17	Si-45	Si-91	Si-107	Si-157	Si-205
Zr	130.6	146.8	142.8	134.6	145.9	137.0	W	3.09	3.12	3.30	2.99	3.00	2.90
Nb	16.02	16.39	17.26	15.68	16.37	16.14	Tl	0.50	0.52	0.51	0.53	0.50	0.45
Mo	0.56	1.38	0.76	1.42	0.71	0.76	Pb	29.58	28.75	29.77	30.62	26.23	25.88
Sn	3.90	4.20	4.47	4.03	4.13	3.88	Bi	0.25	0.25	0.22	0.24	0.24	0.21
Sb	8.06	9.44	12.73	13.98	6.58	12.24	Th	18.16	19.58	19.52	18.63	18.94	17.96
Cs	8.67	9.78	9.18	9.27	8.99	8.45	U	3.14	3.42	3.48	3.33	3.33	3.16
Rb/Sr	2.26	2.30	2.16	2.11	2.06	1.95							

2 Discussion

2.1 Sr and Nd isotopic compositions of detrital sediments

As indicated by Wang, the carbonate contents of the sediments at depth above lysocline in SCS were severely diluted by detrital sediment and exhibit lower $CaCO_3$ contents during glacial periods [7]. The variation of the $CaCO_3$ contents of Core NS90-103 exhibits such a pattern. The maximum carbonate content, about 15% (weight percent), occurred in the Holocene. During the last glacial period, $CaCO_3$ contents were quite low, and the minimum value, about 4%, occurred in the Last Glacial Maximum, reflecting the severe dilution by continental detrital sediment from continents. On the other hand, $CaCO_3$ content of the sediments below 320 cm of Core NS90-103 did not differ much from each other, and were all about 8%. This may probably imply that the dilution from detritus could be roughly compensated by the improvement of carbonate productivity in surface water (fig. 1). Overall, detritus is the main sediment of Core NS90-103.

The carbonate free sediments of Core NS90-103 can be separated into two sections from top to bottom by Sr and Nd isotopic compositions (fig. 1). The upper section is represented by higher Sr and Nd isotopic compositions, with all $^{87}Sr/^{86}Sr>0.722\,2$ and $\varepsilon_{CHUR}(Nd)>-8.8$, and the lower section by lower Sr and Nd isotopic compositions, with $^{87}Sr/^{86}Sr<0.722\,1$ and $\varepsilon_{CHUR}(Nd)<-9.0$. The boundary of these two sections is located at about 250 cm. Comparing the oxygen isotope pattern of *G. saccurifer* with SPECMAP, the boundary is roughly equal to the end of oxygen event Stage 5.5 with age about 120 ka before present[11]. After the last glacial period, the Sr isotopic ratios of the sediments drop significantly.

The modification of Sr and Nd isotopes of these sediments from radioactive decay is neglectable because the half-life times of ^{87}Rb and ^{147}Sm are very long, 4.88×10^{10} a and 1.06×10^{11} a respectively. The Rb/Sr ratios of these sediments are less than 2.5 and Sm/Nd less than 0.19 (table 3). Variations of Sr and Nd isotopes from radioactive decays of ^{87}Rb and ^{147}Sm are undetectable during such a short period of 120 ka. Therefore, all the variations of the Sr and Nd isotopes of these sediments are caused by the change of the relative contribution of their sources.

Core NS90-103 is located at the offshore of the Southern Indo-Sino Peninsula, north of the estuary of Mekong River. The detrital sediments of the area near Core NS90-103 mainly come from Indo-Sino Peninsula, especially those input from Mekong River. The $^{143}Nd/^{144}Nd$ ratios of

