single zircon U-Pb dating of the Kongling high-grade metamorphic terrain: Evidence for >3.2 Ga old continental crust in the Yangtze craton

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Abstract Single zircons from two trondhjemitic gneisses and two clastic metasedimentary rocks without Eu anomaly of the Kongling high-grade metamorphic terrain are dated by the *in situ* SHRIMP U-Pb method. The results show that the trondhjemitic magma emplaced at 2947—2903 Ma. Concordant age of as old as 3.3 Ga is present in the detrital zircons from the clastic metasedimentary rocks. Together with the depleted mantle Nd model age (T_{DM} =3.2—3.3 Ga) of the clastic metasedimentary rocks, this documents the presence of Paleoarchean continental crust in the Yangtze craton.

Keywords: Kongling high-grade metamorphic terrain, zircon U-Pb age, SHRIMP Archean, Yangtze craton.

There is still controversy over whether Archean basement exists in the Yangtze craton. The question is important for understanding tectonic evolution of the Chinese continents in the early Precambrian. The Kongling high-grade metamorphic terrain is the oldest known basement exposed in the Yangtze craton, which has yielded ages of 2.73—2.86 Ga by the conventional U-Pb and evaporation Pb zircon methods and by the whole rock Sm-Nd method[1—4]. However, it is likely that the conventional U-Pb and evaporation Pb zircon methods may give a mixing age or an age of Pb loss which has no geological significance. The Kongling terrain was subjected to widespread anatexis during the high amphibolite- to granulite-facies metamorphism, which led to mobility of REE [5]. Therefore, the age of the Kongling terrain needs further investigation. As a part of joint research between China and Australia, the present paper reports ages of the trondhjemitic gneiss and clastic metasedimentary rocks of the Kongling terrain determined by the SHRIMP single zircon U-Pb method.

1 Geological setting

The Kongling high-grade metamorphic terrain is located at the Huangling area of the northwestern part of the Yangtze craton and about 100 km north of Yichang along the middle Yangtze

River (fig. 1). It is exposed as a small dome of only 360 km^2 and is dominated by dioritic-tonalitic-trondhjemitic-granodiroitic (DTTG) and granitic gneisses with less important metasedimentary rocks, amphibolite and rare mafic granulite. The DTTG and granitic gneisses are mostly trondhjemitic. The metasedimentary rocks consist of banded biotite gneiss with or without graphite, garnet- and sillimanite-bearing quartzite and gneiss, graphite schist, marble, calc-silicate rocks, quartzite and iron-bearing quartzite, which show characteristics of khondalite[4—6]. The clastic metasedimentary rocks can be further divided into three distinct groups according to the nature of Eu anomaly: (1) Group A shows negligible to slight negative Eu anomalies; (2) Group B is characterized by significant negative Eu anomalies; and (3) Group C is restite characterized by high sillimanite (5%—31%) and unusually high ilmenite (7%—11%) contents with highly variable garnet (0.2%—22%). Abundant sillimanite and garnet in metapelite, biotite dehydration melting as seen under the microscope and locally preserved mafic granulite point to peak metamorphic temperature of >750℃[5,7]. Using microprobe analyses of garnet and biotite and geothermometer of Mg-Fe exchange between these two minerals, the temperature for metapelite is estimated to range between 775 and 900℃ for pressures from 500 to 1100 MPa. The three types of clastic metasedimentary rocks show similar appearance and are difficult to distinguish in the field.

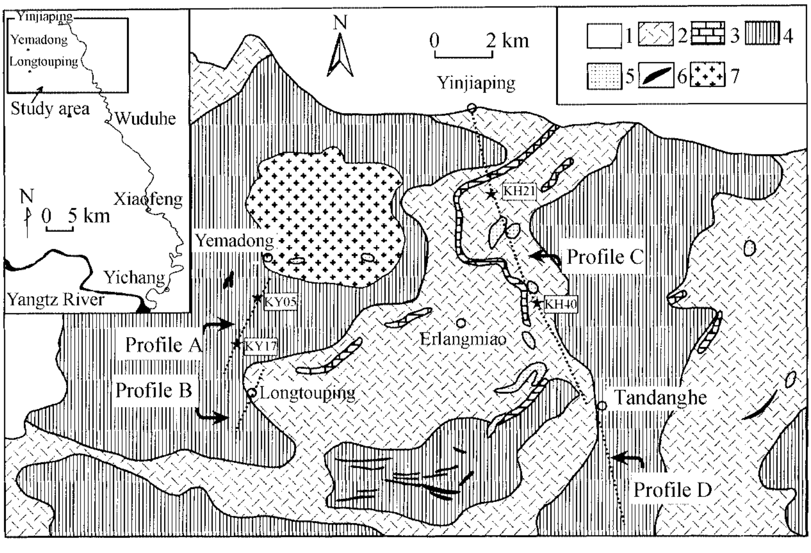

Fig. 1. Simplified geological map of the Archean Kongling high-grade metamorphic terrain. Inset shows location of the study area. 1, post-Archean sedimentary cover; 2, metasedimentary rock; 3, marble marker horizon; 4, dioritic-tonalitic-trondhjemitic-granitic gneiss; 5, ultramafic intrusion; 6, mafic dyke; 7, Paleoproterozoic Quanqitan K-feldspar granite.

