743 ± 17 Ma granite clast from Jurassic conglomerate, Kamiaso, Mino Terrane, Japan: the case for South China Craton provenance (Korean Gyeonggi Block?)

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Abstract

The polymict Kamiaso Conglomerate (Mino Terrane, Japan) contains Jurassic to Palaeoproterozoic clasts—probably derived from Korean basement that lay nearby to the northwest at time of deposition. Clast K2 broke cleanly into two halves during sampling (but the halves were recombined for zircon separation). A third of the K2 zircons are colourless euhedral prisms with oscillatory zoning, with no inheritance and yielded a SHRIMP U/Pb date of 743 ± 17 Ma. Two thirds of K2 zircons are brown oscillatory-zoned corroded prisms with a date of 1860 ± 8 Ma, with inherited cores up to ~2460 Ma. A likely explanation for this could be that clast K2 might have been composite, and contained undistinguished 743 Ma and 1860 Ma granites. Kamiaso granitic clast K3 igneous zircons gave a date of 179.3/−2.1 Ma (Toarcian–Early Jurassic), with 2100–2300 Ma and ~1860 Ma inherited cores.

~740 Ma A-type magmatism related to the extension and break up of Rodinia occurs in both Korea (Gyeonggi Block) and the main part of the South China Craton, but is unknown in the Sino-Korean Craton. Thus from recognition of a 743 Ma clast, the Kamiaso detritus was probably derived from the northernmost part of the South China Craton in Korea.
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Keywords: Kamiaso; Asian terranes; Rodinia; U–Pb zircon geochronology; Precambrian in Japan

1. Introduction

Around Kamiaso (35°32′N 137°08′E), in the Mino Terrane, one of several Mesozoic accretionary terranes of central Japan (Fig. 1) Jurassic turbidite is an important lithology. Rare conglomerates in these turbidites (Adachi, 1971) contain clasts of paragneiss, orthogneiss and metagranitoids. Prior to the opening of the Japan Sea in the Neogene, when the sediments of the Mino Terrane were deposited in the Jurassic, Korean crystalline basement would have formed the hinterland to the northwest. Some of these clasts were derived from

Proterozoic crystalline basement (e.g. Shibata et al., 1971; Hidaka et al., 2002), and are the only known pieces of Precambrian rock in Japan. U–Pb zircon dating has already been used to date metasedimentary and volcano-sedimentary clasts from Kamiaso. The first Kamiaso U–Pb studies using the CHIME (U–Th–total Pb) method by Adachi and Suzuki (1993) found Meso-Archaean detritus in these sediments, indicating that some very old detritus occurs within the Mesozoic accretionary terranes of Japan. More precise and accurate zircon dating with the HU-SHRIMP (Hiroshima University Sensitive High Resolution Ion MicroProbe) by Sano et al. (2000) and Hidaka et al. (2002) also found Archaean and Palaeoproterozoic detritus in the Kamiaso sediments, again indicating derivation from a complex terrane in mainland Asia which included Precambrian crystalline basement rocks.

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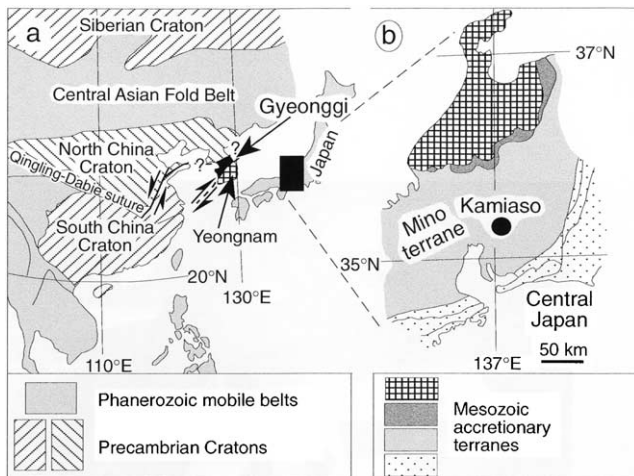E-mail address: allen.nutman@anu.edu.au (A.P. Nutman).

