by Taejin Choi¹, Yong Il Lee², Hyoun Soo Lim^{3*}, and Yuji Orihashi⁴

Detrital zircon geochronology of the Cretaceous Sindong Group, Gyeongsang Basin, Korea and its implications for paleodrainage systems

¹ Department of Energy Resources Engineering, Chosun University, Gwangju 61452, Korea

² School of Earth and Environmental Sciences, Seoul National University, Seoul 08826, Korea

³ Department of Geological Sciences, Pusan National University, Busan 46241, Korea; *Corresponding author, E-mail: tracker@pusan.ac.kr

⁴ Department of Earth and Environmental Sciences, Hiroshima University, Aomori 036-8561, Japan

(Received: August 7, 2019; Revised accepted: November 27, 2019)

<https://doi.org/10.18814/epiugs/2020/020046>

The Lower Cretaceous Sindong Group in southeastern Korea is a fluvio-lacustrine sedimentary package deposited in an elongated basin formed by extension in an active continental margin setting. To characterize its changes in paleodrainage system, we analyzed U-Pb ages of detrital zircons in sandstones from each stratigraphic units in northern, central, and southern parts of the Sindong Group. Detrital zircons show a wide range of ages from 106 Ma to 3494 Ma with spatiotemporal variations in age population. Detrital zircon age spectra and paleocurrent data reveal that at least three drainage basins sourced to the Early Cretaceous river system in the Yeongnam Massif. The drainage system for the central portion of the basin was consistent with time, whereas those for the northern and southern portions shifted between the Nakdong Formation and Hasandong Formation. The strong influences resulting from the confluence of dispersal path draining Jurassic granitoids, possibly aided by faulting activity, likely caused the replacement of paleodrainage system in the northern portion. The drainage system of the southern portion was changed by extension of the drainage basin to the source terrane having similar geology to or shared the source terrane for the paleoflow system for the central portion.

Introduction

Detrital zircons offer an excellent way to track the dispersal system from source to sink. Detrital zircon geochronology has proven to be an essential technique in provenance analysis. This technique determines source rock ages, thereby further discriminating potential source areas for sediment and sediment transport systems (e.g., Rainbird et al., 1997; Gehrels and Stewart, 1998; Dickinson and Gehrels, 2003; Barth et al., 2004; Lawton et al., 2009; Raines et al., 2013). Detrital zircon geochronology has also been successfully defined sediment

source areas and fluvial lineages in the modern Snake River drainage basin of the northwestern United States (Link et al., 2005). By integration of detrital zircon U-Pb geochronology with paleocurrent analysis, Roberts et al. (2012) addressed the timing of rifting, landscape evolution, and drainage development in central-eastern Africa and showed that tectonics of continental provenance affect drainage patterns, directing, and rerouting large rivers.

The Gyeongsang Basin in southeastern Korea is a nonmarine sedimentary basin which was formed by extension in an active continental margin setting (Fig. 1). The earliest basinfill of the Gyeongsang Basin is the Sindong Group (Abtian-Albian; Lee et al., 2010), a fluvio-lacustrine sedimentary package deposited in an elongated basin (the Nakdong Trough). Petrography and paleocurrent data suggest that the western and northwestern Yeongnam Massif located to the west of the Nakdong Trough provided detritus for the Sindong Group (Chang and Kim, 1968; Koh, 1974, 1986). On the other hand, recent studies on the detrital zircon geochronology of the Sindong Group sediments (Lee et al., 2017; Lee et al., 2018a, b) revealed the Okcheon Metamorphic Belt as an additional source region of the Sindong Group.

The integration of petrographic and quartz scanning electron microscope-cathodoluminescence data led Lee et al. (2015) to conclude that the type of source rocks in the Yeongnam Massif was heterogeneous both spatially and temporally, due to different paleodrainage and paleofluvial system developed in the Nakdong Trough. They also interpreted that the temporal decrease in quartz content and increase in feldspar content resulted from tectonic events leading to the active uplift of the source areas and arc magmatism in the late stage. However, it is yet clear the relationship between different provenances and drainage patterns in the Yeongnam Massif for the Sindong Group deposition. Source rocks of the Sindong Group commonly have felsic composition that makes difficult to determine their dispersal pattern. As the formation ages of these source rocks are strikingly different, analysis of detrital zircon population of the Sindong Group is promising to track temporal and spatial changes in sediment dispersal and drainage areas of their provenance. Thus, using detrital zircon U-Pb geochronology, this study intends to document the dispersal path from

Figure 1. (a) Location of the Gyeongsang Basin and Permian-Paleogene granitoids in Korea. (b) Geologic map of the Gyeongsang Basin with sampling locations (from Lee et al., 2010).

the source to the depositional site during the Sindong Group deposition.

