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Research Advances

A New Discovery of ~2.7 Ga Granitic Magmatism in Southeastern Jilin Province, China

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Objective

The North China Craton (NCC) is characterized by widespread tectono-thermal events at ca. 2.5 Ga, which differs from many other older cratons on Earth, which usually record tectono-thermal events at ~2.7 Ga. Therefore, the search for early crustal material, especially rocks within the NCC that record the 2.7 Ga event, is key to understanding the formation and evolution of ancient crust, and the initiation time and mechanism of plate transformation based on comparative studies of the NCC and other major cratons. There are many ancient rocks within the NCC, especially along the northeastern margin of this craton, where zircons yield ages as old as ca. 3.8 Ga. The oldest rocks are concentrated in the Anshan-Benxi area of Liaoning Province. Previous studies have shown that 2.69–2.65 Ga meta-supracrustal rocks, and 2.58–2.52 Ga granitic rocks and coeval meta-supracrustal rocks are exposed in the Jiapigou and Helong areas in the central and eastern parts of Jilin Province, which indicated the possibility of finding evidence of the 2.7 Ga event in southeastern Jilin Province. This paper first reports the discovery of ~2.7 Ga granitic gneiss in the northwest of Tonghua City, which provides information on the nature of this magmatic event within the NCC, and allows for a global comparison of the formation and evolution of early crustal materials.

Methods

With ongoing support by the National Natural Science Foundation since 2013, we have carried out field surveys and petrological, geochronological, geochemical, and isotopic studies of Precambrian rocks along the northeastern margin of the NCC. Rock samples were crushed and zircons were separated at the Langfang Regional Geological Survey Institute in Hebei Province, China. Internal structures in zircon were revealed by cathodoluminescence (CL) imaging. The major, trace, and rare earth element compositions of the samples were analyzed at the National Research Center for Geoanalysis, Chinese Academy of Geological Sciences in Beijing, China. U–Pb dating and *in situ* Lu–Hf isotope analyses of zircons were performed by LA–MC–ICP–MS at the Laboratory Center, Xi'an Center of the Geological Survey of China.

Results

The results show, for the first time, the occurrence of Neo-Archean (2.7 Ga) granitoid gneisses in southeastern Jilin Province. Specific details and features of these rocks are as follows.

(1) The rocks were collected at Sanyuanpu Town, north of Tonghua City (Fig. 1b; 125°50′20.89″E, 41°56′13.20″N; 125°47′04.47″E, 42°01′55.66″N), and are mainly tonalite gneisses with a mineral assemblage of plagioclase (~60%), quartz (~30%), hornblende (<3%), biotite (~5%), and opaque minerals (Fig. 1d). These samples exhibit fine- to medium-grained textures, gneissic structures, and were intruded by ~2.5 Ga monzogranites (Fig. 1c).

(2) Zircons from the tonalite gneisses are long, columnar or oval-shaped, and mainly gray to white in color. They show rhythmic zoning (Fig. 1e) and high Th/U ratios (0.61–1.09), indicating a magmatic origin. Moreover, these features are similar to those of inherited or captured zircons in meta-supracrustal rocks in the same region. The age data show that the magmatic precursors of the tonalite gneiss samples formed at 2.7–2.68 Ga (Fig. 1f). We therefore consider that 2698–2683 Ma represents the age of the original formation of the granitoid gneisses.

(3) The tonalite gneisses are rich in SiO_2, CaO, and Na_2O, and they belong to the medium-K calc-alkaline series. They are enriched in LREEs and strongly depleted in HREEs and HFSEs (Nb, Ta, P, and Ti).