Fig. 1. Sketch maps of principal terranes of east Asia and of Mesozoic terranes of central Japan.

U–Pb zircon dating is a powerful tool in identifying source tectono-stratigraphic terranes of detrital material in sediments. Hidaka et al. (2002) pointed out that 3250 Ma zircons in their sample provided a link with the South China Craton (Fig. 1a), because rocks of that age occur there (Qiu et al., 2000) whereas to the north of the Mesozoic Dabieshan Suture in the North China (formerly Sino-Korean) Craton, rocks of that age are presently unknown (e.g. Song et al., 1996). A South China Craton source for Kamiaso detritus is feasible, because recent geological and geochronological results (reviewed by Li et al., 2003a) indicate that parts of Korea (definitely the Gyeonggi Block and possibly the Yeongam Block—Fig. 1a) represent the northernmost extremity of the South China Craton.

The strongest line of evidence for the Korean–South China Craton linkage comes from the presence of ∼740 Ma volcanic and plutonic rocks with A-type/within plate chemistry in both Korea (e.g. Lee et al., 1998, 2003) and in the South China Craton sensu stricto (e.g. Li et al., 2003b; Wang and Li, 2003). On the other hand ∼740 Ma igneous rocks have not been identified in the North China (Sino-Korean) Craton. Thus, as surmised by Lee et al. (2003), the South China Craton including parts of Korea is a complex ancient terrane that from ∼830 Ma underwent extension and anorogenic bimodal magmatism related to the break-up of the supercontinent Rodinia.

This paper reports zircon dating on granitic clasts from the Kamiaso Conglomerate, and the recognition of ∼740 Ma material. This is strong evidence supporting the suggestion of Hidaka et al. (2002) that the Jurassic conglomerates at Kamiaso contain material derived from the South China Craton-probably its northernmost part in Korea.

2. The Kamiaso Conglomerate—Mino Terrane

The source terrane of at least some of the paragneiss, orthogneiss and metagranitoid clasts in the conglomerates

within the Jurassic turbidites in the Mino Terrane around Kamiaso (Fig. 1b) underwent amphibolite facies metamorphism (Adachi, 1971, 1973; Shibata and Adachi, 1974). Rb–Sr and K–Ar dating of crystalline clasts from the Kamiaso conglomerate gave dates of 1000–2000 Ma (Shibata et al., 1971; Shibata and Adachi, 1972, 1974), whereas some orthogneiss clasts gave an imprecise Sm–Nd date of 2070 ± 60 Ma (Shimizu et al., 1996). CHIME single zircon and monazite dating (Adachi and Suzuki, 1993) gave mostly dates of ∼2000 and 1500–1750 Ma respectively, but some older zircons, ages up to 3040 ± 180 Ma were detected. Using HU-SHRIMP, Sano et al. (2000) dated thirteen zircons from a volcaniclastic rock in the Kamiaso Conglomerate and detected grains with ages of ∼2550 Ma, 2000 Ma, 1300 Ma, 920 Ma, 250 Ma and 220 Ma. These results indicated a Permo-Triassic to Jurassic age for the volcanosedimentary clast, which had incorporated material from a complex Precambrian source. Also using HU-SHRIMP, Hidaka et al. (2002) dated zircons from a clast of coarse-grained garnet + biotite metapelite and obtained ∼3250, 2550 Ma, 2200–2000 Ma and 1860–1850 Ma zircons. As no younger zircons were found, this sample is probably a piece of Palaeoproterozoic paragneiss. Adachi and Suzuki (1993) reported limestone clasts in the conglomerate, which from palaeontological evidence are of Carboniferous age. Thus the Kamiaso Conglomerate contains a wide range of clasts, which are thought to have been derived from a Precambrian continental basement and its Phanerozoic cover, which was exposed and eroded in the Jurassic, not far to the north of the Kamiaso Conglomerate locality.