2 Samples and analytical methods

108 samples from the Kongling terrain were collected along 4 profiles of Yinjiaping to Tandanghe, Yemadong and Longtouping. Based on detailed microscopic studies and major and trace

element as well as Sm-Nd isotopic compositions[4—6], two trondhjemitic gneisses (KY05 and KY17) and two clastic metasedimentary rocks (KH21 and KH40) without Eu anomaly were selected for zircon separation and dating. The four samples are fresh and representative. The trondhjemitic samples were collected at Yemadong (Profile A) and the clastic metasedimentary rocks were taken along Yinjiaping-Tandanghe (Profile C) (fig. 1). Mineral and geochemical and Sm-Nd isotopic compositions are reported elsewhere[5].

Representative zircon grains were stuck to epoxy, ground to half and polished to expose the interior of the zircons and then gilded. Back scatter electron (BSE) and cathodoluminescence (CL) images were made on the zircons prior to analyses at the center of microscope and microanalysis of Western Australia, whereby well preserved parts of the crystals were selected for subsequent SHRIMP analysis. This avoids the parts of Pb loss and transition/mixing zones between core, mantle and margin of the zircons to be analyzed and insures the derived age of clear geological significance. U, Th and Pb isotopic compositions of zircons were analyzed on SHRIMP II. Analysis and data processes follow the established methods of Composton et al. and Williams et al. [8, 9] The CZ3 zircon standard was used as reference and analyzed after every 2—4 analyses of sample zircons. CZ3 has $^{206}Pb/^{238}U$ of 0.0914 and an age of 564 Ma[10]. Analytical precision for U/Pb ratio is 1.2%—3.02% (1σ). The decay constants given by Steiger and Jager are adopted in age calculation. Common Pb is corrected from measured ^{204}Pb. Uncertainties in ages are quoted at the 95% confidence level (2σ).

3 Results

Analytical results for KY05, KY17, KH21 and KH40 are presented in tables 1 to 4 and the corresponding U-Pb concordia diagrams are illustrated in figs. 2—5.

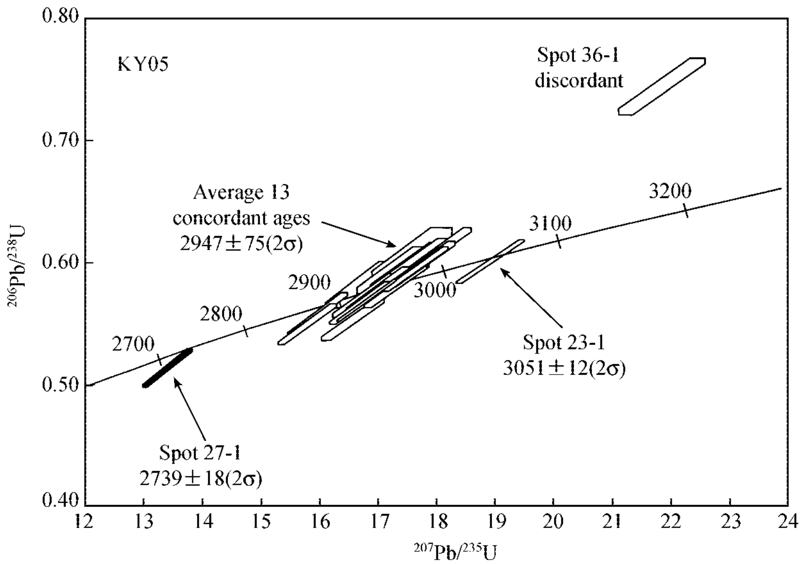

Fig. 2. SHRIMP U-Pb concordia diagram for single zircons from trondhjemitic gneiss KY05.

3.1 Trondhjemitic gneisses

20 analyses were made on 19 zircon grains of the trondhjemitic gneiss KY05 (table 1). Analysis 23-1was from the core of a zircon, which yields a concordant $^{207}Pb/^{206}Pb$ age of 3051 ±12(2σ) Ma interpreted as the age of xenocrystic zircon. Analysis 27-1 gives a near-concordant $^{207}Pb/^{206}Pb$ age of 2739 ±18 Ma. The low Th/U ratio (0.1) and elongate homogeneous morphology of the zircon indicate a metamorphic origin. The other 17 analyses on oscillatory zoned igneous zircons form a coherent group on and around concordia, the oldest 13 concordant analyses (Th/U = 0.3−0.8) of which yield a weighted mean $^{207}Pb/^{206}Pb$ age of 2947±5 Ma. This age is interpreted to be the intrusion age. Reverse discordant analysis 36-1 and the four slightly younger analyses are interpreted to be 2947 Ma zircons that underwent post-formation element mobility, including Pb loss or gain.

