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Discussion on Mesozoic Geochemical Characteristics and Genesis of Nadanhada Terrane

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Abstract

Through field geological survey and drilling exploration in Sanjiang Basin, combined with geochemical analysis, the tectonic thermal evolution history of intrusive rocks is studied. The results show that the Early Mesozoic siliceous rocks in Qianjin Depression of Sanjiang Basin are widely distributed. The siliceous rocks are of post diagenetic hydrothermal metasomatic origin, and the hydrocarbon source rock indicators are good, which is expected to be a new formation for oil and gas exploration in Sanjiang area. The time temperature thermal history simulation of fission track shows that there have been two rapid cooling events (late Early Cretaceous Late Cretaceous and Paleocene Eocene) in the Nadanhadaling area since the Mesozoic era, with cooling rates of 3.42~4.81 ℃/Ma and 1.43~1.83 ℃/Ma, respectively. The two rapid cooling processes were caused by the subduction of the Pacific plate. The rapid cooling during the Early Cretaceous to the Late Cretaceous was caused by the change of the subduction direction of the Pacific plate and the collision and superposition of the Okot Motsk block and the East Asian continental margin; The rapid cooling from Paleocene to Eocene was mainly caused by the subduction and retreat of the Pacific plate, which made the East Asian continental margin in an extensional environment and caused denudation and cooling in most parts of Northeast China..

Keywords

Nadanhada Terrane; Cooling and Exhumation History; Siliceous Rocks; Geochemistry.

1. Introduction

Sanjiang Basin is located in the Sanjiang Plain in the east of Heilongjiang Province in Northeast China, with an area of about 33730km2. It is the largest basin in the east of the periphery of Songliao Basin. It is characterized by large area, deep burial, well developed hydrocarbon source rocks and large resources, but no breakthrough in oil and gas exploration has been made so far. As far as the exploration strata are concerned, most of the oil and gas exploration work carried out in the Sanjiang Basin in the past is aimed at the Cretaceous System and the overlying Mesozoic Cenozoic, while little work has been carried out on the pre Cretaceous strata [1]. The drilling project of "Heitongdi Well 1" was deployed in Qianjin Depression in the east of Sanjiang Basin. The drilling was completed in 2017, and the well encountered a large set of Early Mesozoic siliceous rock and dark mudstone strata [2]. This paper mainly focuses on the Mesozoic Upper Triassic Lower Jurassic siliceous rock stratum, combines the drilling results of "Heitongdi Well 1" with the field geological survey results carried out in the east of Sanjiang Basin, investigates, studies and evaluates the Early Mesozoic marine siliceous rock stratum in Sanjiang Basin, and strives to develop new strata for oil and gas exploration [3].

Well Heitongdi 1 is deployed in Qianjin Depression of Sanjiang Basin, with the drilling depth of 1428.32m. According to the regional stratigraphic data and the comparative analysis of

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peripheral outcrops, it can be determined that the drilled strata are from the new to the old: the Cenozoic Fujin Formation, the Baoquanling Formation, the Mesozoic Cretaceous Hailang Formation, the Jurassic Suibin Formation and the Dajiashan Formation. It is noteworthy that "Well Heitongdi 1" reveals a large set of gray black siliceous mudstone under the siliceous rocks of the Dajiashan Formation of Upper Triassic Lower Jurassic (Fig. 1). Among them, the thickness of the siliceous rock stratum in the Dajiashan Formation is about 57m. This set of siliceous rock stratum is a landmark stratum of the Early Mesozoic in the east of Sanjiang Basin that can be traced and compared. The thickness of the dark mudstone stratum drilled under the siliceous rock is about 351.32m. The lithological characteristics are as follows: dark gray siliceous rock (1020.00~1077.0m), with SiO2 content of more than 70%. The rock is relatively dense, hard, brittle, and partially mixed with thin mudstone (Fig. 1a, b). Black mudstone (1077.0~1428.32m), with SiO2 content less than 70%, is mainly gray black siliceous mudstone with shale (Fig. 1c, d). The siliceous mudstone is dominated by lenticular bedding and parallel bedding, and the convolution bedding can be seen locally; The rock composition is mainly argillaceous, followed by siliceous and a small amount of calcareous. Among them, siliceous components occur in strip and lenticular form, and the rock contains a small amount of sand chips and agglomerated pyrite (Fig. 1c, d). In the logging curve, the resistivity of siliceous mudstone is obviously lower than that of siliceous rock, the natural gamma is obviously higher, the natural potential is slightly higher, and the density is slightly lower.