Geological Setting

The Gyeongsang Basin is a non-marine sedimentary basin formed in the southeastern part of Korea during Early Cretaceous time (Aptian-Albian; Lee et al., 2010) (Fig. 1). It was developed by extensional tectonics in an active continental margin caused by the subduction of the Paleo-Pacific (Izanagi) Plate beneath the East Asian continent. The Cretaceous rocks in the Gyeongsang Basin are divided into four groups based on volcanism and plutonism (Chang, 1975): they are the Sindong, Hayang, Yucheon, and the Bulguksa intrusive groups in ascending order.

The Sindong Group was deposited in an elongated basin (the Nakdong Trough; Chang, 1987) along the western margin of the Gyeongsang Basin. The Sindong Group is underlain unconformably by basement on the west side and overlain conformably by the Hayang Group on the eastern side. The Sindong Group is 2–3 km thick, and consists mainly of sandstone and mudrock, with minor amounts of conglomerate and marl. The Sindong Group is divided, based on lithologic features including rock color, into the Nakdong (alluvial fan to fluvial deposits), Hasandong (fluvial deposits), and Jinju (lacustrine deposits) formations with decreasing age (Chang, 1975; Choi, 1981). The Nakdong Formation is about 550 m thick but thickens northwards. The lowermost part of the formation consists of mid-fan conglomerates overlain by distal-fan sandstones intercalated with dark gray mudstones and black shales. The alluvial-fan deposits grade upwards into fluvial plain deposits, which are composed mainly of an alternation of

channel sandstones and inter-channel dark gray mudstones and siltstones. The Hasandong Formation is approximately 1100 m thick and is similar to the upper part of the Nakdong Formation in that it consists of alternating channel sandstones and inter-channel fine deposits, but shows characteristic red beds containing abundant pedogenic carbonate nodules and layers (Lee, 1999). The lacustrine Jinju Formation is about 1200 m thick and is made up mainly of dark gray to black mudstones, deeper open lake black shales, and channel sandstones. Based on the petrographic study, most Sindong Group sediments are interpreted to have been derived from the Precambrian gneisses and Jurassic granitic rocks in the Yeongnam Massif, located to the west and northwest (Koh, 1974; Lee et al., 2010; Lee et al., 2015). However, the upper half of the Jinju Formation contains a significant amount of volcanic detritus (Choi, 1986; Noh and Park, 1990; Lee and Lim, 2008; Lee et al., 2015), suggestive of its derivation from syndepositional volcanism. Paleocurrent studies indicate that the mean direction of sediment transport was toward the east and southeast (Chang and Kim, 1968; Koh, 1986), whereas detritus in the northernmost part of the Nakdong Trough was derived mostly from the north and northwest (Rhee et al., 1988).

Deposition of the Hayang Group accompanied the basin extension to the east along with the sporadic volcanism in and around the basin (Chang, 1970, 1987). Sediments were derived from both the volcanic and plutonic-metamorphic provenances (Lee and Lee, 2000). During this interval, the Gyeongsang Basin was divided into three subbasins with different subsidence histories and sedimentary environments.

Sedimentary rocks of the Sindong Group are interpreted as the pre-volcanic stage deposits, and the Hayang Group comprises volcano-genic sediments, which are intercalated with some volcanic horizons. Studies on *Charophyta* (Seo, 1985; Choi, 1987, 1989) and spores and

pollen (Choi, 1985; Choi and Park, 1987) suggest that the Sindong and Hayang groups were deposited during the semi-arid climatic conditions. The volcanic and volcanoclastic rocks of the Late Cretaceous are called the Yucheon Group, and the mostly felsic plutonic rocks are collectively called the Bulguksa Granite, whose isotopic ages of granite intrusion generally ranging from ca. 120–40 Ma, and most were clustered between 85 and 70 Ma (Shin and Jin, 1995).

Compilation of petrographic data reveals that Sindong Group sandstones are generally rich in quartz and feldspar with a mean modal composition of $Q_{59}F_{31}R_{10}$ (Lee et al., 2015). Quartz content decreases up sequence for all parts of the basin, whereas feldspar content has the opposite trend, with a slight increase in rock fragments. Rock fragments in the Nakdong and Hasandong sandstones are composed of metamorphic and sedimentary rocks, whereas volcanic rock fragments from contemporary arc volcanism are most common in the upper Jinju Formation sandstones, especially in the central and southern portions of the basin. Based on the spatial distribution of Lower Cretaceous detrital zircons in the Nakdong Trough, Lee et al. (2010) interpreted that location of magmatic activity in the Yeongnam Massif changed from the northern and central parts to the central and southern parts during deposition of the Sindong Group. The Gyeongsang Basin experienced maximum burial paleotemperatures of about 260°C (Lim et al., 2003) and underwent two cooling episodes (ca. 95–80 Ma and after 15 Ma), with the first rapid exhumation facilitated by the subduction of the Izanagi-Pacific Plate ridge (Choi and Lee, 2011).