3. HU-SHRIMP dating of Kamiaso granitic clasts K2 and K3

Sample preparation, analytical protocol, data reduction and assignment of analytical errors follows Stern (1998), Williams (1998) and Hidaka et al. (2002). In this study a few analyses of a fragment of the standard zircon SL13 (with a uniform U of 238 ppm) were used to calibrate U abundance, whereas a greater number of analyses of the 1099 Ma (Paces and Miller, 1993) multicrystal AS3 standard were used to calibrate $^{206}Pb/^{238}U$. The decay constants and present-day $^{238}U/^{235}U$ given by Steiger and Jaeger (1977) were used to calculate ages. Pooled ages presented in this paper are weighted means (95% confidence) calculated with Isoplot/Ex (Ludwig, 1999). For Palaeoproterozoic zircons $^{207}Pb/^{206}Pb$ ages and for Neoproterozoic and Mesozoic zircons $^{206}Pb/^{238}U$ ages are emphasised. Correction for common Pb was made on the basis of measured ^{204}Pb and model Cumming and Richards (1975) common Pb compositions for the likely age of the rock.

3.1. Clast K2

Clast K2 is ~ 8 cm long, and locally on its grey to buff coloured weathered surface a weakly to undeformed granitic texture is apparent. When extracting this clast from the sandstone matrix with a chisel, it broke cleanly into two pieces. Because of its small size, both parts of the clast were recombined for zircon separation.

Despite its small size, the clast yielded >100 non-metamict zircons. The zircon population is distinctly bimodal (Fig. 2). Approximately two thirds of the population are brown to yellow, prismatic, and slightly rounded/corroded and typically 150–200 µm long. From optical and cathodoluminescence (CL) imaging, these grains are locally metamict and show micron-scale oscillatory zoning parallel to grain exteriors (Fig. 2a,b). The CL imaging shows that there are rare inherited cores in these grains (Fig. 2b). The remaining third of the zircons are prisms of similar size, but are colourless to very pale yellow and completely euhedral (Fig. 2c,d). No cores of older zircon were found in these grains.

Thirty-one analyses were undertaken on twenty-five zircons (Table 1), with most yielding close to concordant dates (Fig. 3). Two older cores were dated in the brown, slightly corroded grains, one of which (analysis 19.2) is concordant at ~ 2450 Ma, whilst the other (analysis 8.1)

with a $^{207}Pb/^{206}Pb$ age of ~ 2250 Ma is discordant. Excluding a few analyses of the brown zircon with the highest U, the rest with close to concordant dates yielded a weighted mean $^{207}Pb/^{206}Pb$ date of 1860 ± 8 Ma ($n = 13$, MSWD $= 1.2$). The discordant domains might be 1860 Ma zircon that lost some radiogenic Pb in the Phanerozoic. Regression of the data yield upper and lower intercepts of 1859 ± 11 Ma and 493 ± 140 Ma (MSWD $= 0.96$). All analyses of the euhedral colourless zircons are concordant within error and yielded a weighted mean $^{206}Pb/^{238}U$ date of 743 ± 17 Ma ($n = 10$, MSWD $= 0.48$). Given the magmatic appearance of both the brown and the clear populations, and the lack of (1860 Ma) inheritance in the ~ 750 Ma population, it is suggested that the clast K2 was composite, consisting of granites of two different ages. This may not have been obvious in the field because most of the clast was covered by a weathering skin.