Table 1 SHRIMP U-Pb zircon data of trondhjemitic gneiss KY05 from the Kongling high-grade metamorphic terrain

Spot	U/ ppm	Th/ ppm	Th/U	Pb/ ppm	f_{206} (%)					Age / Ma		Age Concor. (%)
23-1	253	38	0.15	166	0.119	0.600±20	19.02±0.59	0.2299±29	0.0393±56	3030±73	3051±6	99
12-1	112	40	0.36	70	0.025	0.553±18	16.64±0.54	0.2183±13	0.0948±16	2837±71	2968±11	96
10-1	94	30	0.32	61	0.016	0.580±17	17.38±0.57	0.2173±15	0.0873±19	2950±74	2961±10	100
26-1	182	97	0.53	126	0.000	0.594±18	17.72±0.55	0.2164±14	0.1412±11	3005±73	2954±7	102
25-1	102	97	0.95	77	0.025	0.598±17	17.82±0.57	0.2162±5	0.2544±4	3021±75	2953±9	102
1-1	78	38	0.49	55	0.127	0.608±18	18.09±0.59	0.2157±18	0.1317±26	3063±77	2949±10	104
7-1	608	74	0.12	371	0.007	0.568±17	16.88±0.51	0.2154±12	0.0324±14	2901±70	2947±4	98
13-1	129	55	0.42	84	0.025	0.566±19	16.76±0.54	0.2149±22	0.1127±37	2891±72	2942±9	98
4-1	49	23	0.47	34	0.162	0.599±20	17.71±0.62	0.2144±34	0.1294±65	3026±78	2939±17	103
31-1	45	23	0.51	31	0.000	0.596±19	17.61±0.65	0.2143±13	0.1268±14	3013±80	2938±21	103
36-1	229	121	0.53	198	0.009	0.744±18	21.97±0.74	0.2143±9	0.1361±9	3584±86	2938±14	122
28-1	106	42	0.39	70	0.180	0.578±21	17.06±0.55	0.2142±33	0.0993±64	2939±73	2937±10	100
6-1	84	26	0.31	54	0.000	0.572±19	16.86±0.56	0.2136±12	0.0831±19	2918±74	2933±13	99
15-1	40	31	0.77	29	0.000	0.593±18	17.36±0.65	0.2123±9	0.2090±10	3001±79	2923±22	103
3-1	35	21	0.60	25	0.235	0.604±16	17.64±0.68	0.2118±11	0.1635±14	3046±80	2920±26	104
22-1	31	23	0.75	23	0.098	0.607±18	17.67±0.70	0.2112±13	0.1955±17	3057±83	2914±26	105
5-1	124	28	0.22	75	0.318	0.549±20	15.84±0.51	0.2094±28	0.0629±51	2820±70	2901±10	97
32-1	42	29	0.70	29	0.254	0.581±19	16.76±0.61	0.2092±26	0.1863±47	2954±77	2899±20	102
32-2	112	80	0.72	75	0.005	0.557±17	16.03±0.52	0.2086±13	0.1968±21	2855±71	2895±10	99
27-1	256	25	0.10	138	0.000	0.514±23	13.43±0.43	0.1896±19	0.0273±21	2672±67	2739±9	98

f_{206} (%) is the percent of total ^{206}Pb attributed to common ^{206}Pb. Error is 1σ. Concor. is concordance.

27 analyses were done on 24 zircons from KY17 (table 2) and give two age groups (fig. 3). Analysis 19-1 yields a concordant $^{207}Pb/^{206}Pb$ age of 1992±16 Ma with its very low Th/U ratio (0.09) indicating a metamorphic zircon. Its age is close to that of the nearby Quanqitan granite which intruded the Archean basement and has conventional U-Pb zircon age of 1841±4 Ma and single zircon evaporation age of 1851±231 Ma[3]. DTTG gneiss adjacent to the Quanqitan granite is significantly altered by K-feldspar and the alteration increases when approaching to the Quanqitan granite. Consequently, the age is interpreted to represent the age of zircon formed during the

Table 2 SHRIMP U-Pb zircon data of trondhjemitic gneiss KY17 from the Kongling high-grade metamorphic terrain