The Yeongnam Massif is a Paleoproterozoic polymetamorphic terrain bounded to the northwest by the Okcheon fold belt. The Okcheon fold belt is an intra-plate rift composed mainly of Neoproterozoic metavolcanic rocks and Paleozoic metasedimentary sequences (Cho and Kim, 2005; Cho et al., 2013). The Yeongnam Massif is made up of two Precambrian gneiss complexes: the Sobaeksan gneiss complex in the northeast and the Jirisan gneiss complex in the southwest. The Sobaeksan complex includes a broad distribution of Precambrian metasedimentary rocks, such as banded biotite gneiss, mica schist, quartzite, and calc-silicate rocks. The Jirisan complex comprises granite gneiss, porphyroblastic gneiss, augen gneiss, migmatite gneiss, and banded gneiss with minor amounts of schist and amphibolite. N–S-trending Paleoproterozoic anorthosites intruded into the Jirisan complex close to the southwestern boundary of the basin. These Precambrian rocks were metamorphosed up to granulite facies (Lee et al., 1986) and were intruded by Triassic, Jurassic, and Cretaceous granites.

Triassic granitoids in the Yeongnam Massif (240–209 Ma; Cheong and Kim, 2012) are I-type plutons with metaluminous to weakly peraluminous compositions, reflecting the assimilation of crustal material. They were formed as a result of subduction-related primitive arc magmatism and are distributed mainly as small plutons in the Sobaeksan gneiss complex. Most of the Triassic granitoids were foliated during the Middle Jurassic Daebo orogeny. Jurassic granites (196–169 Ma; Cheong and Kim, 2012) form a large batholith and are generally medium- to coarse-grained porphyritic biotite granites (Jwa, 2004). They are mainly felsic I-type, peraluminous, and formed in a calc-alkaline continental-arc environment (Cheong and Chang, 1996a, b; Jwa, 2004; Kim et al., 2005). The Jurassic granites are in general distributed along the long direction of the Yeongnam Massif. The Jurassic granites are thought to have been emplaced at 12–28 km depths (Cho and Kwon, 1994; Hong, 2001). Jwa (2004) posited that the Tri-

assic and Jurassic granites can be separated into high- and low-temperature granites, respectively, based on their Zr contents.

Considering large exhumation of the Yeongnam Massif and the Gyeongsang Basin during the Late Cretaceous caused by the subduction of the Izanagi-Pacific Plate ridge (Choi and Lee, 2011), the present geology of the Yeongnam Massif may not represent the source-area characteristics during the deposition of the Sindong Group. Thus, it is one of the study purposes to compare the provenance of the Sindong Group with the current geology of the Yeongnam Massif.

Methods

A total of nine sandstone samples from the Sindong Group were collected from three different parts of the Nakdong Trough (northern, central, and southern regions; Fig. 1b). In each part of the basin, one channel sandstone sample was collected from each formation, representing the middle stratigraphic level. We mounted a total of 900 zircon grains (63–125 μm in size) (100 zircon grains from each sandstone sample) on PFA Teflon sheets. Then, the grains were polished, cleaned, and carbon-coated to determine internal structures. Cathodoluminescence (CL) images of zircon grains were obtained using a scanning electron microscope (JEOL JSM-5400).

The analytical method for conduction detrital zircon U–Pb age dating for the Sindong Group sandstones is the same as that followed by Lee et al. (2010). LA-ICP-MS was conducted using a Thermo Elemental PlasmaQuad 3 housed at the Earthquake Research Institute, the University of Tokyo. We used the ISOPLOT program (Ludwig, 2003) for data processing, and the error is quoted at 2σ . The age probability plots were constructed using the $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ages for zircons with ages younger and older than 1000 Ma, respectively. Only ages with <15% discordance or <10% reverse discordance were used for provenance interpretation.

Results

Detrital Zircon U–Pb Ages

Zircon grains of the Sindong Group show a wide range in color and morphology. The morphology of zircon grains ranges from euhedral prismatic crystals to irregular- and oval-shaped zircons. Detrital zircon grains showing euhedral prismatic crystal morphology are of Mesozoic in age. Among 900 zircon grains analyzed, 666 zircon grains yielded concordant or slightly discordant Archean to Cretaceous U–Pb ages. Analytical results are listed in Table 1. Among them, 46 Cretaceous U–Pb ages were reported in Lee et al. (2010). Figure 2 shows the distribution of ages in the form of relative age probability curve, which sum probability distributions from all age analyses from a given sample into a single composite probability distribution. Most of the studied zircons show CL images of oscillatory zoning, indicating that they are of igneous origin, supported by all zircons but 18 grains have Th/U ratios larger than 0.1 (Table 1).

