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C-isotope composition and significance of the Sinian on the Tarim plate

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Abstract **102 samples of limestones, mudrocks shales and tillites from the Sinian in Kuluketage have been analyzed. Four formations in the Sinian belong to glacial deposits in which the differences in δ^{13}C are distinct (–14.7‰—+4.2‰). Distinctly negative δ^{13}C excursions for three times support the view of three glacial deposits in this area suggested by previous authors, except for the durations of them. δ^{13}C values are generally positive in the Beiyixi Formation of lower part of the Lower Sinian, representing probably the rock records of a continental rift related to break-up of the Rodinian supercontinent. There are three times of distinct excursions of δ^{13}C curve in all strata. The first one is from positive values at the bottom to about –5‰ at the top of the Beiyixi Formation. The second one, from 0‰—3‰ in the Arletonggou Formation of upper part of the Lower Sinian to –3.4‰— –14.4‰ in the Teruiaiken Formation. The third one, from positive values in the Zhamoketi Formation of lower part of the Upper Sinian to negative values in glacial varves at the top of the Hankeerqiaoke Formation.**

Keywords: C-isotope composition, Tarim plate, Sinian.

The study on the Precambrian Rodinia supercontinent and "snowball" Earth events has been paid more and more close attention in international geological circles[1—3]. Focal points of the study are emphasized on the assemblage and break-up of the Rodinia supercontinent and the late Precambrian global glacial events. For exam ple, the origin of the Proterozoic "cap carbonate" and its negative C-isotope excursion have been discussed[1—5]. There is wide exposure of the Precambrian and Sinian tillites in the Tarim, North China and Yangtze plates, which benefit the study[6—9]. The Tarim plate is well-known for a complete Sinian and three ice ages where a lot of studies on strata and tillites have been done[9—11], but not any study on the Sinian C-isotope composition and signification has been reported. In this report we show preliminary study results in Kuluketage, north of the Tarim plate.

1 Geological setting and sampling

Located in Zhaobishan-Xingeer, Kuluketage, the study area belongs to a typical Sinian exposure area (Fig. 1). By detailed geological sections there, Gao Zhenjia et al. defined the Sinian strata composed of eight formations: the lower Sinian including the Beiyixi, Zhaobishan, Arletonggou and Teruiaiken formations, the upper Sinian including the Zhamoketi, Yukengou, Shuiquan and Hankeerqiaoke formations[9]. We completed 7 measured sections of the eight formations (Fig. 2) and collected 102 samples for C-isotope analysis (Table 1). From buttom to top the main lithology of each formation is as follows:

The Beiyixi Formation (BYX): Mainly exposed in Xingeer, it is the lowest strata in the Sinian and disconformably overlies the pre-Sinian Paergangtage Group. With a thickness of 2381 m in the measured section, this formation has 50-m-thick pebbled sandstones at the base, followed by 350-m-thick volcanic rocks in lower part, 1200-m-thick sandstones and shales in middle part, with 4 interbedded tillites several to more than 10 m thick, 440-m-thick interbedded succession of mudrocks and tillites that are up to 145 m thick in upper part, and 320-m-thick mudrocks in the top part. 21 samples have been collected from the Beiyixi Formation.

Zhaobishan Formation (ZHB): Conformably overlying the Beiyixi Formation, the Zhaobishan Formation is a