Spot	U/ ppm	Th/ ppm	Th /U	Pb/ ppm	f_{206} (%)					Age / Ma $^{206}Pb/^{238}U$	Age / Ma	Age Concor. (%)
12-1	78	55	0.70	55	0.207	0.578±17	16.82±0.56	0.2111±12	0.1924±16	2941±74	2914±13	101
23-1	285	125	0.44	183	0.360	0.561±11	16.31±0.50	0.2108±7	0.1197±10	2872±70	2911±6	99
3-1	324	141	0.44	207	0.000	0.560±17	16.24± 0.50	0.2104±7	0.1165±7	2866±70	2908±5	99
17-1	535	341	0.64	344	0.000	0.540±16	15.58± 0.48	0.2094±6	0.1717±6	2782±68	2901±4	96
6-1	179	46	0.26	109	0.023	0.552±15	15.84± 0.50	0.2081±14	0.0678±21	2833±70	2891±8	98
11-1	121	56	0.46	79	0.058	0.570±17	16.30±0.52	0.2073±10	0.1268±13	2908±72	2884±9	101
23-2	282	39	0.14	145	0.066	0.479±13	13.69±0.47	0.2072±5	0.0319±5	2523±66	2884±18	87
25-1	191	119	0.63	125	0.010	0.554±16	15.79±0.50	0.2066±9	0.1713±9	2843±70	2879 ± 8	99
1-1	180	56	0.31	109	0.000	0.542±16	15.40±0.49	0.2060±8	0.0837±5	2793±69	2874±9	97
24-1	270	29	0.11	159	0.020	0.554±11	15.68±0.49	0.2052±8	0.0287±9	2844±70	2868±7	99
5-2	197	98	0.50	124	0.001	0.547±18	15.47±0.48	0.2050±12	0.1348±17	2814±69	2866±8	98
14-1	226	72	0.32	136	0.102	0.542±18	15.28±0.48	0.2046±17	0.0828±30	2791±69	2863±7	97
8-1	228	39	0.17	127	0.085	0.518±17	14.50±0.45	0.2030±10	0.0466±13	2691±67	2850±7	94
15-1	422	67	0.16	260	0.008	0.573±13	16.00±0.49	0.2027±9	0.0452±11	2919±71	2848±5	102
9-1	217	37	0.17	126	0.072	0.542±16	15.00±0.47	0.2006±9	0.0475±11	2792±69	2831±7	99
16-1	172	36	0.21	99	0.021	0.532±17	14.61±0.46	0.1990±6	0.0526±5	2751±68	2818±9	98
4-1	346	113	0.33	206	0.118	0.539±16	14.73±0.45	0.1982±11	0.0883±13	2779±68	2811±5	99
7-1	771	85	0.11	360	0.003	0.444±16	11.60±0.35	0.1895±6	0.0306±8	2368±59	2738±4	86
5-1	117	37	0.32	62	0.063	0.478±15	12.48±0.41	0.1893±10	0.1033±12	2519±64	2736±12	92
18-1	437	65	0.15	194	0.202	0.416±13	10.85±0.33	0.1890±7	0.0423±10	2244±57	2733±6	82
17-2	223	25	0.11	114	0.023	0.490±11	12.71±0.40	0.1883±6	0.0279±7	2569±64	2727±8	94
20-1	934	63	0.07	362	0.024	0.374±11	9.51 ± 0.29	0.1845±5	0.0188±4	2047±52	2694±4	76
13-1	233	34	0.15	106	0.117	0.436±4	10.93±0.34	0.1818±6	0.0353±9	2332±59	2669±8	87
10-1	410	47	0.11	160	0.011	0.376±17	8.55±0.27	0.1650±7	0.0415±9	2057±53	2508±8	82
2-1	558	26	0.05	213	0.156	0.373±15	8.31±0.26	0.1615±23	0.0132±33	2044±53	2471±7	83
19-1	420	39	0.09	149	0.020	0.360±17	6.07±0.19	0.1225±8	0.0247±8	1980±51	1992±8	99
21-1	1398	59	0.04	191	0.000	0.141±17	2.07±0.06	0.1060±10	0.0133±12	853±24	1732±10	49

f_{206} (%) is the percent of total ^{206}Pb attributed to common ^{206}Pb. Error is 1σ. Concor. is concordance.

alteration. The Archean analyses vary from concordant to discordant. The discordant ages indicate Pb loss during a later event. The six most concordant analyses on oscillatory zoned igneous zircons (Th/U = 0.3—0.7) yield a weighted mean $^{207}Pb/^{206}Pb$ age of 2903 ± 10 Ma interpreted as the emplacement age of the trondhjemite. Analysis 17-2 on the homogeneous rim (Th/U = 0.1) gives a metamorphic age of 2727±16 Ma, whereas the oscillatory zoned area of the same zircon (17-1) gives a magmatic age of 2901±8 Ma (Th/U = 0.6).

3.2 Clastic metasedimentary rocks

As described above, two clastic metasedimentary rocks without Eu anomaly were selected for SHRIMP dating. 42 analyses were done on KH21(table 3). They form an age ranging along the concordia (fig. 4), suggesting a source provenance consisting of rocks of varying ages. The concordant analyses yield $^{207}Pb/^{206}Pb$ ages from 3.28 Ga to 2.64 Ga, with several ages >3.0 Ga and few even >3.2 Ga. Most of the concordant zircons are 2.9—3.0 Ga old, suggesting that the major sediment source is of this age.