Zircon U–Pb ages of the Sindong Group range from 106.0 ± 1.9 Ma to 3494 ± 74 Ma. Most Sindong Group zircons fall into three major peak-age groups: 1870 Ma (25%), 176–185 Ma (13%), and 227 Ma

Table 1. Detrital zircon U-Pb ages of Sindong Group sandstones in the Gyeongsang Basin

Sample Code	Th/U	²⁰⁶ Pb/ ²³⁸ U (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc ^(b) (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
<i>Southern Nakdong Fm. (n=80)</i>															
nd2-47	0.73	0.40	0.0473 ± 0.0014		0.0287 ± 0.0006		0.187 ± 0.007			182.1 ± 3.6		174.0 ± 6.3		66 ± 2.0	
nd2-44	0.89	n.d	0.0539 ± 0.0045		0.0287 ± 0.0007		0.213 ± 0.018			182.5 ± 4.4		196.3 ± 16.9		367 ± 30.3	
nd2-57	0.75	n.d	0.0489 ± 0.0018		0.0290 ± 0.0012		0.195 ± 0.011			184.1 ± 7.4		181.0 ± 10.0		142 ± 5.3	
nd2-26	1.41	n.d	0.0486 ± 0.0032		0.0294 ± 0.0014		0.197 ± 0.016			186.5 ± 8.9		182.4 ± 14.7		131 ± 8.6	
nd2-63	0.58	n.d	0.0524 ± 0.0021		0.0300 ± 0.0014		0.217 ± 0.013			190.8 ± 9.0		199.5 ± 12.4		304 ± 12.1	
nd2-38	0.83	n.d	0.0484 ± 0.0039		0.0302 ± 0.0007		0.202 ± 0.017			191.8 ± 4.6		186.5 ± 15.8		121 ± 9.9	
nd2-20	0.49	n.d	0.0540 ± 0.0024		0.0303 ± 0.0014		0.225 ± 0.014			192.3 ± 8.9		206.4 ± 13.2		371 ± 16.4	
nd2-34	1.09	n.d	0.0552 ± 0.0026		0.0303 ± 0.0008		0.231 ± 0.013		-0.8	192.5 ± 5.2		210.7 ± 11.4		420 ± 19.8	
nd2-73	1.02	n.d	0.0551 ± 0.0047		0.0303 ± 0.0014		0.230 ± 0.023			192.6 ± 9.1		210.4 ± 20.7		415 ± 35.7	
nd2-79	0.52	0.71	0.0461 ± 0.0026		0.0307 ± 0.0015		0.195 ± 0.015			195.1 ± 9.7		181.3 ± 13.7		6 ± 0.3	
nd2-17	1.20	n.d	0.0566 ± 0.0035		0.0311 ± 0.0015		0.243 ± 0.019			197.3 ± 9.8		220.6 ± 17.6		478 ± 29.9	
nd2-87	1.48	n.d	0.0517 ± 0.0029		0.0323 ± 0.0012		0.230 ± 0.015			204.8 ± 7.4		210.3 ± 14.1		273 ± 15.3	
nd2-95	0.80	n.d	0.0529 ± 0.0018		0.0335 ± 0.0009		0.244 ± 0.011			212.2 ± 5.7		221.9 ± 9.7		327 ± 11.2	
nd2-56	0.80	n.d	0.0605 ± 0.0026		0.0343 ± 0.0014		0.286 ± 0.017		-6.5	217.1 ± 8.8		255.1 ± 15.2		621 ± 26.9	
nd2-48	0.82	n.d	0.0502 ± 0.0017		0.0362 ± 0.0014		0.250 ± 0.013			229.0 ± 9.2		226.9 ± 11.9		205 ± 6.9	
nd2-27	0.68	0.25	0.1164 ± 0.0025		0.2842 ± 0.0130		4.561 ± 0.230		-10.9	1612 ± 74		1742 ± 88		1902 ± 41	
nd2-75	0.14	0.14	0.1121 ± 0.0022		0.3026 ± 0.0148		4.679 ± 0.246		-0.7	1704 ± 83		1763 ± 93		1835 ± 35	
nd2-40	0.32	0.68	0.1154 ± 0.0025		0.3029 ± 0.0059		4.820 ± 0.141		-6.3	1706 ± 33		1788 ± 52		1887 ± 41	
nd2-60	0.13	0.06	0.1140 ± 0.0021		0.3111 ± 0.0145		4.889 ± 0.246		-0.1	1746 ± 82		1800 ± 91		1864 ± 35	
nd2-49	0.51	0.97	0.1209 ± 0.0018		0.3111 ± 0.0123		5.186 ± 0.219		-7.2	1746 ± 69		1850 ± 78		1970 ± 29	