(4) Lu–Hf isotope analyses yield ages of 2698 to 2683 Ma, corresponding $\varepsilon_{Hf}(t)$ values of 4.25 to 7.96, and T^{c}_{DM}

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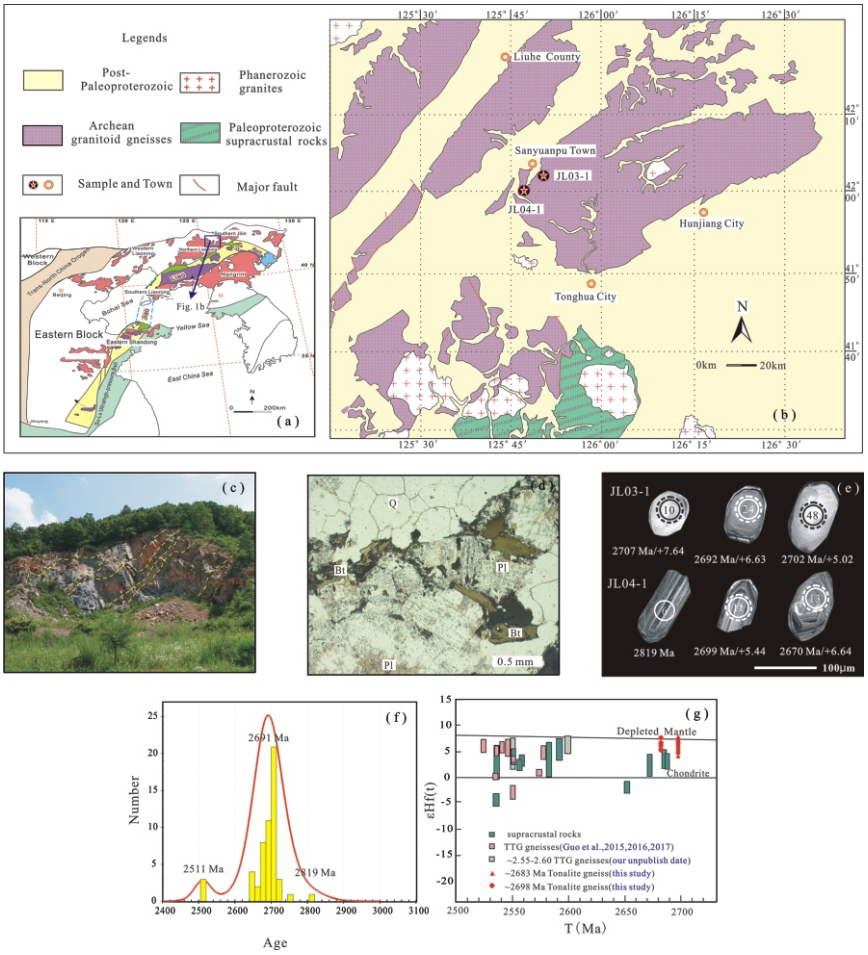

Fig. 1. (a–b), Geological map of Precambrian rocks showing ~2.7 Ga granitoid gneisses in southeastern Jilin Province; (c–d), Field photographs and photomicrographs of the tonalite gneiss; (e), Cathodoluminescence (CL) images of zircons from the tonalite gneiss samples; (f), Age spectra (age (in Ma) versus number of zircons) for zircons in the tonalite gneiss; (g), $\varepsilon_{Hf}(t)$ vs. T (Ma) diagram.
Q, Quartz; Pl, Plagioclase; Bt, Biotite.

model ages of 2.65 to 2.93 Ga (Fig. 1g), indicating the parental magma of these tonalite gneisses originated from partial melting of juvenile crustal materials and represents an episode of crustal growth in southern Jilin Province at 2.9–2.7 Ga.

(5) Previous studies reported that basement rocks in southern Jilin Province are characterized by the continuous development of 2.6–2.5 Ga rocks (Fig. 1g). This result, combined with the observation that most of these rocks have positive $\varepsilon_{Hf}(t)$ values (Fig. 1g), raised the possibility that 2.6–2.5 Ga was the most important period of crustal growth in southern Jilin Province. However, the ~2.7 Ga granitoid gneisses of the present study yield $\varepsilon_{Hf}(t)$ values of 4.25 to 7.96, representing the early Neoarchean (~2.7 Ga). These results indicate that ~2.7 Ga was also the main stage of crustal growth in southern Jilin Province.