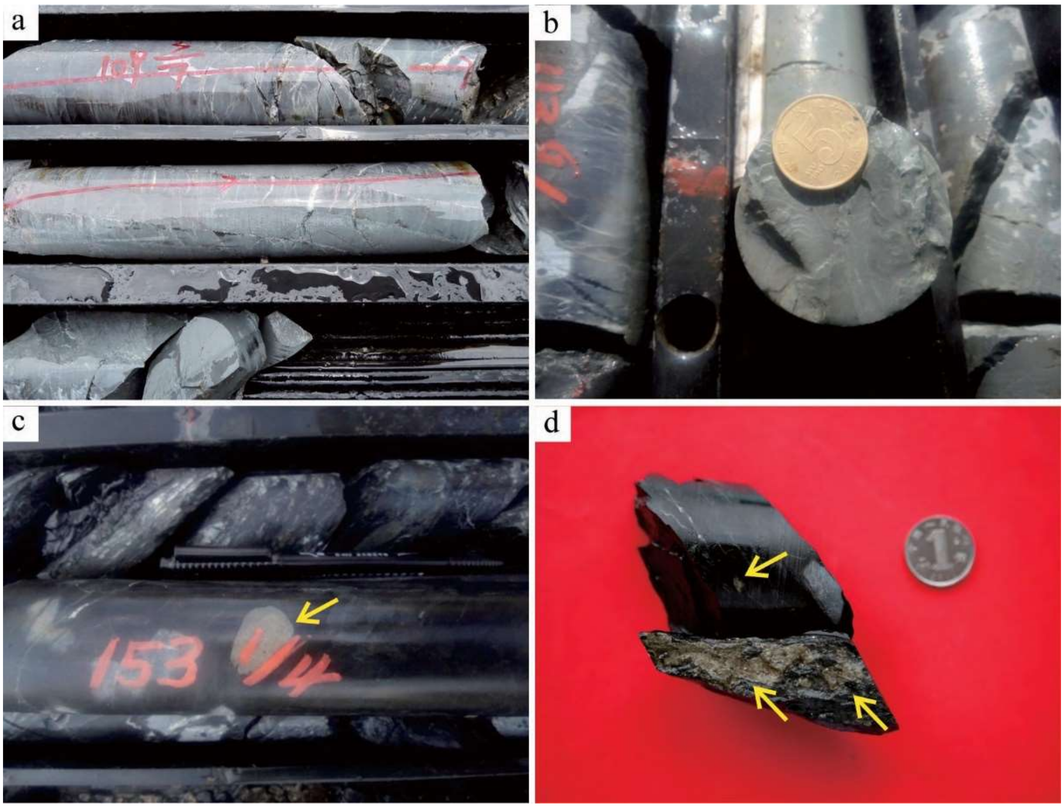

Fig. 1 Early Mesozoic core characteristics of Heitongdi 1 well a, b-Dark gray siliceous rock, 1050 m; c, d-Black siliceous mudstone, pyrite visible (arrow indicating pyrite)

According to the field geological survey and regional geological data on the lithology and distribution characteristics of the Early Mesozoic strata in Sanjiang area, in addition to the siliceous rock and dark siliceous mudstone strata encountered during the drilling of Well Heitongdi 1, Fuyuan area, Qindeli Farm, Hongqiling Farm and Wandashan area (including Raohe) in the northeast of Sanjiang Basin are all developed with marine siliceous strata of the

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Early Mesozoic Late Triassic Early Jurassic Dajiashan Formation, mainly composed of siliceous rock Siliceous mudstone [4].