nd2-74	0.27	n.d	0.1144 ± 0.0024		0.3116 ± 0.0139		4.913 ± 0.244		-0.2	1749 ± 78		1804 ± 89		1870 ± 40	
nd2-45	0.32	n.d	0.1147 ± 0.0026		0.3130 ± 0.0062		4.950 ± 0.149		-2.4	1755 ± 35		1811 ± 54		1875 ± 42	
nd2-8	0.19	0.01	0.1167 ± 0.0014		0.3144 ± 0.0088		5.060 ± 0.155		-4.1	1762 ± 49		1829 ± 56		1907 ± 23	
nd2-21	0.11	0.19	0.1141 ± 0.0026		0.3146 ± 0.0144		4.947 ± 0.253			1763 ± 81		1810 ± 93		1865 ± 43	
nd2-68	0.36	0.05	0.1239 ± 0.0024		0.3182 ± 0.0142		5.434 ± 0.265		-6.3	1781 ± 80		1890 ± 92		2013 ± 40	
nd2-97	0.05	0.03	0.1135 ± 0.0029		0.3199 ± 0.0085		5.005 ± 0.185		0.0	1789 ± 48		1820 ± 67		1856 ± 48	
nd2-67	0.31	n.d	0.1148 ± 0.0022		0.3203 ± 0.0150		5.072 ± 0.256			1791 ± 84		1831 ± 92		1878 ± 36	
nd2-52	0.17	0.04	0.1169 ± 0.0015		0.3204 ± 0.0127		5.165 ± 0.216		-1.2	1792 ± 71		1847 ± 77		1910 ± 25	
nd2-50	0.18	0.15	0.1179 ± 0.0015		0.3207 ± 0.0127		5.214 ± 0.217		-2.0	1793 ± 71		1855 ± 77		1925 ± 25	
nd2-58	0.47	n.d	0.1146 ± 0.0022		0.3209 ± 0.0150		5.070 ± 0.256			1794 ± 84		1831 ± 93		1874 ± 36	
nd2-6	0.20	0.01	0.1160 ± 0.0014		0.3226 ± 0.0091		5.160 ± 0.159		-1.1	1802 ± 51		1846 ± 57		1896 ± 24	
nd2-81	0.04	0.08	0.1168 ± 0.0022		0.3237 ± 0.0158		5.212 ± 0.273			1808 ± 88		1855 ± 97		1908 ± 36	
nd2-72	0.13	n.d	0.1164 ± 0.0023		0.3239 ± 0.0145		5.196 ± 0.254			1809 ± 81		1852 ± 91		1901 ± 38	
nd2-59	0.49	0.35	0.1130 ± 0.0024		0.3259 ± 0.0153		5.077 ± 0.261			1818 ± 85		1832 ± 94		1849 ± 39	
nd2-62	0.18	n.d	0.1143 ± 0.0022		0.3262 ± 0.0153		5.140 ± 0.261			1820 ± 85		1843 ± 94		1869 ± 37	
nd2-69	0.18	n.d	0.1156 ± 0.0024		0.3286 ± 0.0147		5.237 ± 0.258			1832 ± 82		1859 ± 91		1890 ± 39	
nd2-13	0.26	0.09	0.1150 ± 0.0027		0.3295 ± 0.0157		5.224 ± 0.278			1836 ± 88		1856 ± 99		1880 ± 44	
nd2-98	0.26	0.42	0.1119 ± 0.0030		0.3321 ± 0.0089		5.125 ± 0.195			1848 ± 50		1840 ± 70		1831 ± 49	
nd2-30	0.40	n.d	0.1148 ± 0.0027		0.3373 ± 0.0085		5.340 ± 0.183			1874 ± 47		1875 ± 64		1878 ± 44	
nd2-55	0.25	n.d	0.1190 ± 0.0016		0.3381 ± 0.0134		5.548 ± 0.233			1877 ± 74		1908 ± 80		1942 ± 27	
nd2-15	0.11	0.03	0.1213 ± 0.0027		0.3383 ± 0.0161		5.657 ± 0.298			1878 ± 90		1925 ± 101		1976 ± 44	
nd2-10	0.17	0.04	0.1127 ± 0.0026		0.3393 ± 0.0162		5.274 ± 0.280			1883 ± 90		1865 ± 99		1844 ± 43	
nd2-12	0.47	n.d	0.1193 ± 0.0027		0.3397 ± 0.0162		5.586 ± 0.295			1885 ± 90		1914 ± 101		1946 ± 44	
nd2-31	0.46	0.59	0.1222 ± 0.0027		0.3415 ± 0.0086		5.755 ± 0.194		-0.2	1894 ± 48		1940 ± 65		1990 ± 45	
nd2-29	0.34	0.49	0.1118 ± 0.0026		0.3424 ± 0.0086		5.281 ± 0.181			1898 ± 48		1866 ± 64		1830 ± 42	
nd2-93	0.25	n.d	0.1165 ± 0.0026		0.3442 ± 0.0120		5.527 ± 0.229			1907 ± 67		1905 ± 79		1903 ± 42	