Conclusions

Neo-Archean granitic basement rocks to the northwest of Tonghua formed at 2.70–2.68 Ga rather than 2.5 Ga as previously thought. Geochemical and Lu–Hf data indicate that these rocks were derived by partial melting of juvenile crustal materials, suggesting a ~2.7 Ga magmatic event in southeastern Jilin Province, which was previously unknown. The results contribute to research on the northeastern margin of the NCC and provide a new basis for comparisons between the NCC and other ancient cratons.

Acknowledgments

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Table 1 LA–ICP–MS U–Pb age data for zircons in the Early Neoarchean granitoid gneisses of southeastern Jilin Province, China

Sample No.	Th/U	Isotopic ratios						Ages (Ma)						
		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		Dis.
		ratio	1σ	ratio	1σ	ratio	1σ	age	1σ	age	1σ	age	1σ	(%)
JL03-1-01	0.73	0.17978	0.00526	12.61344	0.35783	0.50830	0.00840	2651	47	2651	27	2649	36	0.1
JL03-1-02	0.67	0.17991	0.00545	12.02833	0.35297	0.48437	0.00813	2652	49	2607	28	2546	35	4.0
JL03-1-03	0.67	0.18048	0.00769	12.63225	0.51883	0.50709	0.01129	2657	69	2653	39	2644	48	0.5
JL03-1-04	0.81	0.18765	0.00424	13.59972	0.29971	0.52507	0.00747	2722	37	2722	21	2721	32	0.0
JL03-1-05	0.79	0.18817	0.00539	13.64609	0.37882	0.52542	0.00871	2726	46	2726	26	2722	37	0.2
JL03-1-06	0.88	0.18567	0.00524	13.38927	0.36682	0.52248	0.00858	2704	46	2708	26	2710	36	−0.2
JL03-1-07	0.84	0.18455	0.00530	13.17624	0.36736	0.51729	0.00857	2694	47	2692	26	2688	36	0.2
JL03-1-08	0.50	0.17462	0.00421	9.74365	0.22781	0.40428	0.00576	2602	40	2411	22	2189	26	15.9
JL03-1-09	0.91	0.18635	0.00530	13.33744	0.36823	0.51856	0.00850	2710	46	2704	26	2693	36	0.6
JL03-1-10	0.80	0.18601	0.01111	13.48804	0.77554	0.52539	0.01595	2707	95	2714	54	2722	67	−0.5
JL03-1-11	0.77	0.18581	0.00482	13.28555	0.33499	0.51807	0.00801	2705	42	2700	24	2691	34	0.5
JL03-1-12	0.90	0.18288	0.00407	13.01483	0.28299	0.51565	0.00723	2679	36	2681	21	2681	31	−0.1
JL03-1-13	0.62	0.18443	0.00762	13.21570	0.52673	0.51920	0.01139	2693	67	2695	38	2696	48	−0.1
JL03-1-14	0.65	0.18371	0.00495	13.23895	0.34675	0.52216	0.00826	2687	44	2697	25	2708	35	−0.8
JL03-1-15	0.61	0.18324	0.00379	13.06415	0.26430	0.51662	0.00697	2682	34	2684	19	2685	30	−0.1
JL03-1-16	0.70	0.18522	0.00922	13.30341	0.63801	0.52045	0.01330	2700	80	2701	45	2701	56	0.0