3.2. Clast K3

Granitic clast K3 also had a brownish weathering skin and was <10 cm long. It yielded abundant zircons. Most grains are clear, euhedral and prismatic with well developed oscillatory zoning in CL images (Fig. 2e,f). This is interpreted as the magmatic zircon. However, a minority of the grains contain cores of older zircon (Fig. 2e), with ages of
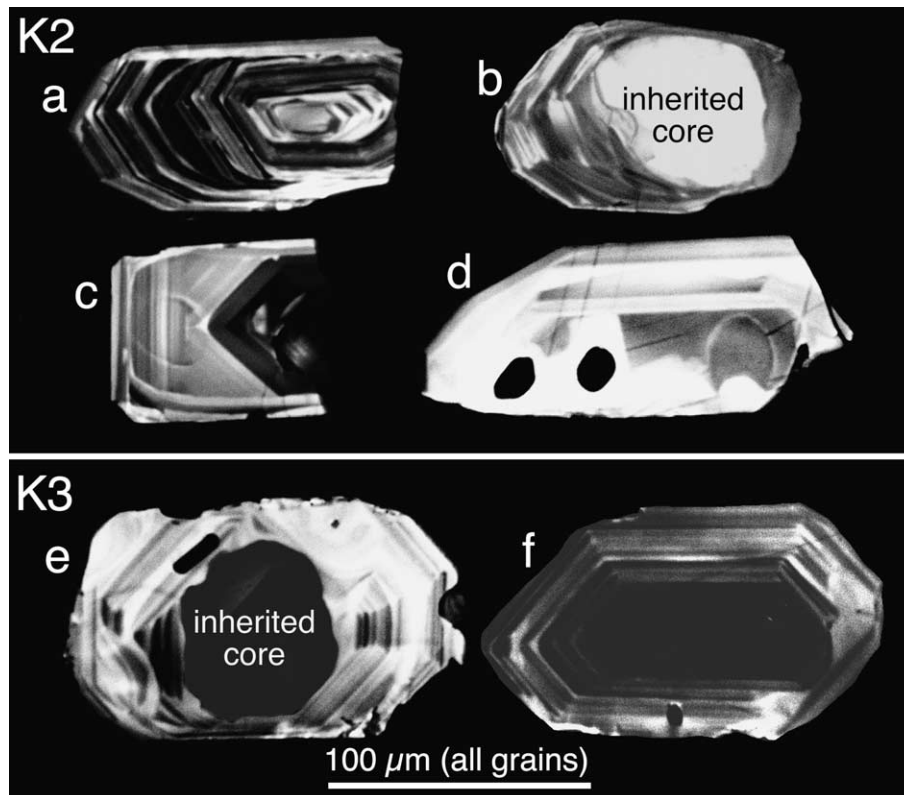
Fig. 2. Cathodoluminescence images of representative zircons (clast K2 grains a–d and clast K3 grains e and f); (a) K2 typical brown ~ 1860 Ma oscillatory-zoned zircon; (b) K2 brown ~ 1860 Ma oscillatory-zoned zircon with older inherited core; (c and d) fragments of K3 colourless oscillatory zoned 743 Ma zircons—devoid of inheritance; (e) K3 Jurassic oscillatory-zoned zircon with a Palaeoproterozoic inherited core; (f) K3 Jurassic oscillatory-zoned zircon devoid of inheritance.