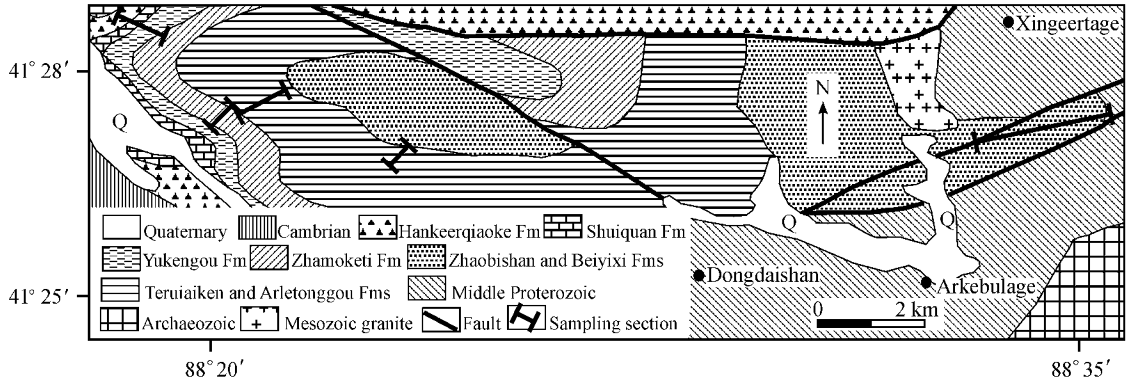

Fig. 1. Geological map of the Sinian in Kuluketage area (simplified from the 1 ∶ 50000 geological map of Xingeer area1)).

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1) No.1 Geological Team of Xinjiang, BGMRED, Geological Map of Xingeer Area (1 ∶ 50000), 1995.

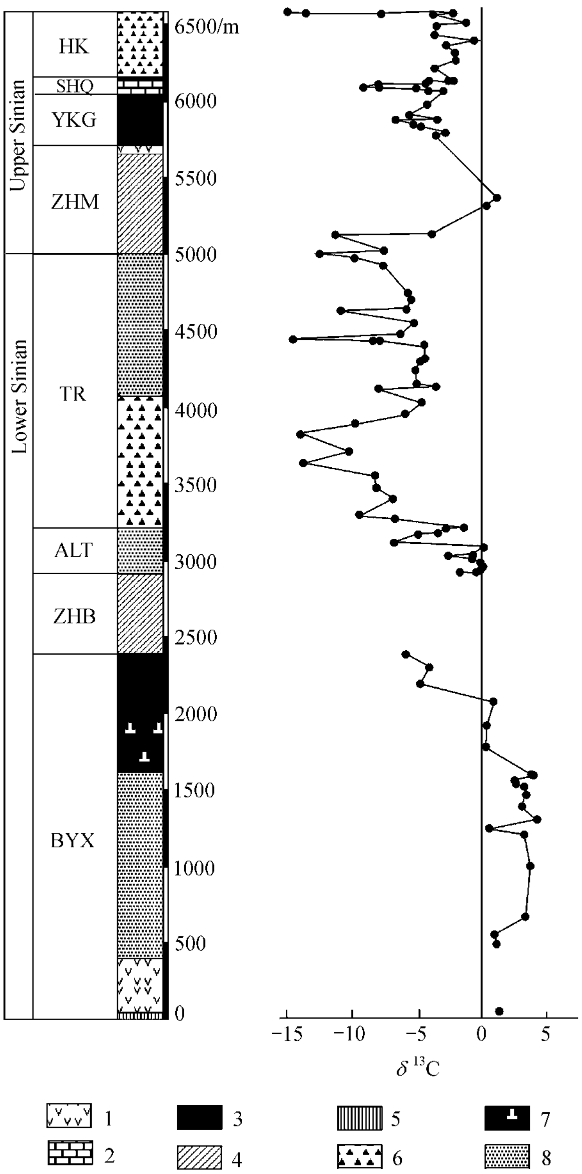

Fig. 2. δ^{13}C curve of samples. 1, Volcanic rock; 2, limestone; 3, mudstone/shale; 4, interbedded sandstone and mudstone; 5, pebbled sandstone; 6, tillite; 7, interbedded tillite and mudstone; 8, tillite-bearing interbedded sandstone and mudstone. Capital letters are abbreviations from the formations (see the text).

succession of sandstones and siltstones with interbedded mudrocks, without tillites. We have not done any study in this formation. A thickness of 544 m has been defined in the measured section by previous work[9].