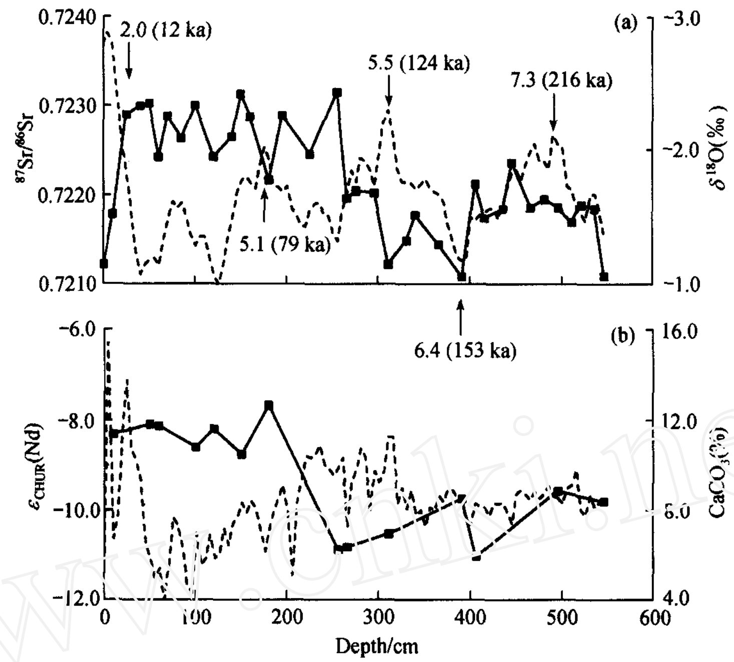

Fig. 1. Variations of Sr and Nd isotopes of Core 90-103 with depth. (a) Sr isotopes; (b) Nd isotopes. Dash line in (a) represents the pattern of planktonic oxygen isotopes after 3 points running smooth. Numbers represent oxygen events, and data within brackets are their ages. Dash line in (b) represents the pattern of $CaCO_3$[1)].

the river-carried detritus of Mekong are about 0.512 15, giving a Nd model age of 1.54 Ga (T_{DM}) with respect to depleted mantle[12]. The sediments of the lower section of Core NS90-103 have similar T_{DM} and $^{143}Nd/^{144}Nd$ ratios as that from Mekong river, indicating that detritus carried by Mekong may be the main part of these detrital sediments. However, sediments of the upper section differ much from those of the lower section in Sr and Nd isotopic compositions. They have higher $^{143}Nd/^{144}Nd$ ratios and younger T_{DM} (1.28—1.36 Ga except Si-25 sample). T_{DM} of the Si-25 sample is unexpectedly old, about 1.60 Ga due to abnormally high Sm/Nd ratios (about 0.125 2). It is still not known how it was caused. However, the $^{143}Nd/^{144}Nd$ ratios of Si-25 are still high, similar to other samples of the upper section. Nevertheless, the higher $^{143}Nd/^{144}Nd$ ratios and younger T_{DM} of the upper section sediments of Core NS90-103 indicate whether much more detritus from the geological bodies of younger T_{DM} were carried to this area or more authigenic sediments were produced during this period.

2.2 Variation of the production of authigenic sediments

Authigenic sediments are made up of biological-derived materials, such as $CaCO_3$, particle organic, barite and opal, authigenic clay and ferromanganese. They absorb dissolved Sr and Nd

1) Wei Gangjian, Oxygen, carbon and strontium isotopic compositions of Core NS90-103 and their paleoclimate implications, Dissertation for Master's Degree, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 1994.

from around seawater, and record the Sr and Nd isotopic compositions of the seawater. The ocean Sr isotope is homogeneous with $^{87}Sr/^{86}Sr$ ratio being about 0.709, which is much lower than the detrital $^{87}Sr/^{86}Sr$ ratios of Core NS90-103. If the amount of authigenic sediments increases, the detrital $^{87}Sr/^{86}Sr$ ratios will decrease. However, because most of the authigenic Sr are bounded in $CaCO_3$, but $CaCO_3$ in all the samples analyzed here had been leached by acetic acid, authigenic material may not contribute much to our Sr isotope variations. On the other hand, Nd contents in $CaCO_3$ are very low, less than 1 μg/g, but they are up to 200 μg/g to 500 μg/g in ferromanganese[13], much higher than in detritus. Moreover, global oceanic water Nd isotopes are not homogeneous, and Pacific seawater has higher $^{143}Nd/^{144}Nd$ ratios. The $\varepsilon_{CHUR}(Nd)$ of the Pacific seawater varied from −4.5 to −4.0 over the past 200 ka, which was much higher than those of detritus. Higher authigenic material production may significantly increase the $^{143}Nd/^{144}Nd$ ratios of the sediments.