Table 1. Continued

Sample Code	Th/U	²⁰⁶ Pb/ ^a (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc ^d (b) (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
nd2-25	0.28	0.35	0.1125 ± 0.0025		0.3456 ± 0.0158		5.362 ± 0.273			1914 ± 87		1879 ± 95		1841 ± 41	
nd2-16	0.35	0.53	0.1114 ± 0.0027		0.3491 ± 0.0167		5.363 ± 0.288			1930 ± 92		1879 ± 101		1823 ± 44	
nd2-85	0.45	n.d	0.1153 ± 0.0026		0.3519 ± 0.0123		5.596 ± 0.234			1944 ± 68		1915 ± 80		1885 ± 43	
nd2-33	0.14	0.04	0.1220 ± 0.0026		0.3522 ± 0.0088		5.926 ± 0.196			1945 ± 49		1965 ± 65		1986 ± 43	
nd2-36	0.84	0.10	0.1123 ± 0.0030		0.3526 ± 0.0091		5.458 ± 0.201			1947 ± 50		1894 ± 70		1837 ± 49	
nd2-78	0.21	0.17	0.1116 ± 0.0023		0.3536 ± 0.0173		5.439 ± 0.288			1952 ± 96		1891 ± 100		1826 ± 37	
nd2-71	0.25	n.d	0.1141 ± 0.0023		0.3571 ± 0.0160		5.616 ± 0.275			1968 ± 88		1918 ± 94		1866 ± 38	
nd2-53	0.21	0.01	0.1236 ± 0.0016		0.3575 ± 0.0141		6.093 ± 0.253			1970 ± 78		1989 ± 83		2009 ± 25	
nd2-7	1.13	0.04	0.1318 ± 0.0019		0.3630 ± 0.0103		6.595 ± 0.208		-2.0	1996 ± 56		2059 ± 65		2122 ± 30	
nd2-92	0.43	n.d	0.1217 ± 0.0027		0.3688 ± 0.0129		6.186 ± 0.255			2024 ± 71		2002 ± 83		1981 ± 43	
nd2-23	1.42	0.79	0.1219 ± 0.0031		0.3812 ± 0.0175		6.406 ± 0.336			2082 ± 96		2033 ± 107		1984 ± 50	
nd2-2	0.35	n.d	0.1359 ± 0.0017		0.3823 ± 0.0108		7.166 ± 0.221		-0.2	2087 ± 59		2132 ± 66		2177 ± 28	
nd2-1	0.35	0.46	0.1385 ± 0.0018		0.3848 ± 0.0108		7.347 ± 0.228		-1.1	2099 ± 59		2155 ± 67		2209 ± 29	
nd2-83	0.60	0.27	0.1501 ± 0.0031		0.3886 ± 0.0190		8.044 ± 0.427		-3.8	2116 ± 104		2236 ± 119		2348 ± 48	
nd2-22	0.74	0.23	0.1508 ± 0.0033		0.3907 ± 0.0179		8.121 ± 0.412		-3.8	2126 ± 97		2245 ± 114		2355 ± 52	
nd2-14	0.28	n.d	0.1549 ± 0.0035		0.3962 ± 0.0189		8.462 ± 0.447		-4.3	2152 ± 103		2282 ± 121		2401 ± 54	
nd2-41	0.27	n.d	0.1567 ± 0.0035		0.3974 ± 0.0078		8.584 ± 0.254		-7.7	2157 ± 43		2295 ± 68		2420 ± 53	
nd2-66	0.93	n.d	0.1607 ± 0.0032		0.4021 ± 0.0188		8.911 ± 0.454		-6.2	2179 ± 102		2329 ± 119		2464 ± 49	
nd2-18	0.73	0.32	0.1547 ± 0.0039		0.4069 ± 0.0187		8.680 ± 0.454		-1.7	2201 ± 101		2305 ± 121		2399 ± 60	
nd2-96	0.57	0.10	0.1604 ± 0.0041		0.4193 ± 0.0112		9.272 ± 0.343		-3.5	2257 ± 60		2365 ± 88		2460 ± 63	
nd2-89	0.28	n.d	0.1388 ± 0.0033		0.4218 ± 0.0148		8.075 ± 0.342		0.0	2269 ± 80		2239 ± 95		2213 ± 52	
nd2-64	0.51	n.d	0.1466 ± 0.0027		0.4228 ± 0.0198		8.547 ± 0.430		0.0	2273 ± 106		2291 ± 115		2307 ± 43	
nd2-61	1.14	n.d	0.1612 ± 0.0034		0.4242 ± 0.0199		9.426 ± 0.484		-1.3	2279 ± 107		2380 ± 122		2468 ± 52	
nd2-43	1.41	n.d	0.1612 ± 0.0039		0.4270 ± 0.0087		9.489 ± 0.299		-3.1	2292 ± 47		2386 ± 75		2469 ± 60	
nd2-28	0.62	n.d	0.1498 ± 0.0035		0.4367 ± 0.0111		9.022 ± 0.312			2336 ± 59		2340 ± 81		2345 ± 55	