Arletonggou Formation (ALT): With a thickness of more than 345 m, this formation is characterized by an interbedded succession of sandstones, siltstones, shales and tillites. There are 2 lenticular thin limestone beds in middle part and 4 tillite beds up to 20 m thick. 14 samples have been collected from this formation.

Teruiaiken Formation (TR). It is a very thick succession composed mainly of tillites, with a thickness of 1756 m in the measured section. The about 800-m-thick tillites in lower part of the succession is blocky. About 900-m-thick tillites and interbedded shales and lenticular limestones in upper part of the succession compose 5 cycles in which the tillites show a thinning-upward trend from more than 200 m to more than 10 m thick. 29 samples have been collected from this formation.

Zhamoketi Formation (ZHM): With a thickness of more than 699 m in the measured section, it is a flysh succession mainly composed of sandstones and shales, with several layers of volcanic rocks at the top of this formation. There are sedimentary structures such as slump structures, cross beddings, graded beddings and flute casts in thick sandstones. 6 shale samples have been collected from this formation.

Yukengou Formation (YKG): With a thickness of 345 m in the measured section, this is a fine clastic succession composed of interbedded shales and thin siltstones, characterized by paper-shaped chips in weathering outcrops. 11 samples have been collected from this formation.

Shuiquan Formation (SHQ): With a thickness of 53 m in the measured section, this formation is a succession composed only of thin laminar limestones. Unalterable contribution and special lithology make it a marker bed of the Sinian in the Kuluketage area. 7 samples have been collected from this formation.

Hangeerqiaoke Formation (HK): As the uppermost formation of the Sinian in the Kuluketage area, it is composed of thick tillites. There are 2—4-m-thick glacial varves at the top of the formation on which the Cambrian silicalites disconformably overlie. Its thickness is 442 m in the measured section. 14 samples including 4 glacial varves have been collected.

Collected samples come from all Sinian in the Kuluketage area except the Zhaobishan Formation. Age estimate for lower limit of the samples is about 814 Ma, because previous authors obtain ages of (814±90.9) Ma from the lower Beiyixi Formation in the Yaerdang mountain area[12], 773 Ma from the Beiyixi Formation[12] and (814.3±97.3) Ma from the volcanic rocks in the Beiyixi Formation in the Kuluketage area[13]. Age estimate for upper limit has not any date. Generally, it is considered

Table 1 Contribution, lithology and amount of C-isotope samples

	Beiyixi Fm	Arletonggou Fm	Teruiaiken Fm	Zhamoketi Fm	Yukengou Fm	Shuiquan Fm	Hankeerqiaoke Fm
Limestone		1	4			7	
Shale/mudstone	17	10	9	6	11		
Tillite	4	3	16				14

that the Hankeerqiaoke Formation correlates with the Dengying Formation in South China.

2 Methods and results

Washed limestones, shales and mudstones samples are crushed to 200 meshes by the pollution-free method. Acid treatments show that the shales and mudstones contain carbonate composition that can be used to analyze C-isotope composition. To obtain enough CO_2 gas for C-isotope analysis, the weight of shales and mudstones for analysis has been increased. After sieving and removing gravels more than 2 mm, the mud components in matrix of tillites are collected by oscillating table and analyzed.

Analysis procedures are as follows: the powder samples for C and O isotope analyses are heated to 350—400℃ in vessels for more than 1 h to remove orgnic materials. The powder samples react with 100% phosphoric acid to form CO_2 in vacuum. Reaction temperature is 25℃ and reaction times are 72 h. C and O isotope compositions are determined using MAT-251 thermal ionization instrument in the Stable Isotopic Laboratory, Institute of Geology and Geophysics, the Chinese Academy of Sciences. Several samples are analyzed for the second time in the Institute of Deposit, the Ministry of Land and Resources of China to ensure the analysis accuracy. A few of samples with very low values have been analyzed for the second or third time. All data of C and O isotope compositions are expressed relative to the PDB standard. Analysis errors for $\delta^{13}C$ and $\delta^{18}O$ are $\pm 0.1‰$ (1σ).