Table 1
SHRIMP U/PB zircon analyses

Spot	U (ppm)	Th (ppm)	Th/U	Comm. (206Pb%)	238U/206/Pb (ratio)	207Pb/206Pb (ratio)	Age	%Conc.
Clast K2								
Brown and yellow grains								
1.1	604	174	0.29	0.20	3.038 ± 0.115	0.1123 ± 0.0007	*1837 ± 11*	0
2.1	638	202	0.32	0.10	3.010 ± 0.109	0.1134 ± 0.0009	*1855 ± 14*	0
3.1	803	232	0.29	0.17	3.080 ± 0.116	0.1139 ± 0.0006	*1863 ± 9*	−3
4.1	624	241	0.39	0.03	2.907 ± 0.118	0.1147 ± 0.0006	*1875 ± 10*	2
5.1	1578	1286	0.81	0.52	4.636 ± 0.210	0.1055 ± 0.0015	*1723 ± 26*	−27
6.1	753	156	0.21	0.20	3.061 ± 0.125	0.1121 ± 0.0018	*1833 ± 30*	−1
7.1	1036	943	0.91	3.01	4.773 ± 0.223	0.1022 ± 0.0079	*1665 ± 150*	−26
8.1	1078	482	0.45	0.04	2.871 ± 0.117	0.1423 ± 0.0010	*2256 ± 12*	−15
10.1	564	218	0.39	0.02	2.910 ± 0.140	0.1140 ± 0.0007	*1864 ± 12*	2
11.1	629	188	0.30	0.06	2.949 ± 0.127	0.1128 ± 0.0007	*1845 ± 11*	2
17.1	757	207	0.27	<0.01	2.978 ± 0.131	0.1139 ± 0.0006	*1862 ± 10*	0
18.1	668	231	0.35	0.22	3.126 ± 0.111	0.1161 ± 0.0014	*1897 ± 22*	−6
19.1	991	32	0.03	0.07	2.876 ± 0.183	0.1115 ± 0.0029	*1824 ± 48*	6
19.2	1403	1121	0.80	<0.01	2.098 ± 0.098	0.1611 ± 0.0006	*2468 ± 6*	2
20.2	865	441	0.51	1.08	4.004 ± 0.140	0.1084 ± 0.0020	*1773 ± 34*	−19
21.1	578	275	0.47	0.02	2.991 ± 0.127	0.1142 ± 0.0007	*1868 ± 12*	0
22.1	793	755	0.95	0.55	3.623 ± 0.152	0.1069 ± 0.0021	*1747 ± 37*	−10
23.1	814	215	0.26	0.03	3.038 ± 0.121	0.1142 ± 0.0007	*1867 ± 11*	−2
24.1	568	169	0.30	0.30	2.849 ± 0.205	0.1143 ± 0.0022	*1870 ± 35*	4
25.1	400	75	0.19	<0.01	2.892 ± 0.101	0.1147 ± 0.0010	*1875 ± 16*	2
25.2	411	83	0.20	0.05	2.829 ± 0.141	0.1120 ± 0.0011	*1833 ± 18*	7
Clear euhedral grains								
9.1	201	172	0.85	0.88	8.043 ± 0.262	0.0664 ± 0.0015	749 ± 23	
12.1	236	147	0.62	0.78	7.930 ± 0.305	0.0656 ± 0.0009	760 ± 28	
12.2	537	864	1.61	0.58	7.925 ± 0.467	0.0640 ± 0.0013	762 ± 42	
13.1	740	372	0.50	0.74	8.064 ± 0.265	0.0653 ± 0.0010	748 ± 23	
13.2	1549	1106	0.71	0.75	8.212 ± 0.405	0.0653 ± 0.0004	736 ± 34	
14.1	247	127	0.51	0.76	8.141 ± 0.276	0.0654 ± 0.0009	742 ± 24	
15.1	1546	1315	0.85	0.92	8.610 ± 0.309	0.0668 ± 0.0005	702 ± 24	
15.2	548	306	0.56	0.63	8.121 ± 0.240	0.0644 ± 0.0008	744 ± 21	
16.1	387	208	0.54	0.75	8.021 ± 0.342	0.0653 ± 0.0013	752 ± 30	
16.2	125	98	0.78	0.83	7.780 ± 0.431	0.0660 ± 0.0018	773 ± 41	
Clast K3								
1.1	673	592	0.88	0.36	29.137 ± 0.847	0.0517 ± 0.0025	218 ± 6	
1.2	427	194	0.45	0.76	38.205 ± 1.139	0.0451 ± 0.0030	167 ± 5	
2.1	266	153	0.58	1.31	35.461 ± 1.077	0.0521 ± 0.0054	179 ± 5	
3.1	1324	334	0.25	0.01	2.288 ± 0.098	0.1435 ± 0.0079	*2270 ± 97*	3
4.1	1744	252	0.14	<0.01	2.897 ± 0.052	0.1156 ± 0.0003	*1889 ± 5*	1
5.1	664	312	0.47	0.07	3.233 ± 0.074	0.1521 ± 0.0008	*2369 ± 10*	−27
6.1	509	506	0.99	0.47	36.812 ± 1.170	0.0476 ± 0.0037	173 ± 5	
7.1	1029	1028	1.00	5.48	35.499 ± 1.594	0.0721 ± 0.0391	179 ± 8	
8.1	719	191	0.27	0.06	2.944 ± 0.067	0.1147 ± 0.0010	*1876 ± 16*	1
9.1	467	431	0.92	0.35	36.571 ± 1.220	0.0519 ± 0.0029	174 ± 6	
10.1	259	212	0.82	<0.01	37.185 ± 1.485	0.0558 ± 0.0067	171 ± 7	
10.2	289	173	0.60	0.89	35.195 ± 1.462	0.0495 ± 0.0037	181 ± 7	
11.1	505	581	1.15	0.72	34.631 ± 0.966	0.0492 ± 0.0027	184 ± 5	
12.1	674	297	0.44	0.31	3.673 ± 0.114	0.1297 ± 0.0019	*2094 ± 26*	−26
13.1	543	451	0.83	0.55	36.486 ± 1.078	0.0483 ± 0.0022	174 ± 5	
14.1	596	365	0.61	0.28	34.512 ± 1.228	0.0493 ± 0.0028	184 ± 6	
15.1	420	337	0.80	0.68	35.492 ± 1.071	0.0511 ± 0.0044	179 ± 5	
16.1	631	473	0.75	0.66	35.117 ± 0.975	0.0497 ± 0.0023	181 ± 5	
17.1	413	353	0.85	0.75	35.861 ± 0.976	0.0521 ± 0.0042	177 ± 5	
17.2	231	144	0.62	3.39	39.301 ± 1.817	0.0321 ± 0.0099	162 ± 7	
17.3	289	172	0.60	2.57	38.034 ± 1.262	0.0446 ± 0.0119	167 ± 5	
18.1	686	565	0.82	1.96	35.562 ± 1.006	0.0517 ± 0.0081	179 ± 5	
19.1	553	402	0.73	1.30	36.361 ± 1.146	0.0443 ± 0.0042	175 ± 5	
20.1	245	137	0.56	1.81	36.527 ± 1.590	0.0541 ± 0.0059	174 ± 7	
21.1	2032	658	0.32	0.05	2.978 ± 0.053	0.1138 ± 0.0009	*1861 ± 15*	0
22.1	262	65	0.25	0.38	3.440 ± 0.087	0.1482 ± 0.0015	*2325 ± 17*	−29