nd2-100	0.21	n.d	0.1576 ± 0.0041		0.4371 ± 0.0117		9.498 ± 0.352			2338 ± 62		2387 ± 89		2430 ± 63	
nd2-84	0.97	n.d	0.1659 ± 0.0039		0.4436 ± 0.0219		10.148 ± 0.556			2367 ± 117		2448 ± 134		2517 ± 60	
nd2-91	0.37	0.04	0.1501 ± 0.0033		0.4471 ± 0.0156		9.249 ± 0.380			2382 ± 83		2363 ± 97		2347 ± 51	
nd2-4	0.96	0.13	0.1608 ± 0.0021		0.4550 ± 0.0128		10.085 ± 0.314			2417 ± 68		2442 ± 76		2464 ± 32	
nd2-32	1.33	0.44	0.1601 ± 0.0038		0.4573 ± 0.0117		10.097 ± 0.352			2428 ± 62		2444 ± 85		2457 ± 58	
nd2-76	0.95	n.d	0.1676 ± 0.0032		0.4618 ± 0.0226		10.671 ± 0.562			2448 ± 120		2495 ± 131		2534 ± 49	
nd2-86	0.11	n.d	0.1670 ± 0.0036		0.4753 ± 0.0166		10.943 ± 0.449			2507 ± 88		2518 ± 103		2528 ± 55	
nd2-90	0.62	0.13	0.1645 ± 0.0036		0.5062 ± 0.0177		11.483 ± 0.475			2640 ± 92		2563 ± 106		2503 ± 55	
nd2-46	1.05	n.d	0.3045 ± 0.0065		0.6116 ± 0.0121		25.677 ± 0.747		-9.2	3077 ± 61		3334 ± 97		3494 ± 75	
<i>Central Nakdong Fm. (n=58)</i>															
nd1-54	1.47	0.10	0.0476 ± 0.0020		0.0185 ± 0.0005		0.121 ± 0.006			118.0 ± 3.0		116.2 ± 5.7		80 ± 3.4	
nd1-46	0.41	0.02	0.0539 ± 0.0021		0.0191 ± 0.0005		0.142 ± 0.007		-3.0	122.2 ± 2.9		135.0 ± 6.2		367 ± 14.5	
nd1-8	0.80	n.d	0.0477 ± 0.0026		0.0216 ± 0.0011		0.142 ± 0.011			137.9 ± 7.1		134.9 ± 10.2		83 ± 4.6	
nd1-63	0.88	n.d	0.0509 ± 0.0019		0.0264 ± 0.0007		0.185 ± 0.008			167.8 ± 4.3		172.6 ± 7.7		239 ± 8.7	
nd1-40	0.57	n.d	0.0528 ± 0.0016		0.0265 ± 0.0006		0.193 ± 0.007			168.8 ± 3.9		179.2 ± 6.8		320 ± 9.6	
nd1-52	0.45	n.d	0.0478 ± 0.0017		0.0267 ± 0.0007		0.176 ± 0.008			170.1 ± 4.3		164.8 ± 7.2		90 ± 3.2	
nd1-25	0.49	n.d	0.0505 ± 0.0026		0.0268 ± 0.0009		0.186 ± 0.012			170.3 ± 5.8		173.5 ± 10.8		218 ± 11.4	
nd1-26	0.92	n.d	0.0508 ± 0.0017		0.0278 ± 0.0009		0.195 ± 0.009			177.1 ± 5.9		180.8 ± 8.6		231 ± 7.9	
nd1-32	0.97	n.d	0.0515 ± 0.0015		0.0283 ± 0.0006		0.201 ± 0.007			179.7 ± 3.8		185.6 ± 6.8		262 ± 7.8	
nd1-10	0.90	n.d	0.0486 ± 0.0018		0.0286 ± 0.0014		0.192 ± 0.012			182.0 ± 9.2		178.3 ± 11.1		130 ± 4.7	
nd1-29	0.68	n.d	0.0504 ± 0.0013		0.0294 ± 0.0006		0.204 ± 0.007			186.9 ± 4.0		188.7 ± 6.4		212 ± 5.6	
nd1-43	1.26	n.d	0.0520 ± 0.0017		0.0295 ± 0.0007		0.211 ± 0.009			187.2 ± 4.4		194.6 ± 7.9		287 ± 9.5	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	Error 2 σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2 σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	Disc (%)	^{238}U - ^{206}Pb age (Ma)	Error 2 σ	^{235}U - ^{207}Pb age (Ma)	Error 2 σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2 σ
nd1-15	0.88	n.d	0.0565 $\pm$ 0.0029		0.0300 $\pm$ 0.0015		0.234 $\pm$ 0.017			190.8 $\pm$ 9.8		213.4 $\pm$ 15.3		471 $\pm$ 23.8	
nd1-48	0.89	n.d	0.0595 $\pm$ 0.0033		0.0305 $\pm$ 0.0008		0.250 $\pm$ 0.016		-7.0	193.4 $\pm$ 5.3		226.4 $\pm$ 14.1		586 $\pm$ 32.8	