36 analyses were carried out on KH40 (table 4). Its zircons have $^{207}Pb/^{206}Pb$ ages of 3133±14 Ma, with concordant to near-concordant ages at 2949±4 Ma, 2871 ±14 Ma and 1928 ±18 Ma. The 2949 Ma zircon is coeval with magmatic zircons in the trondhjemitic gneiss KY05, suggesting that similar rocks are one of the sedimentary sources. However, the >3.1 Ga discordant zircons suggest that the source includes a pre-trondhjemite component. The 2871 Ma ages (Th/U = 0.3–0.7) interpreted as the age of the protolith are derived from slightly rounded euhedral zircon cores which are surrounded by homogeneous rims. The one near-concordant ca. 1.9 Ga zircon of

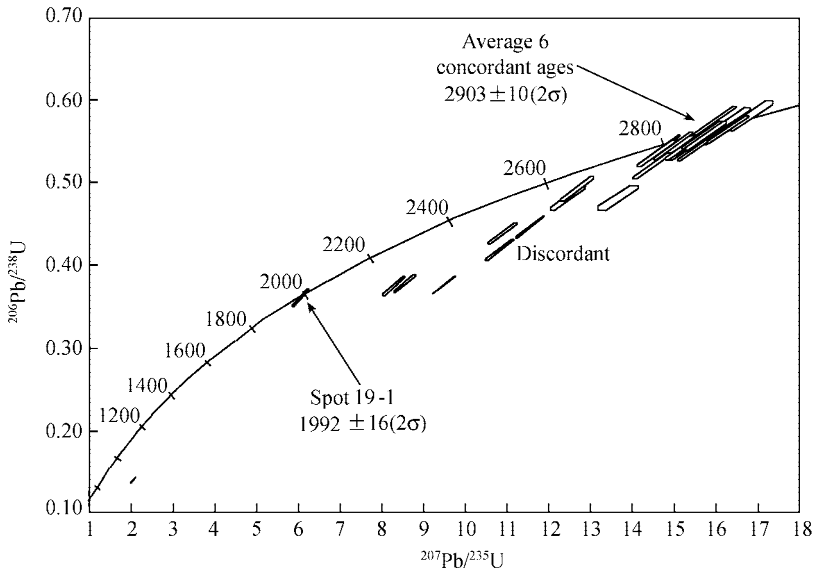

Fig. 3. SHRIMP U-Pb concordia diagram for single zircons from trondhjemitic gneiss KY17.

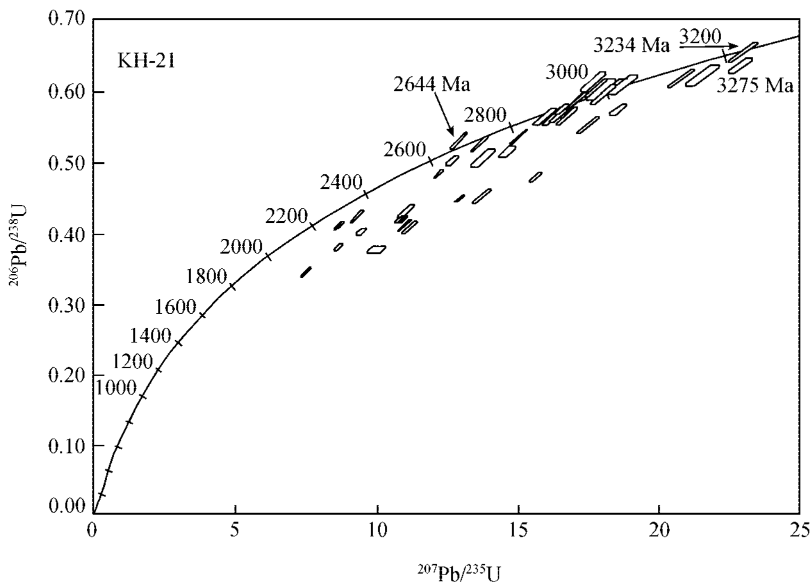

Fig. 4. SHRIMP U-Pb concordia diagram for single zircons from clastic metasedimentary rock KH21.

Table 3 SHRIMP U-Pb zircon data of clastic metasedimentary rock without Eu anomaly KH21 from the Kongling high-grade metamorphic terrain