Table 1 (*continued*)

Spot	U (ppm)	Th (ppm)	Th/U	Comm. (206Pb%)	238U/206/Pb (ratio)	207Pb/206Pb (ratio)	Age	%Conc.
23.1	740	420	0.57	0.08	36.544 ± 0.922	0.0540 ± 0.0028	174 ± 4	
24.1	327	176	0.54	0.25	34.074 ± 1.510	0.0554 ± 0.0065	186 ± 8	
25.1	438	441	1.01	0.70	34.901 ± 1.081	0.0477 ± 0.0045	182 ± 6	

All analytical errors are given at 1 sigma. Ages (after correction for common Pb): Italics, 207Pb/206Pb; Roman 206Pb/238U corrected with 1860, 750 and 180 Ma model Pb of Cumming and Richards (1975).

> 2300 Ma detected (^{207}Pb/^{206}Pb date on grains 5 and 22—Table 1 and Fig. 3). All analyses of the dominant prismatic oscillatory zoned zircon yielded a weighted mean ^{206}Pb/^{238}U date of 177.6 ± 2.6 Ma (MSWD = 1.5). Using a model of some loss of radiogenic Pb justified by multiple analyses on grains 10 and 17, a few analyses were culled until those remaining agreed with their mutual mean. This gives a ^{206}Pb/^{238}U date of 179.3 ± 2.1 Ma (MSWD = 0.68).

Fig. 3. Tera-Waserburg ^{238}U/^{206}Pb–^{207}Pb/^{206}Pb Concordia diagrams of HU-SHRIMP U/Pb zircon dating of clasts K2 and K3. Errors are depicted at the 1 sigma level.

4. Discussion

K3 with an age of 179.3 ± 2.1 Ma indicates that this igneous clast is Toarcian (Early Jurassic) and gives the maximum age of deposition of the conglomerate. This is consistent with the revision of the age of the conglomerate from Permian (Adachi, 1971) to Jurassic (Niwa et al., 2002) based on palaeontological evidence. The "old" K2 clast zircons indicates a granitic rock with an age of ~ 1860 Ma with some inherited older Palaeoproterozoic material. This 1860 Ma rock experienced Pb loss at 493 ± 140 Ma, suggesting a thermal event in the source region prior to erosion and then deposition at Kamiaso in the Jurassic. The "young" K2 clast zircons (probably from another granitic phase in the clast) indicate a granitic rock with an age of 743 ± 17 Ma with no older inherited zircon detected by either CL imaging or the HU-SHRIMP dating.