JL03-1-17	0.20	0.09661	0.00133	1.23878	0.01709	0.09292	0.00100	1559	26	818	8	573	6	63.3
JL03-1-18	0.24	0.13373	0.00165	3.43571	0.04283	0.18617	0.00199	2147	21	1512	10	1101	11	48.7
JL03-1-19	0.18	0.12142	0.00164	2.23968	0.03018	0.13366	0.00145	1977	24	1193	9	809	8	59.1
JL03-1-20	0.67	0.18345	0.00406	13.15327	0.28460	0.51957	0.00722	2684	36	2691	20	2697	31	−0.5
JL03-1-21	0.65	0.18632	0.00468	13.44622	0.32886	0.52297	0.00791	2709	41	2712	23	2712	33	−0.1
JL03-1-22	0.67	0.16481	0.00234	10.80301	0.15304	0.47500	0.00537	2505	24	2506	13	2506	23	0.0
JL03-1-23	1.09	0.16576	0.00306	10.90351	0.19848	0.47669	0.00597	2515	31	2515	17	2513	26	0.1
JL03-1-24	0.74	0.18426	0.00519	13.20981	0.36132	0.51952	0.00846	2691	46	2695	26	2697	36	−0.2
JL03-1-25	0.67	0.18307	0.00416	13.09716	0.29084	0.51845	0.00737	2680	37	2687	21	2693	31	−0.4
JL03-1-26	0.36	0.15044	0.00187	5.18092	0.06496	0.24958	0.00269	2351	21	1850	11	1436	14	38.9
JL03-1-27	0.17	0.11560	0.00173	1.65418	0.02460	0.10370	0.00114	1889	27	991	9	636	7	66.3
JL03-1-28	0.70	0.18624	0.00429	13.41789	0.30197	0.52214	0.00746	2709	38	2710	21	2708	32	0.0
JL03-1-29	0.65	0.19190	0.00739	14.14706	0.52622	0.53427	0.01119	2759	62	2760	35	2759	47	0.0
JL03-1-30	0.72	0.18418	0.00490	13.21779	0.34204	0.52010	0.00815	2691	43	2695	24	2700	35	−0.3
JL03-1-31	0.10	0.14349	0.00185	4.30372	0.05565	0.21737	0.00236	2270	22	1694	11	1268	12	44.1
JL03-1-32	0.03	0.15860	0.00182	7.87408	0.09203	0.35983	0.00383	2441	19	2217	11	1981	18	18.8
JL03-1-33	0.79	0.18489	0.00465	13.23045	0.32441	0.51863	0.00782	2697	41	2696	23	2693	33	0.1
JL03-1-34	0.29	0.11642	0.00174	2.35183	0.03499	0.14642	0.00162	1902	27	1228	11	881	9	53.7
JL03-1-35	1.05	0.18581	0.00421	13.36563	0.29545	0.52133	0.00742	2706	37	2706	21	2705	31	0.0
JL03-1-36	0.93	0.18408	0.00675	13.17300	0.46687	0.51867	0.01026	2690	59	2692	33	2694	44	−0.1
JL03-1-37	0.76	0.18641	0.00567	13.42133	0.39549	0.52183	0.00901	2711	49	2710	28	2707	38	0.1
JL03-1-38	0.67	0.18578	0.00512	13.37024	0.35776	0.52161	0.00841	2705	45	2706	25	2706	36	0.0
JL03-1-39	0.71	0.16556	0.00197	10.85398	0.13143	0.47517	0.00512	2513	20	2511	11	2506	22	0.3
JL03-1-40	0.88	0.18500	0.00458	13.26392	0.32017	0.51967	0.00779	2698	40	2699	23	2698	33	0.0
JL03-1-41	0.90	0.18620	0.00540	13.39055	0.37658	0.52127	0.00873	2709	47	2708	27	2705	37	0.2