To evaluate the influence of replacement on C isotope values, $\delta^{18}O$, Mn and Sr are also been determined. Generally, a positive correlation between $\delta^{13}C$ and $\delta^{18}O$ suggests the influence of replacement[14]. No positive correlation is shown among the plots of the samples of study area (Fig. 3), with the exception of an ambiguous positive correlation in the samples from the Teruiaiken Formation, which suggests that the acquired C isotope values can basically represent the sedimentary medium when the rocks formed. Mn/Sr value is a general method that judges if the sample is influenced by replacement[14]. If Mn/Sr value <10, it is thought that the sample saves the original C isotope composition. There only are 3 samples Mn/Sr values >10 in analysis results of 74 samples, suggesting that the samples in the study area were not influenced on the whole. Lithology, $\delta^{13}C$ and $\delta^{18}O$ of the samples are listed in Table 2, and $\delta^{13}C$ curve is shown in Fig. 2. The samples of $\delta^{18}O$ value < –10‰ in Fig. 3 have certainly been influenced by alteration during diagenesis processes, so the maximum $\delta^{13}C$ values are used to represent C isotope composition during sedimentation.

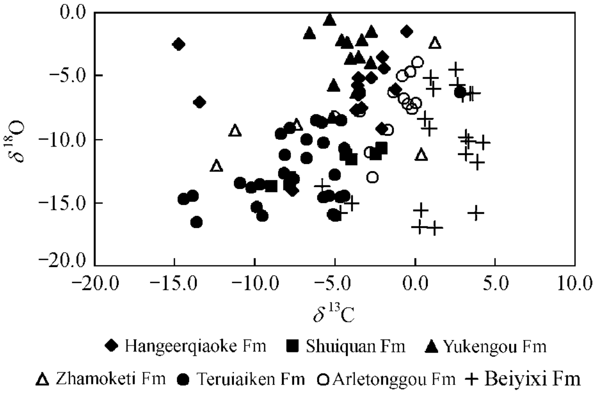

Fig. 3. $\delta^{13}C$-$\delta^{18}O$ cross-plot of samples.

3 Geological significance

Variation in the $\delta^{13}C$ curve and its significance of the Sinian strata in the Kuluketage area, north of Tarim plate are as follows:

(1) The $\delta^{13}C$ values are positive in the Beiyixi Formation on the whole, varying between +0.3‰ and +4.2‰, but they change abruptly to –4.0‰—–5.8‰ at the top, forming a distinctly negative excursion. These characteristics are completely similar to the early Neoproterozoic curves in the Congo craton, Namibia and Amundsen island, Canada, where $\delta^{13}C$ values are between +3‰ and +4‰ and change abruptly to –3‰ at the top[14]. They are correlatable one another in terms of C isotope. It is worth noticing that the early Neoproterozoic strata in the Congo craton and Amundsen island are below the Sturtian tillites, so the position of the tillites in the Beiyixi Formation is lower than that of the Sturtian tillites. Generally, the main factor to influence C isotope compositions is organic carbon reserves in nature carbon stock. An increase in the organic carbon reserves results in a relative decrease in ^{12}C in the sedimentary medium, consequently, increase in $\delta^{13}C$ values in inorganic carbon (carbornate), and *vice versa*. The continental margin is the most active region for biogenic agency and sedimentation, which benefits the burying of organic carbon. For the positive $\delta^{13}C$ values occurring in the early Neoproterozoic strata, Hoffman et al. considered that break-up caused the increase in the continental margin area, resulting in the increase in organic carbon[15]. Karlstrom et al. discussed the relation between the positive $\delta^{13}C$ values in the Chuar Group and break-up of the Rodinia supercontinent[16]. Because there are more than 50-m-thick pebbled sandstones at the base, more than 1200-m-thick sandstones with slump structures and shales in middle part, and a lot of volcanic rocks in the Beiyixi Formation, it represents probably a continental marginal rift related to break-up of the Rodinia supercontinent. Those positive $\delta^{13}C$ values in the Beiyixi Formation were probably caused by the increase in organic carbon reserves resulting from break-up of the Rodinia supercontinent.