In the upper section of Core NS90-103, Mn contents are higher than 700 μg/g, and the maximum is up to 815 μg/g. However, Mn contents of the sediments of the lower section are much lower, ranging from 500 μg/g to 560 μg/g (table 3). This indicates that during the last 120 ka, productivity of ferromanganese had increased significantly in this area. These ferromanganese carried more Nd with higher $^{143}Nd/^{144}Nd$ ratios than detritus from seawater to sediments, and to some extent contributed to the increase of the $^{143}Nd/^{144}Nd$ ratios of the upper section sediments of Core NS90-103. The surface biological productivity is considered to be higher during the last glacial in SCS. The increase of ferromanganese production happened synchronically with biological productivity increase, implying that there might be some close relationship between them.

However, the amount of authigenic sediment in the detritus for Sr and Nd isotope analysis is very small. This can be inferred from following geochemistry characters. First, the $^{87}Sr/^{86}Sr$ ratios of the upper section show no trends to decrease. Because some authigenic materials in addition to $CaCO_3$, such as ferromanganese, have pretty high Sr contents (several hundred to 1 000 μg/g), and lower $^{87}Sr/^{86}Sr$ ratios (about 0.709 2), if their amount is great, the $^{87}Sr/^{86}Sr$ ratios should dramatically decrease. Second, the REE patterns of these sediments are all close to unit when normalized to mean crust values (MCV) (fig. 2(a)). The Ce abnormal indexes, one of the indexes of authigenic sediments amount, Ce/Ce*, which is defined as $2Ce_n/(La_n+Pr_n)$, and Ce_n, La_n and Pr_n are normalized values, are all close to unit too (0.92 to 0.95). Third, the MCV normalized patterns of some nutrient elements, such as Ba, Cd, Ge, Ni, Co and P, and Mn, the main component of ferromanganese, are close to unit (fig. 2(b)). These nutrient elements are distributed in seawater similar to C, N and P, and usually concentrate in biological sediment[15]. In fig. 2(b), the MCV normalized values of Mn and P are even slightly less than 1. This may probably be due to the scatter of P and Mn data in MCV tables[14]. Anyhow, none of these nutrient elements exhibit significantly higher value than MCV in fig. 2(b). Therefore, detritus from continent are absolutely major component of the sediments of Core NS90-103, and their Nd isotope variation is mainly due to the change of their source.

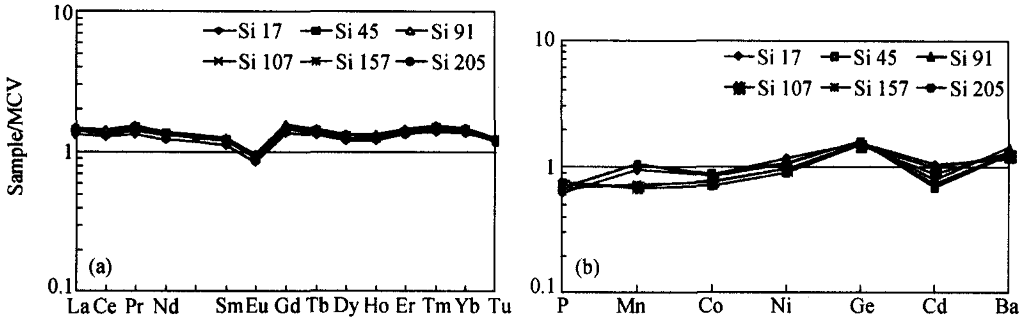

Fig. 2. Trace element diagram of detrital sediments of Core NS90-103. (a) Rare earth element patterns; (b) patterns of some trace elements. (All these elements are normalized to mean crust values from ref. [14].)

2.3 Variation of continent input

Continent detritus input to the ocean is the product of the weathering of continental crust. According to Goldstein and Jacobson, the river carried detritus have the same Nd isotope model ages with their source rocks, but Sr isotopes differ much from their sources[16]. Dasch indicated that detrital Sr isotopic compositions could proxy the intensity of continental crust weathering. The stronger the weathering, the more crystal rocks were weathered, and the higher $^{87}Sr/^{86}Sr$ ratios of the detritus [5]. As indicated from the $^{87}Sr/^{86}Sr$ variation of detrital sediments of Core NS90-103, after the maximum of the last interglacial (Stage 5.5), especially during the last glacial period, the weathering of the source areas is stronger, producing higher $^{87}Sr/^{86}Sr$ detritus. During Stage 5.5 and Holocene, weathering seems weaker and detrital $^{87}Sr/^{86}Sr$ ratios are lower. On the other hand, the enhancement of weathering can also infer from higher Rb/Sr ratios of the detritus due to strengthening leach of Sr from source rocks by weathering [5]. Rb/Sr ratios of the detritus of Core NS90-103 are about 1.90 in the lower section, and increase to about 2.30 in the upper section (table 3). This also indicates stronger weathering in source areas during the last glacial period.