2. Geochemical Analysis

The analysis results are shown in Table 1 and Table 2. The results of major element analysis show that the SiO2 content of siliceous rock samples in Sanjiang area ranges from 66.79% to 91.12%, with an average of 75.38%, which is lower than that of pure siliceous rock (91% to 99.8%) [5]. The content of CaO in other components is the highest, ranging from 3.51% to 17.59% with an average of 11.7%, followed by Fe2O3, ranging from 0.57% to 1.45% with an average of 1.1%. The SiO2 content of siliceous rock samples decreases with the increase of ignition loss, which is related to the fact that there are more carbonate minerals in siliceous rock samples. In general, the siliceous rock is mainly composed of siliceous rock, dolomite or calcite. The total content is SiO2+CaO+MgO+LOI, and the variation range is 96.98%~98.81%, with an average of 98.02%. The content of other elements is low [6]. In terms of rare earth element composition, the total amount of rare earth elements in siliceous rocks is relatively low, ranging from 2.39 to 7.57 ×10-6, average 4.50 ×10-6. On the PAAS standardized distribution map of rare earth elements, siliceous rocks show a nearly horizontal distribution feature. LREE/HREE is small, ranging from 6.9 to 10.74, with an average of 8.91. The sample generally shows positive Eu anomaly, δ Eu values are 0.98~1.31, with an average of 1.17. All samples showed weak Ce negative anomaly, δ Ce value is 0.96~0.98, with an average of 0.97. The results of Si and O isotope analysis show that the siliceous rock δ The distribution range of 30 Si value is 2.2 ‰~2.9 ‰, with an average of 2.5 ‰, The distribution range of δ180 value is 19.8 ‰~21.9 ‰, with an average of 20.8 ‰.

Table 1. Results of major elements and isotope

Sample number	Lithology	Content/%											$\delta^{18}O$/‰ (V-SMOW)	$\delta^{30}Si$/‰ (V-NBS28)
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI		
GC9-1	Siliceous rock	76.15	0.03	0.63	1.30	0.003	3.60	8.14	0.04	0.12	0.01	9.60	19.8	2.3
GC15-1	Siliceous rock	73.15	0.02	0.27	1.20	0.005	0.17	14.13	0.15	0.03	0.01	10.98	21.9	2.9
GC15-2	Siliceous rock	66.79	0.01	0.23	1.00	0.005	0.18	17.59	0.03	0.03	0.01	13.84	21.8	2.7
GC15-3	Siliceous rock	91.12	0.01	0.22	0.57	0.002	0.73	3.51	0.03	0.02	0.01	3.46	19.8	2.2
GC8-1	Siliceous rock	69.72	0.03	0.78	1.45	0.008	0.32	15.13	0.01	0.24	0.01	11.81	20.7	/

Table 2. Results of trace element concentrations

Sample number	Content/(10^{-6})														
	Li	Be	Sc	Ti	V	Cr	Mn	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y
GC9-1	4.78	0.10	0.29	130.63	5.83	6.30	49.09	0.86	75.47	5.33	1.19	0.77	2.76	47.32	0.82
GC15-1	3.33	0.04	0.16	45.67	2.13	3.97	37.99	0.40	2.62	2.21	0.21	0.39	0.65	39.23	0.36
GC15-2	5.69	0.08	0.27	67.26	2.39	6.98	65.77	0.64	3.43	4.14	1.00	0.63	1.16	63.79	0.63
GC15-3	4.39	0.06	0.22	57.27	5.31	5.10	31.05	0.37	1.92	3.16	0.14	0.56	0.62	24.74	0.43
GC8-1	10.44	0.20	0.72	172.91	5.91	8.97	81.36	1.94	41.88	10.53	1.20	1.36	5.77	64.96	1.05