(2) Gao et al. suggested and discussed that there are

Table 2 Lithology, δ^{13}C and δ^{18}O of samples in Kuluketage area

Strata	Sample	Lithology	δ^{13}C (‰)	δ^{18}O (‰)
Hk	Dh134	glacial varves	−7.6	−14.0
	Dh134C	glacial varves	−14.7	−2.5
	Dh135	glacial varves	−13.4	−7.1
	Dh137	glacial varves	−3.7	−7.7
	Dh138	tillite	−2.1	−9.2
	Dh139	tillite	−3.5	−6.5
	Dh141	tillite	−1.2	−6.0
	Dh142	tillite	−3.4	−7.5
	Dh143	tillite	−3.6	−5.7
	Dh144	tillite	−0.5	−1.5
	Dh145	tillite	−2.7	−5.2
	Dh146	tillite	−1.9	−4.5
	Dh147	tillite	−2.0	−3.6
	Dh148	tillite	−3.5	−5.2
SHQ	Dh150	limestone	−2.1	−10.8
	Dh149	limestone	−4.0	−11.6
	Dh151	limestone	−2.5	−11.2
	Dh152	limestone	−4.3	−11.3
	Dh153	limestone	−7.8	−13.6
	Dh154	limestone	−7.9	−13.1
	Dh155	limestone	−8.9	−13.7
YKG	Dh156	shale	−5.1	−5.8
	Dh157	shale	−4.1	−3.7
	Dh158	shale	−2.8	−4.0
	Dh159	shale	−4.2	−2.4
	Dh160	shale	−5.4	−0.5
	Dh161	shale	−3.3	−2.3
	Dh162	shale	−6.6	−1.7
	Dh163	shale	−5.2	−8.3
	Dh164	shale	−4.6	−2.2
	Dh165	shale	−2.7	−1.6
	Dh166	shale	−3.5	−3.6
ZHM	Dh024	Shale	1.2	−2.5
	Dh020	Shale	0.3	−11.1
ZHM	Z-16	shale	−3.7	−6.3
	DH006	shale	−11.2	−9.3
	Z-4	shale	−7.4	−8.8
	Z-2	shale	−12.4	−12.0
TR	Dh40	shale	−9.8	−15.3
	Dh41	shale	−7.5	−13.2
	Dh45	shale	−5.7	−14.6
	Dh47	tillite	−5.4	−14.5
	Dh51	tillite	−5.7	−10.3
	Dh49	shale	−10.9	−13.5
	Dh54	tillite	−5.1	−16.0
	Dh55	tillite	−6.1	−8.5
	Dh57	limestone	−14.4	−14.8
	Dh58	shale	−7.8	−9.1
	Dh59	shale	−8.4	−9.6
	Dh60	tillite	−4.4	−10.8
	Dh61	limestone	−4.4	−14.4
	Dh62	tillite	−4.7	−14.6
	Dh63	tillite	−5.0	−12.8
	Dh66	timestone	−4.9	−16.1
	Dh67	shale	−3.4	−6.3
	Dh69	tillite	−7.8	−13.7
	Dh71	tillite	−4.6	−8.5
	Dh73	tillite	−5.8	−8.7
	Dh75	tillite	−9.6	−13.6
	Dh77	tillite	−13.9	−14.5
	Dh79	tillite	−10.2	−13.8
	Dh81	tillite	−13.6	−16.5
	Dh83	tillite	−8.2	−12.7
	Dh85	tillite	−8.1	−11.2
	Dh87	tillite	−6.7	−11.5
	Dh90	shale	−9.4	−16.1
	Dh92	shale	−6.8	−10.0
	Dh129	shale	−1.3	−6.3
ALT	Dh128	tillite	−2.8	−11.1
	Dh126	shale	−3.4	−7.9
	Dh125	shale	−5.0	−8.3
	Dh121	limestone	−6.8	−11.5
	Dh119	shale	0.2	−4.0
	Dh113	shale	−0.7	−6.8
	Dh112	tillite	−2.6	−13.0
	Dh110	shale	−0.8	−5.1
	Dh107	shale	−0.2	−4.8
	Dh103	Shale	0.1	−7.2
	Dh101	shale	−0.2	−7.7
	Dh98	shale	−0.4	−7.3
	Dh97	tillite	−1.7	−9.2
BYX	Xb66	mudstone	−5.8	−13.7
	Xb64	mudstone	−4.0	−15.1
	Xb63	mudstone	−4.7	−15.8
	Xb61	tillite	0.9	−9.2
	xb57	tillite	0.3	−15.6
	xb54	tillite	0.3	−16.9
	xb50	shale	3.8	−15.8
	xb49	shale	3.9	−11.8
	xb48	shale	2.5	−4.5
	xb47	shale	2.6	−5.7
	xb45	shale	3.2	−11.1
	xb44	shale	3.4	−10.2
	xb42	shale	3.0	−6.5
	xb41	shale	4.2	−10.3
	xb37	shale	0.6	−8.4
	xb36	shale	3.2	−9.9
	xb27	shale	3.6	−6.4
	xb21	shale	3.4	−6.4
	xb19	shale	0.9	−5.2
	xb18	shale	1.1	−6.0
	xb04	shale	1.3	−17.0