Spot	U/ Ppm	Th/ ppm	Th/ U	Pb/ ppm	F_{206} (%)	$\frac{^{206}Pb}{^{238}U}$				Age / Ma $\frac{^{206}Pb}{^{238}U}$	Age / Ma	Age Concor. (%)
35-1	68	48	0.70	53	0.029	0.629±11	22.97±0.42	0.2647±8	0.1823±17	3147±40	3275±11	96
25-1	177	125	0.70	143	0.007	0.648±13	23.05±0.51	0.2579±9	0.1869±13	3221±54	3234±6	100
16-1	48	19	0.40	35	0.000	0.616±9	21.62±0.58	0.2546±11	0.1164±9	3093±59	3213±16	96
20-1	208	48	0.23	144	0.339	0.611±14	20.86±0.46	0.2476±28	0.0612±52	3074±52	3169±6	97
25-2	206	110	0.53	118	0.066	0.474±11	15.65±0.23	0.2396±10	0.1664±15	2499±27	3117±8	80
31-1	175	119	0.68	124	0.340	0.568±7	18.64±0.30	0.2378±12	0.1822±20	2902±32	3105±11	93
3-1	209	79	0.38	133	0.027	0.546±13	17.55±0.39	0.2330±15	0.1145±25	2809±48	3073±8	91
9-2	57	55	0.97	44	0.156	0.603±12	18.80±0.50	0.2260±18	0.2514±28	3042±57	3024±15	101
9-3	82	104	1.27	66	0.131	0.601±12	18.58±0.39	0.2244±11	0.3347±14	3032±41	3012±17	101
21-1	176	56	0.32	89	0.486	0.446±15	13.74±0.31	0.2232±25	0.0913±41	2380±42	3004±8	79
24-1	96	36	0.38	64	0.000	0.589±12	18.10±0.44	0.2231±10	0.1025±13	2984±54	3003±10	99
9-1	66	60	0.91	50	0.154	0.596±12	18.02±0.51	0.2193±26	0.2475±47	3014±57	2976±20	101
2-1	188	137	0.73	128	0.000	0.559±14	16.80±0.37	0.2180±20	0.1990±30	2862±49	2966±7	96
34-1	98	56	0.58	65	0.063	0.564±9	16.88±0.29	0.2172±14	0.1632±20	2882±35	2960±11	97
13-1	193	128	0.66	139	0.001	0.598±12	17.85±0.40	0.2164±9	0.1769±13	3023±51	2954±7	102
17-1	210	131	0.63	145	0.074	0.579±10	17.12±0.38	0.2143±19	0.1726±33	2947±50	2939±7	100
19-1	126	102	0.81	90	0.000	0.581±13	17.14±0.39	0.2140±11	0.2171±15	2952±52	2936±8	101
23-1	158	78	0.49	103	0.032	0.562±13	16.57±0.39	0.2139±10	0.1360±10	2874±51	2936±9	98
6-1	117	83	0.71	86	0.093	0.607±10	17.75±0.42	0.2121±12	0.1902±14	3057±53	2922±12	105
29-1	542	206	0.38	275	0.106	0.444±12	12.98±0.17	0.2121±16	0.1144±28	2368±23	2922±7	81
22-1	91	77	0.84	63	0.005	0.559±12	16.33±0.40	0.2119±12	0.2261±16	2862±51	2920±12	98
13-2	283	221	0.78	197	0.000	0.569±13	16.62±0.24	0.2119±15	0.2063±13	2904±29	2920±9	99
15-2	102	72	0.71	63	0.036	0.509±14	14.65±0.31	0.2088±11	0.1965±14	2652±34	2896±19	92
6-2	96	58	0.61	63	0.024	0.558±11	16.00±0.40	0.2079±8	0.1600±12	2859±51	2889±14	99
14-1	208	278	1.34	150	0.116	0.530±9	15.07±0.33	0.2061±10	0.3690±16	2742±47	2875±6	95
15-1	139	46	0.33	63	0.181	0.404±8	11.20±0.27	0.2012±25	0.0996±45	2187±41	2836±12	77
37-1	43	22	0.52	25	0.039	0.501±7	13.80±0.40	0.1998±12	0.1436±18	2618±53	2824±22	93
12-1	190	35	0.19	84	0.000	0.406±10	11.02±0.25	0.1967±23	0.0743±44	2198±40	2799±9	79
28-1	144	37	0.26	77	0.202	0.373±6	10.03±0.30	0.1952±15	0.1408±27	2041±25	2787±41	73
21-2	388	69	0.18	173	7.466	0.415±5	10.99±0.15	0.1921±48	0.0524±106	2236±23	2760±9	81
10-1	202	119	0.59	123	0.115	0.521±5	13.66±0.30	0.1903±10	0.1634±17	2702±46	2745±8	98
20-2	601	195	0.32	277	0.056	0.415±5	10.85±0.14	0.1896±9	0.1007±11	2237±22	2739±8	82
18-1	110	60	0.54	55	0.003	0.426±5	11.08±0.29	0.1885±7	0.1652±8	2289±44	2729±17	84
10-2	248	164	0.66	146	0.674	0.497±8	12.72±0.21	0.1855±16	0.1789±28	2602±28	2703±14	96
16-2	240	180	0.75	139	0.119	0.478±5	12.22±0.17	0.1854±11	0.2150±13	2518±26	2702±8	93
26-1	217	101	0.47	128	2.689	0.525±5	12.96±0.29	0.1791±18	0.1248±39	2719±47	2644±8	103
33-1	325	139	0.43	163	0.094	0.398±6	9.48±0.16	0.1726±9	0.1703±15	2162±22	2583±17	84
36-1	337	309	0.92	165	0.035	0.376±5	8.68±0.13	0.1675±9	0.3122±12	2056±21	2533±12	81
27-1	211	79	0.37	97	0.015	0.420±8	9.32±0.21	0.1611±15	0.1043±22	2260±40	2467±10	92
8-1	225	40	0.18	82	0.000	0.341±10	7.52±0.17	0.1600±18	0.0635±21	1892±34	2455±12	77
22-2	222	66	0.30	98	0.866	0.407±5	8.72±0.14	0.1552±12	0.1048±28	2202±25	2404±11	92
30-1	370	84	0.23	160	0.075	0.406±6	8.65±0.11	0.1546±12	0.0832±15	2196±22	2398±7	92

f_{206} (%) is the percent of total ^{206}Pb attributed to common ^{206}Pb. Error is 1σ. Concor. is concordance.

high Th/U ratio (1.3) is coeval with the intrusive Quanqitang granite.