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Sample number	Content/(10^{-6})												Y/Ho	Th/U	La/Ho
	Zr	Nb	Mo	Cs	Ba	Hf	Ta	Pb	Th	U	La	Ho			
GC9-1	3.93	1.04	9.95	0.13	84.67	0.11	0.09	22.16	0.50	1.93	0.90	0.03	28.00	0.26	0.81
GC15-1	1.47	0.71	3.01	0.05	63.52	0.04	0.02	20.83	0.29	1.54	0.53	0.01	27.80	0.19	1.07
GC15-2	3.96	0.99	8.31	0.10	98.72	0.09	0.08	19.06	0.58	6.21	1.02	0.02	30.04	0.09	1.29
GC15-3	3.75	0.44	3.11	0.05	31.62	0.09	0.02	5.12	0.31	1.82	0.81	0.02	26.72	0.17	1.34
GC8-1	5.43	1.48	20.92	0.24	101.84	0.14	0.05	28.42	1.01	7.70	1.62	0.04	26.59	0.13	1.08

2.1. Major Element

The enrichment of Fe and Mn in siliceous rocks is related to the participation of hydrothermal solution, and the enrichment of Al and Ti is mostly related to the input of terrigenous materials. The Al/(Fe+Mn+Al) values of siliceous rocks of different origins are different. In marine sediments, the Al/(Fe+Mn+Al) values greater than 0.4 reflect their biological origin, while those less than 0.4 indicate hydrothermal origin, which varies from 0.01 (pure hydrothermal origin) to 0.6 (pure biological origin). The Al/(Fe+Mn+Al) values of siliceous rocks in the study area range from 0.14 to 0.29, with an average of 0.21, all less than 0.4, indicating that they are of hydrothermal origin. Al Fe Mn trigonometry has been proposed by predecessors to identify the origin of siliceous rocks. At present, this method has been widely used. When the research data in this paper are put into the triangle diagram (Fig. 2), it can be seen that all the data fall on the Fe rich end of the diagram, indicating that the siliceous rocks are of hydrothermal origin. Fe/Ti>20, (Fe+Mn)/Ti>20±5 for typical modern marine hydrothermal sediments. The distribution range of Fe/Ti values studied in this paper is 54.39~89.67, with an average of 68.16, and the distribution range of (Fe+Mn)/Ti values is 54.72~90.17, with an average of 68.48, which are consistent with the distribution range of hot water sediments, revealing that the siliceous rocks are of hydrothermal origin.

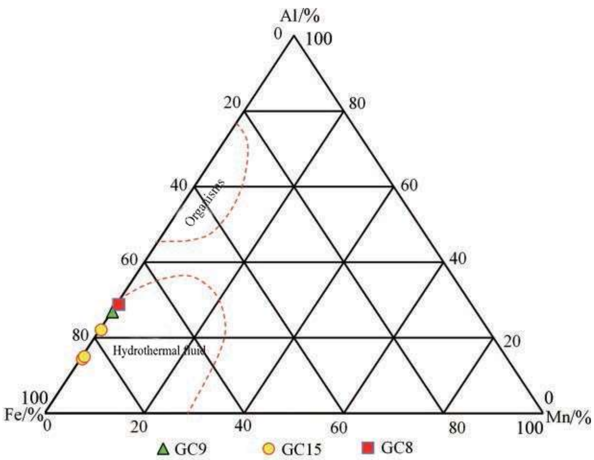

Fig. 2 Al-Fe-Mn diagram of siliceous rocks of 3rd Member of Yingshan Formation in Gucheng area