3 ice ages, including the Beiyixi, Teruiaiken (Teruiaiken and Arletonggou formations) and Hankeerqiaoke, from bottom to top in the Sinian of the Kuluketage area[9]. Our study suggests that the differences in $\delta^{13}C$ values are distinct in the three ice ages. In the Beiyixi Formation there are 18 samples with positive values except 3 samples with the values of –4.0‰— –5.8‰ at the top. Except 2 samples with the values of –6.8‰ and –5.0‰, the values of the other samples vary between +0.1‰ and +3.4‰ in 14 samples from the Arletonggou Formation. There is a variation from –3.4‰ to –14.4‰ in 29 samples from the Teruiaiken Formation, which overlaps the variation of the Arletonggou Formation, so these two formations can merge into one successive glacial deposit in which the variation in C isotope compositions shows an increasing depleted model. C isotope values vary from – 0.5‰ to –3.6‰ in most strata of the Hankeerqiaoke Formation, suggesting a slightly depleted model, but an abrupt change of $\delta^{13}C$ from –3.7‰ to –14.7‰ occurred in the top glacial varves. The differences of C isotope composition in all strata are not corresponding with the idea of 3 ice ages suggested by previous authors. The negative $\delta^{13}C$ values correspond to characteristics of the “cap carbonate” after ice age, so the relation between the negative $\delta^{13}C$ values and the ice ages is obvious.

(3) There are 3 times of distinct excursions of $\delta^{13}C$ curve in all strata. The first one is from positive values at the bottom to about –5‰ at the top of the Beiyixi Formation. The second one, from 0‰ —–3‰ in the Arletonggou Formation to –3.4‰— –14.4‰ in the Teruiaiken Formation. Even though a possible alteration lowers the values of samples from the Teruiaiken Formation, an overall change tendency is distinct. The third time is from positive values in the Zhamoketi Formation to negative values in glacial varves at the top of the Hankeerqiaoke Formation. Though the reason to make negative excursions of the Proterozoic C isotope is controversial[3—5], 3 times of distinct negative $\delta^{13}C$ excursions support the view of 3 glacial deposits in this area suggested by previous authors. As for the precise times and correlative relations to the Sturtian and Marinoan ice ages, there still is a lot of careful isotopic dating work to be done.

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