Table 4 SHRIMP U-Pb zircon data of clastic metasedimentary rock without Eu anomaly KH40 from the Kongling high-grade metamorphic terrain

Spot	U/ ppm	Th/ ppm	Th/ U	Pb/ ppm	f_{206} (%)	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{208}Pb}{^{206}Pb}$	Age (Ma) $\frac{^{206}Pb}{^{238}U}$	Age (Ma) $\frac{^{207}Pb}{^{206}Pb}$	Age Concor. (%)
25-1	149	78	0.52	101	0.360	0.569±10	18.94±0.42	0.2415±15	0.1480±24	2903±50	3130±7	93
6-2	60	15	0.25	38	0.051	0.561±9	18.52±0.45	0.2396±7	0.0625±9	2869±42	3118±23	92
1-1	156	75	0.48	85	0.000	0.452±12	14.49±0.34	0.2326±9	0.1473±16	2403±43	3070±10	78
6-1	152	30	0.20	88	0.000	0.527±11	16.49±0.37	0.2269±11	0.0574±7	2729±47	3030±7	90
3-2	210	197	0.94	152	0.184	0.569±8	17.04±0.24	0.2173±12	0.2581±20	2902±30	2961±8	98
3-1	169	184	1.09	122	0.032	0.553±9	16.45±0.36	0.2158±8	0.3017±17	2837±49	2950±7	96
11-1	77	23	0.30	51	0.116	0.588±6	16.97±0.44	0.2093±5	0.0783±6	2981±55	2900±16	103
26-1	195	55	0.28	119	0.058	0.551±6	15.60±0.35	0.2056±5	0.0796±7	2828±48	2871±7	98
18-1	115	75	0.65	71	0.123	0.510±7	14.12±0.33	0.2007±6	0.1897±9	2657±47	2832±11	94
26-2	203	46	0.22	105	0.452	0.481±7	13.10±0.20	0.1976±9	0.0546±17	2532±27	2806±11	90
20-1	388	182	0.47	213	0.208	0.477±14	12.90±0.27	0.1962±21	0.1397±30	2514±43	2795±5	90
24-1	210	48	0.23	107	0.406	0.476±7	12.51±0.28	0.1905±8	0.0545±13	2512±44	2746±8	91
2-1	344	171	0.50	176	0.000	0.448±8	11.46±0.25	0.1854±17	0.1391±51	2387±41	2702±6	88
8-1	260	244	0.94	148	0.046	0.450±6	11.42±0.25	0.1842±7	0.2864±8	2394±41	2691±8	89
31-1	262	158	0.60	138	0.131	0.454±6	11.51±0.26	0.1839±8	0.1615±13	2412±43	2688±8	90
28-1	457	133	0.29	178	0.167	0.345±11	8.59±0.18	0.1803±14	0.1105±24	1913±34	2655±7	72
7-1	172	69	0.40	72	0.092	0.376±5	9.16±0.21	0.1767±6	0.1224±10	2056±38	2622±11	78
16-1	307	36	0.12	137	0.000	0.427±12	10.38±0.22	0.1761±10	0.0336±11	2293±40	2617±7	88
23-1	263	47	0.18	107	0.024	0.384±10	9.30±0.20	0.1757±8	0.0503±13	2095±37	2613±8	80
21-1	256	174	0.68	127	0.030	0.417±12	10.00±0.22	0.1738±9	0.2110±11	2248±40	2594±8	87
17-1	234	95	0.41	102	0.012	0.382±9	9.05±0.20	0.1717±8	0.1414±14	2087±37	2574±10	81
8-2	304	142	0.47	124	0.223	0.353±8	8.19±0.13	0.1681±9	0.1557±15	1950±21	2539±13	77
26-3	944	708	0.75	392	0.001	0.351±10	8.11±0.11	0.1676±6	0.2017±8	1940±19	2534±9	77
23-2	369	35	0.09	139	0.135	0.367±9	8.47±0.13	0.1675±8	0.0292±10	2014±22	2533±12	80
30-1	324	29	0.09	123	0.265	0.366±8	8.21±0.18	0.1628±10	0.0360±17	2010±36	2485±10	81
5-1	480	133	0.28	187	0.062	0.362±6	7.91±0.17	0.1585±7	0.0888±9	1991±35	2439±7	82
27-1	316	129	0.41	123	0.038	0.346±10	7.46±0.17	0.1564±9	0.1284±11	1914±34	2417±10	79
28-2	431	98	0.23	130	0.068	0.281±8	5.99±0.08	0.1547±8	0.0876±10	1595±17	2398±11	67
13-1	448	29	0.06	132	0.009	0.291±7	5.97±0.13	0.1485±11	0.0262±19	1649±30	2329±8	71
10-1	710	248	0.35	226	0.221	0.296±10	5.92±0.12	0.1449±34	0.0992±53	1674±30	2287±6	73
19-1	425	128	0.30	123	0.517	0.270±4	5.32±0.12	0.1431±14	0.0944±26	1539±28	2265±9	68
14-1	802	362	0.45	228	0.071	0.255±6	4.81±0.10	0.1367±14	0.1535±16	1466±27	2186±7	67
12-2	711	137	0.19	202	0.124	0.272±4	5.12±0.07	0.1367±9	0.0643±16	1549±16	2185±12	71
15-1	404	53	0.13	113	0.000	0.273±5	5.09±0.11	0.1354±12	0.0539±7	1555±28	2169±9	72
9-1	695	44	0.06	199	0.171	0.288±3	5.30±0.11	0.1333±10	0.0190±15	1633±29	2142±7	76
29-1	52	68	1.32	22	0.407	0.323±3	5.28±0.16	0.1184±9	0.4084±17	1805±38	1933±25	93