Continued Table 1

Sample No.	Th/U	Isotopic ratios						Ages (Ma)						
		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		Dis.
		ratio	1σ	ratio	1σ	ratio	1σ	age	1σ	age	1σ	age	1σ	(%)
JL03-1-42	1.03	0.18595	0.00377	13.33458	0.26544	0.51977	0.00695	2707	33	2704	19	2698	29	0.3
JL03-1-43	0.86	0.18340	0.00342	13.13002	0.24101	0.51892	0.00664	2684	31	2689	17	2695	28	−0.4
JL03-1-44	0.99	0.18540	0.00402	13.28623	0.28198	0.51944	0.00720	2702	35	2700	20	2697	31	0.2
JL03-1-45	0.83	0.18586	0.00439	13.33469	0.30771	0.52006	0.00751	2706	38	2704	22	2700	32	0.2
JL03-1-46	0.74	0.18599	0.00470	13.37944	0.32963	0.52143	0.00789	2707	41	2707	23	2705	33	0.1
JL03-1-47	0.83	0.18567	0.00566	12.57972	0.37146	0.49111	0.00841	2704	49	2649	28	2576	36	4.8
JL03-1-48	0.72	0.18538	0.00585	13.36194	0.40901	0.52248	0.00924	2702	51	2706	29	2710	39	−0.3
JL03-1-49	1.05	0.18853	0.00742	13.65209	0.51899	0.52492	0.01110	2729	63	2726	36	2720	47	0.3
JL03-1-50	0.73	0.18554	0.00586	12.42672	0.37927	0.48550	0.00853	2703	51	2637	29	2551	37	5.6
JL04-1.01	0.17	0.16494	0.00277	2.80097	0.04640	0.12308	0.00147	2507	28	1356	12	748	8	70.2
JL04-1.02	0.36	0.35756	0.00429	13.71912	0.16799	0.27808	0.00315	3740	18	2731	12	1582	16	57.7
JL04-1.03	0.31	0.17426	0.00251	8.39027	0.12206	0.34895	0.00405	2599	24	2274	13	1930	19	25.8
JL04-1.04	0.54	0.19976	0.00269	4.73649	0.06438	0.17184	0.00196	2824	22	1774	11	1022	11	63.8
JL04-1.05	0.87	0.18258	0.00236	11.65289	0.15439	0.46255	0.00524	2677	21	2577	12	2451	23	8.4
JL04-1.06	0.24	0.19914	0.00452	14.96884	0.33318	0.54475	0.00803	2819	37	2813	21	2803	34	0.6
JL04-1.07	0.55	0.19006	0.00364	10.60535	0.19968	0.40438	0.00530	2743	31	2489	17	2189	24	20.2
JL04-1.08	0.20	0.18026	0.00309	12.66776	0.21642	0.50928	0.00638	2655	28	2655	16	2654	27	0.1
JL04-1.09	0.13	0.24058	0.00361	10.51792	0.15682	0.31683	0.00381	3124	24	2482	14	1774	19	43.2