2.2. Trace Element

Thorium/uranium (Th/U) values reflect the degree of deep provenance addition of the lower crust or upper mantle during the formation of siliceous rocks. When the siliceous rocks are marine deposits, the Th/U value is high; When siliceous fluid comes from deep crust or upper

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mantle, Th/U value is very low. Y/Ho value can indicate the material source of elements in rocks. The Y/Ho value of normal marine sedimentary siliceous rocks is less than 28, and the average Y/Ho value of igneous rocks and clastic rocks is about 28. The Th/U-Y/Ho relationship is used to distinguish the origin of siliceous rocks: high Th/U value and low Y/Ho value are characteristics of marine sedimentation; High Y/Ho value and low Th/U value are deep hydrothermal characteristics. The Y/Ho Th/U relationship of siliceous rocks in the study area (Fig. 3) shows that all samples fall into the "metasomatic area". Its Y/Ho value is 26.59~30.04, with an average value of 27.83, which is close to the Y/Ho value of chondrites (about 28); Th/U value is 0.09~0.26, and the average value is 0.17. Both of them reveal the addition of deep hydrothermal solution. La/Ho value is an indicator to measure the source and migration of hot water. Using La/Ho Y/Ho relationship to determine the source of siliceous fluid: higher Y/Ho value is the sedimentary characteristics of seawater source and syngenetic brine source; The lower Y/Ho value and La/Ho value are the deposition characteristics of SiO2 rich ascending hydrothermal solution; The mixed thermal fluid of the two fluids forms siliceous rocks. With the increase of silicification degree, the La/Ho value decreases sharply and the Y/Ho value decreases slightly. When the data points of this study are put on the chart (Fig. 4), it can be seen that the La/Ho values of the data points are extremely low (0.81~1.34, with an average of 1.12), reflecting the high degree of silicification of the siliceous rocks in the study area, and the silicified fluid has the characteristics of mixed thermal fluid.

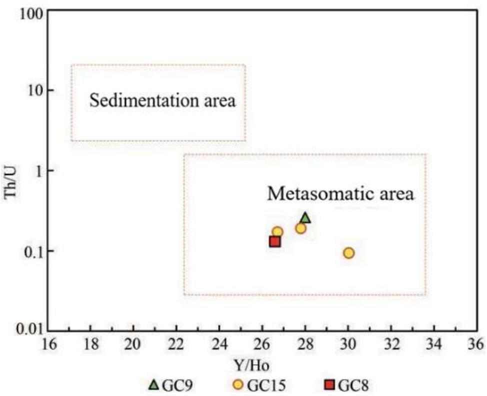

Fig. 3 Th/U-Y/Ho relationship diagram of siliceous rocks of 3rd Member of Yingshan Formation in Gucheng area

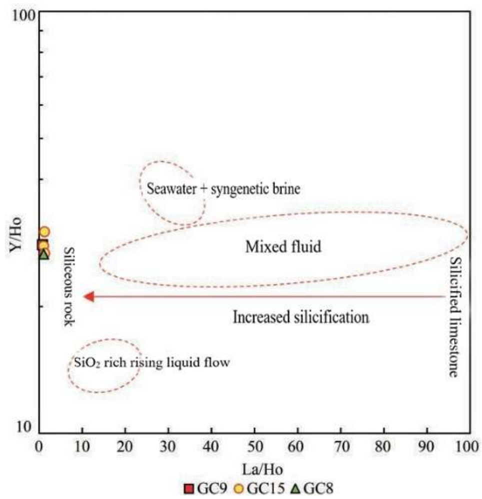

Fig. 4 La/Ho-Y/Ho relationship diagram of siliceous rocks of 3rd Member of Yingshan Formation in Gucheng area