f_{206} (%) is the percent of total ^{206}Pb attributed to common ^{206}Pb. Error is 1σ. Concor. is concordance.

4 Discussion

The above results indicate that the DTTG gneiss, which dominates the Kongling terrain, emplaced at 2947—2903 Ma. The age represents the oldest known age in the Yangtze craton. Due to the limited ages, it is unclear whether trondhjemitic magmatism extended from 2.95 Ga to 2.90 Ga or was in two or more episodic events.

The detrital zircons as old as ca. 3.3 Ga in clastic metasedimentary rocks, and the >3.0 Ga xenocrystic zircon core in one trondhjemite (fig. 2), provide the direct evidence for >3.2 Ga continental crust in the craton. This is reinforced by the depleted-mantle model ages of 3.2—3.3 Ga of the clastic metasedimentary rocks without Eu anomaly[5]. Mineralogical, geochemical and Sm-Nd isotopic studies[5] suggest that the clastic metasedimentary rocks without Eu anomaly are first-cycle near-source sediments. Their sources are dominated by the DTTG rocks with less important amphibolite and K-feldspar granite as well as minor komatiitic ultramafic rock. They were mixtures of the four components in the proportion of 62%, 25%, 7% and 6%, respectively.

Both the deposition age of the three types of clastic metasedimentary rocks and the age of metamorphism of the Kongling high-grade metamorphic terrain are suggested to be Archean based on the following lines of evidence:

(1) All the concordant or near-concordant zircons from the two clastic metasedimentary rocks have $^{207}Pb/^{206}Pb$ ages of ⩾2.64 Ga (figs. 4 and 5), although there are ca. 2.75 Ga zircons in KH21 whose morphology and chemistry are consistent with either a high-grade metamorphic or a magmatic origin. As the trondhjemites also contain ca. 2.75 Ga zircon of typical metamorphic character (Th/U<0.1) and because both the trondhjemites and metasedimentary rocks underwent high amphibolite- to granulite-facies metamorphism, it is most likely that the ca. 2.75 Ga zircons in the metasedimentary rock are also metamorphic. Therefore, the 2.75 Ga age can be used as the minimum deposition age of the metasedimentary rocks.

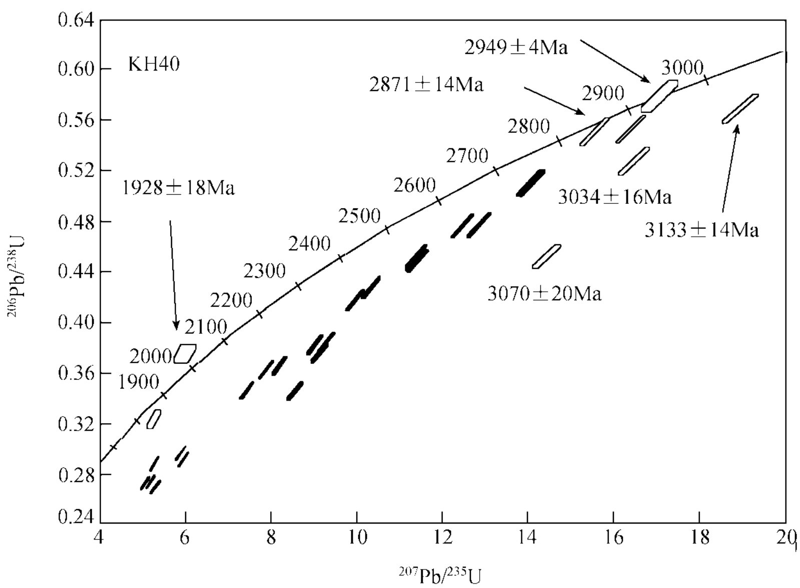

Fig. 5. SHRIMP U-Pb concordia diagram for single zircons from clastic metasedimentary rock KH40.

(2) As Paleoproterozoic felsic basements are exposed at the northern margin of the Yangtze craton[11], the absence of concordant Paleoproterozoic zircons in the metasedimentary rocks also infers an Archean deposition age. Otherwise, Paleoproterozoic zircons would be expected in the Kongling metasedimentary rocks.

(3) The first-cycle near-source nature of the clastic metasedimentary rocks without Eu anomaly implies that their deposition age should be close to the age of their sources of the Kongling felsic gneiss and amphibolite. The latter has a whole rock Sm-Nd age of 2742 ± 83 Ma[4].

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