JL04-1.10	0.69	0.18380	0.00298	13.10693	0.21299	0.51678	0.00635	2688	27	2687	15	2686	27	0.1
JL04-1.11	0.90	0.18503	0.00268	13.22522	0.19406	0.51796	0.00610	2699	24	2696	14	2691	26	0.3
JL04-1.12	0.62	0.18525	0.00262	13.32977	0.19096	0.52143	0.00609	2701	23	2703	14	2705	26	−0.2
JL04-1.13	0.50	0.18187	0.00281	12.89875	0.20032	0.51394	0.00618	2670	25	2672	15	2673	26	−0.1
JL04-1.14	0.52	0.18275	0.00316	13.00161	0.22368	0.51554	0.00649	2678	28	2680	16	2680	28	−0.1
JL04-1.15	0.43	0.18294	0.00276	13.01265	0.19784	0.51546	0.00615	2680	25	2681	14	2680	26	0.0
JL04-1.16	0.48	0.18591	0.00344	13.37177	0.24498	0.52121	0.00678	2706	30	2706	17	2704	29	0.1
JL04-1.17	0.29	0.17992	0.00293	12.65333	0.20610	0.50961	0.00624	2652	27	2654	15	2655	27	−0.1
JL04-1.18	0.59	0.18469	0.00305	13.17623	0.21734	0.51696	0.00639	2695	27	2692	16	2686	27	0.3
JL04-1.19	0.83	0.18430	0.00234	9.97302	0.12922	0.39210	0.00440	2692	21	2432	12	2133	20	20.8
JL04-1.20	0.53	0.17990	0.00385	12.43286	0.26157	0.50078	0.00696	2652	35	2638	20	2617	30	1.3
JL04-1.21	1.24	0.18556	0.00379	13.36683	0.26906	0.52197	0.00714	2703	33	2706	19	2708	30	−0.2
JL04-1.22	0.40	0.16925	0.00254	7.60777	0.11430	0.32571	0.00381	2550	25	2186	13	1818	19	28.7
JL04-1.23	0.60	0.17348	0.00309	3.55652	0.06193	0.14855	0.00182	2592	29	1540	14	893	10	65.5
JL04-1.24	0.33	0.17488	0.00228	8.78304	0.11676	0.36391	0.00410	2605	22	2316	12	2001	19	23.2
JL04-1.25	0.32	0.17501	0.00228	6.77578	0.08979	0.28053	0.00315	2606	22	2083	12	1594	16	38.8
JL04-1.26	0.24	0.16463	0.00223	3.54363	0.04838	0.15596	0.00175	2504	23	1537	11	934	10	62.7
JL04-1.27	0.65	0.23124	0.00390	11.15723	0.18485	0.34958	0.00440	3061	27	2536	15	1933	21	36.9
JL04-1.28	0.58	0.16015	0.00205	4.29301	0.05594	0.19422	0.00215	2457	22	1692	11	1144	12	53.4
JL04-1.29	0.23	0.17539	0.00253	7.34367	0.10627	0.30336	0.00350	2610	24	2154	13	1708	17	34.6
JL04-1.30	0.17	0.16335	0.00219	2.80980	0.03793	0.12463	0.00139	2491	22	1358	10	757	8	69.6