The 1860 Ma K2 date is not particularly diagnostic, because 1900–1800 Ma granitoids and high grade metamorphism occur in all the three main Precambrian crystalline blocks of east Asia (the South China Craton—e.g. Yuan et al., 1991; the North China Craton—summarised by Zhai and Liu, 2003; and the Aldan/Stonovoy Shield of Siberia—e.g. Nutman et al., 1992; Frost et al., 1998). These 1900–1800 Ma events are also common in the nearest crystalline basement in Korea (e.g. Cheong et al., 2000; Lee et al., 2000; Sagong et al., 2003). Much more diagnostic is the 743 ± 17 Ma date obtained from other K2 clast igneous zircons. In the South China Craton (sensu stricto) ~ 750 Ma is the time of the second pulse of bimodal magmatism and rifting equated with the break up of the supercontinent Rodinia (Li et al., 2003b). A-type granitoids and volcanic rocks of this age have also been detected in Korea (Lee et al., 1998, 2003). Conversely magmatism of this age is presently unknown within the North China (Sino-Korean) Craton (summarised by Li et al., 2003b) north of the Mesozoic Qinling-Dabie Suture. Thus 743 ± 17 Ma magmatic zircons from a Kamiaso clast is the clearest evidence yet (first proposed by Hidaka et al., 2002 from the presence of ~ 3250 detrital grains in a Palaeoproterozoic paragneiss clast) that the source continental terrane for the Kamiaso Conglomerate had affinities with
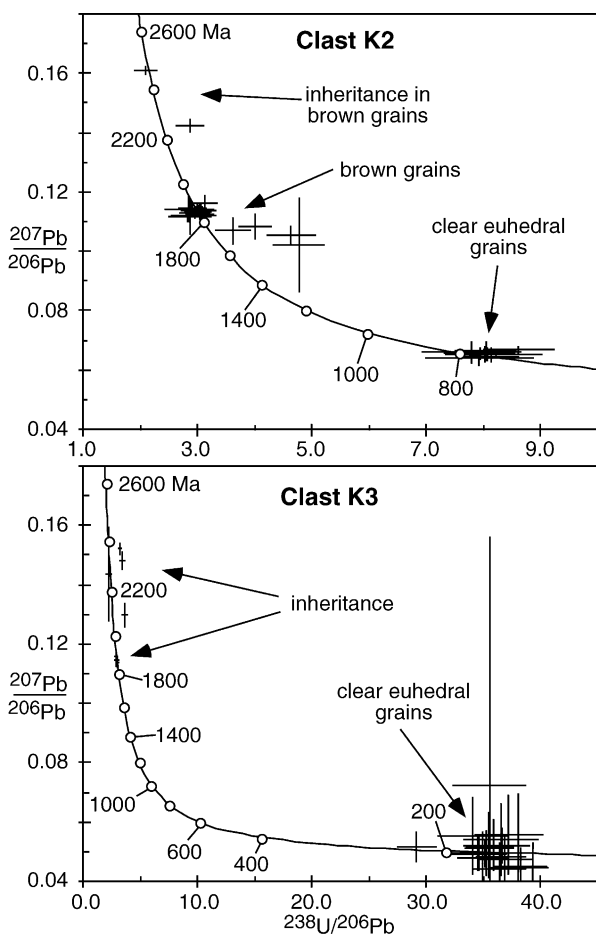
the South China Craton. The most likely immediate source of the detritus would have been the northern extremity of this craton in Korea. A Korean source is also consistent with the presence of ∼180 Ma granite clasts in the conglomerate indicated from dating of K3, because Jurassic granites are common in South Korea (e.g. Kim and Turek, 1996).

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