2.3. Feature Analysis

The undeveloped siliceous rock indicates that the original physical property of the stratum is poor, the surrounding rock is dense, and it is difficult for siliceous hydrothermal fluid to enter the stratum for reconstruction. The extreme development of siliceous rock indicates that the original porosity of the formation is good, and siliceous hydrothermal fluid is easy to enter the formation for corrosion and transformation. However, due to the large amount of siliceous precipitation, the pores are blocked and the reservoir is damaged. The relatively undeveloped siliceous rock indicates that the original physical property of the stratum is good, which is conducive to the siliceous hydrothermal fluid to conduct dissolution transformation to improve the physical property of the reservoir. At the same time, there is a certain amount of siliceous precipitation, but the amount of siliceous rock precipitated is small, which will not block the dissolution holes on a large scale, and the damage to the reservoir is weak, and its existence just indicates the development interval and distribution range of the reservoir [7].

3. Thermal Evolution Simulation and Exfoliation Rate Analysis

The multi mineral isotope system and HeFTY simulation are used to discuss the tectonic thermal evolution history and exhumation rate in different stages of the Nadanhada Ridge terrane.

3.1. HeFTY Simulation

In order to better understand the time temperature history of the sample, HeFTY software is used to simulate the thermal history of the sample. The input data include single particle fission track age, length, Dpar value and C-axis angle of apatite, and the initial track length is 16.3 μ m. Kolmogorov SmirnovTest is selected as the optimal equation for length fitting, and Monte Carlo is selected as the calculation method. In the simulation process, the starting point of the time temperature path is constrained by the measured weighted ZrnHe age and its sealing temperature (the sealing temperature of ZrnHe is 160~200 ℃), Low temperature is constrained by the measured weighted ApHe age and its closure temperature (The closure temperature of ApHe is 40~80 ℃. According to the current average temperature in the study area, the end point of the time temperature path is set to 15 ℃. The simulation stops until the good paths reach 100. For each model, the best fitting path and the weighted average path are shown as black and blue curves respectively. The age GOF value of the thermal history simulation in this paper is greater than 0.8, and the track length GOF value is greater than 0.4, indicating that the thermal simulation results are reliable The historical model shows that there were two rapid cooling events in the Nadanhadaling region in northeast China. The first cooling occurred during the Cretaceous, about 110~80 Ma; The second cooling event occurred during Paleocene Eocene about 60~40 Ma.

3.2. Exfoliation Rate Analysis

According to the exhumation rate in Table 3, although there are some differences in the exhumation rates obtained by different methods, the exhumation rates show that the exhumation rates were relatively large during the Mesozoic and relatively small in the Cenozoic. Because the thermal history simulation method records the exfoliation rate of samples in each cooling stage, the age closure temperature method records the average exfoliation rate. Therefore, it can be seen from Table 3 that the stripping rates of JM1804 and JM1806 calculated by the age sealing temperature method are 33~42m/Ma and 27~43m/Ma respectively, which are both within the range of stripping rates calculated by the thermal history simulation method (11~98m/Ma, 9~138 m/Ma). The exhumation rates (65~161m/Ma, 30~35m/Ma) obtained by ZrnHe/ApFT and ApFT/ApHe based on mineral pairing methods are higher than those obtained by ApFT and ApHe based on age sealing temperature methods (28~34m/Ma,

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27~33m/Ma), which also shows that the exhumation in Mesozoic is stronger than that in Cenozoic.

Table 3. Exhumation rates of bedrock at Nadanhada region in NE China based on thermal history simulation method, age=closure temperature method and mineral-pair method

Sample number	Thermal history				Age-closed temperature						Mineral pairing method			
	Fast phase		Slow stage		ZrnHe		ApFT		ApHe		ZrnHe/ ApFT		ApFT/ ApHe	
	Time	Rate	Time	Rate	Age	Rate	Age	Rate	Age	Rate	Time	Rate	Time	Rate
JM1804	110~72 52~40	98 52	72~52	11	111.6	42	80.6	34	48.1	33	111.6~80.6	65	80.6~48.1	35
JM1806	110~83 57~50	138 41	93~57	9	108.7	43	96.3	28	58.6	27	108.7~96.3	161	96.3~58.6	30