Table 2 Lu–Hf isotopic data for zircons in the the early Neoarchean granitoid gneisses of southeastern Jilin Province, China

Sample No.	t (Ma)	±1σ	Dis. (%)	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	±2σ	Hf_i	$\varepsilon_{Hf}(t)$	T_{DM} (Ga)	±1σ	T^C_{DM} (Ga)	±1σ
JL03-1.01	2651	48	0.1	0.012830	0.000492	0.281271	0.000034	0.281246	5.57	2.73	0.05	2.79	0.05
JL03-1.03	2657	69	0.5	0.017503	0.000696	0.281240	0.000049	0.281205	4.25	2.78	0.07	2.88	0.07
JL03-1.04	2722	37	0.0	0.013187	0.000481	0.281278	0.000031	0.281253	7.45	2.72	0.04	2.72	0.04
JL03-1.05	2726	46	0.2	0.013895	0.000548	0.281287	0.000028	0.281258	7.75	2.71	0.04	2.70	0.04
JL03-1.07	2694	47	0.2	0.013963	0.000524	0.281235	0.000033	0.281208	5.24	2.78	0.04	2.84	0.04
JL03-1.08	2602	40	15.9	0.014834	0.000537	0.281329	0.000031	0.281302	6.45	2.65	0.04	2.69	0.04
JL03-1.09	2710	46	0.6	0.013715	0.000491	0.281292	0.000031	0.281266	7.66	2.70	0.04	2.70	0.04
JL03-1.10	2707	95	−0.5	0.016402	0.000625	0.281300	0.000043	0.281267	7.64	2.70	0.06	2.70	0.06
JL03-1.11	2705	42	0.5	0.015465	0.000558	0.281276	0.000032	0.281247	6.88	2.73	0.04	2.74	0.04
JL03-1.12	2679	36	−0.1	0.014646	0.000543	0.281238	0.000033	0.281210	4.95	2.78	0.04	2.85	0.04
JL03-1.13	2693	67	−0.1	0.009460	0.000364	0.281279	0.000030	0.281260	7.05	2.71	0.04	2.72	0.04
JL03-1.14	2687	44	−0.8	0.013509	0.000498	0.281272	0.000035	0.281247	6.43	2.73	0.05	2.76	0.05
JL03-1.15	2682	34	−0.1	0.011760	0.000491	0.281266	0.000029	0.281240	6.10	2.74	0.04	2.78	0.04
JL03-1.16	2700	80	0.0	0.014751	0.000545	0.281279	0.000037	0.281251	6.90	2.72	0.05	2.74	0.05
JL03-1.20	2684	36	−0.5	0.009147	0.000402	0.281299	0.000037	0.281279	7.51	2.68	0.05	2.69	0.05
JL03-1.21	2710	41	−0.1	0.004896	0.000201	0.281268	0.000022	0.281258	7.37	2.71	0.03	2.72	0.03
JL03-1.23	2515	31	0.1	0.015995	0.000547	0.281360	0.000038	0.281334	5.56	2.61	0.05	2.68	0.05
JL03-1.24	2692	46	−0.2	0.015020	0.000542	0.281277	0.000030	0.281249	6.63	2.72	0.04	2.75	0.04
JL03-1.25	2681	37	−0.4	0.011453	0.000420	0.281293	0.000025	0.281272	7.18	2.69	0.03	2.70	0.03
JL03-1.29	2759	62	0.0	0.013540	0.000481	0.281268	0.000032	0.281243	7.96	2.73	0.04	2.71	0.04
JL03-1.30	2691	43	−0.3	0.017427	0.000674	0.281296	0.000035	0.281261	7.03	2.71	0.05	2.72	0.05
JL03-1.33	2697	41	0.1	0.014482	0.000545	0.281291	0.000037	0.281262	7.23	2.71	0.05	2.71	0.05
JL03-1.35	2706	37	0.0	0.018109	0.000652	0.281288	0.000033	0.281254	7.14	2.72	0.04	2.73	0.04
JL03-1.36	2690	59	−0.1	0.014569	0.000552	0.281255	0.000033	0.281227	5.79	2.75	0.04	2.80	0.04
JL03-1.37	2711	49	0.1	0.014908	0.000556	0.281243	0.000039	0.281214	5.81	2.77	0.05	2.82	0.05
JL03-1.42	2707	33	0.3	0.031430	0.001114	0.281311	0.000039	0.281253	7.13	2.72	0.05	2.73	0.05
JL03-1.43	2684	31	−0.4	0.013297	0.000488	0.281246	0.000032	0.281221	5.46	2.76	0.04	2.82	0.04
JL03-1.44	2702	35	0.2	0.015947	0.000579	0.281273	0.000041	0.281243	6.65	2.73	0.06	2.76	0.06
JL03-1.46	2707	41	0.1	0.010839	0.000403	0.281257	0.000054	0.281236	6.51	2.74	0.07	2.77	0.07
JL03-1.48	2702	51	−0.3	0.010902	0.000409	0.281219	0.000052	0.281197	5.02	2.79	0.07	2.86	0.07
JL04-1.10	2688	27	0.1	0.013731	0.000490	0.281263	0.000039	0.281238	6.12	2.74	0.05	2.78	0.05
JL04-1.11	2699	24	0.3	0.010261	0.000403	0.281232	0.000032	0.281211	5.44	2.77	0.04	2.83	0.04
JL04-1.12	2701	23	−0.2	0.008080	0.000317	0.281289	0.000030	0.281272	7.66	2.69	0.04	2.69	0.04
JL04-1.13	2670	25	−0.1	0.013284	0.000500	0.281289	0.000028	0.281264	6.64	2.70	0.04	2.73	0.04
JL04-1.15	2680	25	0.0	0.011518	0.000410	0.281315	0.000033	0.281294	7.96	2.66	0.04	2.65	0.04
JL04-1.18	2695	27	0.3	0.015857	0.000560	0.281312	0.000030	0.281283	7.94	2.68	0.04	2.67	0.04
JL04-1.20	2652	35	1.3	0.019669	0.000690	0.281272	0.000044	0.281237	5.28	2.74	0.06	2.81	0.06