Similar conclusion of stronger continent crust weathering during glacial had been drawn by Hodell et al. in their study of seawater $^{87}Sr/^{86}Sr$ variation [17]. However, Froelich et al. arrived at an inverse conclusion that continental weathering intensity is lower according to lower opal Ge/Si ratios during glacial periods [18], but their conclusion required doubling the dissolved silica fluxes to the ocean from river during glacial periods [18]. Gibbs and Kump re-assessed these contradictory conclusions by model calculation, and their results indicated that there was slight increase (about 20 percent) of continental weathering intensity during the last glacial period[19]. Therefore, our conclusion that weathering in the continents around the SCS was stronger during the last glacial period, inferred from the variation of detrital $^{87}Sr/^{86}Sr$ of Core NS90-103, is not contrary to the above results.

Due to stronger weathering, more detritus origins were produced from crystal rocks, and some of them were transported to the SCS by rivers during the last glacial period. Detritus in

Qinghai-Tibet Plateau, the upper reaches of Mekong, have lower $^{143}Nd/^{144}Nd$ ratios, and their Nd model ages to depleted mantle are quite old (T_{DM} about 2.10 Ga) [2,12]. However, the detritus of the upper section of Core NS90-103 have higher $^{143}Nd/^{144}Nd$ ratios and younger T_{DM} (about 1.30 Ga). It implies that the proportion of the detritus from Mekong may be less within the detrital sediments in the sea floor near Core NS90-103 during the last glacial period.

During the last glacial period, northeast monsoon was enhanced in SCS [20]. More material from the north of SCS should be carried to the south by enhanced southward surface current or by wind. Materials from the South China Continent, such as those detritus carried by the Pearl River and the Red River, might reach the area near Core NS90-103 more. According to Chen and John, there expose a large amount of granite with T_{DM} equal to or less than 1.40 Ga in South China, such as Guangxi and Fujian[21]. They might produce a large number of weathering detritus with $T_{DM} \leqslant$ 1.40 Ga accompanied by the enhanced weathering during the last glacial period and input to the SCS by rivers. Due to the enhancement of northeast monsoon, the transport capacities of the southward currents increase, and more of these detritus were carried to the area near Core NS90-103. This may be an important reason for the T_{DM} of the detritus of the upper section of Core NS90-103 turning younger.

In addition to detritus carried by sea surface currents, the amounts of wind-carried dust from the north wind may also increase. There exist some T_{DM} data of the eolian dust of present day in the nearby area of SCS as about 1.42 Ga in the East Indian Ocean and 1.52 Ga in the West Pacific[16]. They are all close to the values of the detritus of Core NS90-103. Unfortunately, we know little about the possible sources of these eolian dusts. It is hard to estimate the possible contribution of eolian dust to the sediment Nd isotopic compositions.

3 Summary

We measured the strontium and neodymium isotopes and trace elements of the detrital sediments of Core NS90-103, and discussed their paleoclimate implications. Some conclusions could be drawn.

1) During the last glacial period, the production of authigenic sediments, such as ferromanganese, increases with the increase of surface productivity. More Nd from the seawater was added into the sediment, and this raised the sediment $^{143}Nd/^{144}Nd$ ratios to some extent.

2) As inferred from detrital strontium isotopic compositions, continental weathering intensity around SCS was stronger during the last glacial period than in the last interglacial period and Holocene.

3) Due to the enhancement of northeast monsoon and continental weathering during the last glacial period, more detritus from South China Continent in the north of SCS were carried to this area. As a result, the Nd model ages of the detritus of the upper section of Core NS90-103 became younger, and $^{143}Nd/^{144}Nd$ increased.

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