In addition, the thermal evolution history of Nadanhadaling is established according to the sealing temperature and corresponding cooling age of minerals in combination with the high, medium and low temperature thermal chronological data of the Nadanhadaling area (Fig. 5). The study shows that the cooling process of the Nadanhada Ling terrane since the Cretaceous is uneven. About 120 Ma, the Nadanhadaling granitic magma intruded and quickly reached thermal balance with the wall rock. Its cooling rate is 35~58 ℃/Ma, representing a rapid cooling and consolidation process. When the intrusion is cooled to a temperature close to the surrounding rock, it is mainly dominated by tectonic uplift and denudation cooling. From the low-temperature thermal chronology data and thermal year simulation results, three main cooling stages have been experienced: ① The samples studied in this paper dropped from 180 ℃ to 110 ℃, with an average cooling rate of 2.26~5.65 ℃/Ma and an average stripping rate of 64.6~161.4 ℃/Ma; ② The temperature dropped from 110 ℃ to 70 ℃, the average cooling rate was 1.06~1.23 ℃/Ma, and the average stripping rate was 30.3~35.1 ℃/Ma; ③ The temperature dropped from 70 ℃ to the current surface temperature, with an average cooling rate of 0.94~1.14 ℃/Ma and an average stripping rate of 26.8~32.6 ℃/Ma.

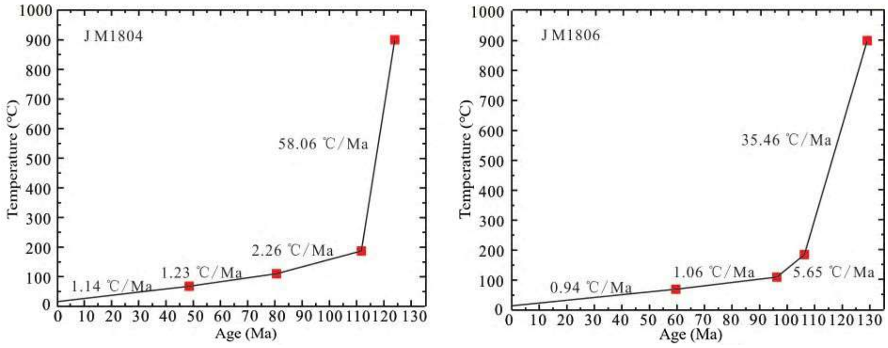

Fig. 5 Time-temperature histories of the Nadanhada in NE China(based on data in Table 1)

4. Conclusion

Early Mesozoic siliceous rock strata in Qianjin Depression of Sanjiang Basin are widely distributed. The siliceous rock is of post diagenetic hydrothermal metasomatic origin, with good hydrocarbon source rock indicators, and is expected to become a new formation for oil and gas exploration in Sanjiang area. The time temperature thermal history simulation of fission track shows that there have been two rapid cooling events (late Early Cretaceous Late Cretaceous and Paleocene Eocene) in the Nadanhadaling area since the Mesozoic era, with cooling rates of 3.42~4.81 °C/Ma and 1.43~1.83 °C/Ma, respectively. The two rapid cooling processes were caused by the subduction of the Pacific plate. The rapid cooling during the Early

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Cretaceous to the Late Cretaceous was caused by the change of the subduction direction of the Pacific plate and the collision and superposition of the Okot Motsk block and the East Asian continental margin; The rapid cooling from Paleocene to Eocene was mainly caused by the subduction and retreat of the Pacific plate, which made the East Asian continental margin in an extensional environment and caused denudation and cooling in most parts of Northeast China.As a hot research technology, moving target tracking technology has been widely used in various fields. With the help of low cost, low power consumption, self-organization and high error tolerance of wireless sensor networks, moving target tracking based on wireless sensor networks also has broad application prospects.

Acknowledgments

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