nd1-31	1.33	0.54	0.0612 $\pm$ 0.0027		0.0313 $\pm$ 0.0007		0.264 $\pm$ 0.013		-11.6	198.5 $\pm$ 4.5		237.8 $\pm$ 11.7		647 $\pm$ 28.2	
nd1-4	0.22	n.d	0.0544 $\pm$ 0.0038		0.0331 $\pm$ 0.0015		0.248 $\pm$ 0.021			210.0 $\pm$ 9.8		225.2 $\pm$ 18.9		388 $\pm$ 27.0	
nd1-42	0.09	n.d	0.0502 $\pm$ 0.0015		0.0354 $\pm$ 0.0008		0.245 $\pm$ 0.009			224.4 $\pm$ 5.2		222.8 $\pm$ 8.3		207 $\pm$ 6.1	
nd1-45	0.07	n.d	0.0515 $\pm$ 0.0021		0.0358 $\pm$ 0.0009		0.254 $\pm$ 0.012			226.9 $\pm$ 5.4		230.2 $\pm$ 10.7		264 $\pm$ 10.6	
nd1-16	0.88	0.52	0.0477 $\pm$ 0.0015		0.0361 $\pm$ 0.0018		0.238 $\pm$ 0.014			228.7 $\pm$ 11.5		216.4 $\pm$ 12.7		84 $\pm$ 2.6	
nd1-33	0.48	n.d	0.0542 $\pm$ 0.0015		0.0416 $\pm$ 0.0009		0.311 $\pm$ 0.011			262.4 $\pm$ 5.6		274.8 $\pm$ 9.7		382 $\pm$ 10.7	
nd1-30	0.74	n.d	0.0506 $\pm$ 0.0020		0.0449 $\pm$ 0.0010		0.313 $\pm$ 0.014			283.1 $\pm$ 6.3		276.8 $\pm$ 12.7		224 $\pm$ 9.0	
nd1-14	0.66	n.d	0.0628 $\pm$ 0.0019		0.0744 $\pm$ 0.0037		0.644 $\pm$ 0.038			462.3 $\pm$ 23.3		504.7 $\pm$ 29.5		702 $\pm$ 20.8	
nd1-21	0.49	0.39	0.0614 $\pm$ 0.0015		0.0942 $\pm$ 0.0031		0.797 $\pm$ 0.033			580.5 $\pm$ 19.1		595.2 $\pm$ 24.7		652 $\pm$ 16.4	
nd1-67	0.29	n.d	0.0637 $\pm$ 0.0012		0.0985 $\pm$ 0.0024		0.864 $\pm$ 0.027			605.3 $\pm$ 15.0		632.4 $\pm$ 19.8		731 $\pm$ 13.9	
nd1-24	1.47	10.92	0.0591 $\pm$ 0.0016		0.1096 $\pm$ 0.0036		0.894 $\pm$ 0.038			670.7 $\pm$ 22.3		648.5 $\pm$ 27.8		573 $\pm$ 15.5	
nd1-28	1.46	0.62	0.0598 $\pm$ 0.0016		0.1170 $\pm$ 0.0025		0.964 $\pm$ 0.033			713.4 $\pm$ 15.2		685.4 $\pm$ 23.5		595 $\pm$ 16.0	
nd1-9	0.95	n.d	0.0671 $\pm$ 0.0018		0.1293 $\pm$ 0.0065		1.196 $\pm$ 0.069			784.1 $\pm$ 39.5		798.8 $\pm$ 45.8		841 $\pm$ 23.1	
nd1-2	0.73	n.d	0.0681 $\pm$ 0.0017		0.1302 $\pm$ 0.0059		1.223 $\pm$ 0.063			788.9 $\pm$ 35.6		811.1 $\pm$ 41.9		873 $\pm$ 21.9	
nd1-12	0.40	n.d	0.0673 $\pm$ 0.0025		0.1335 $\pm$ 0.0068		1.240 $\pm$ 0.078			807.8 $\pm$ 41.0		818.7 $\pm$ 51.7		849 $\pm$ 31.8	
nd1-6	0.77	n.d	0.0668 $\pm$ 0.0016		0.1360 $\pm$ 0.0061		1.253 $\pm$ 0.064			822.2 $\pm$ 37.1		824.7 $\pm$ 42.3		832 $\pm$ 20.3	
nd1-17	1.13	n.d	0.0680 $\pm$ 0.0025		0.1403 $\pm$ 0.0071		1.315 $\pm$ 0.083			846.3 $\pm$ 43.0		852.4 $\pm$ 53.7		869 $\pm$ 32.3	
nd1-57	1.11	0.43	0.0850 $\pm$ 0.0015		0.2243 $\pm$ 0.0055		2.627 $\pm$ 0.080			1304 $\pm$ 32		1308 $\pm$ 40		1315 $\pm$ 23	
nd1-37	0.57	0.33	0.1147 $\pm$ 0.0025		0.2856 $\pm$ 0.0060		4.516 $\pm$ 0.138		-11.2	1619 $\pm$ 34		1734 $\pm$ 53		1876 $\pm$ 41	
nd1-23	0.20	0.01	0.1141 $\pm$ 0.0027		0.2867 $\pm$ 0.0094		4.512 $\pm$ 0.182		-8.9	1625 $\pm$ 53		1733 $\pm$ 70		1867 $\pm$ 43	
nd1-58	0.54	n.d	0.1169 $\pm$ 0.0018		0.2948 $\pm$ 0.0073		4.749 $\pm$ 0.138		-10.4	1665 $\pm$ 41		1776 $\pm$ 52		1909 $\pm$ 29	
nd1-51	0.15	0.17	0.1139 $\pm$ 0.0017		0.2972 $\pm$ 0.0073		4.669 $\pm$ 0.134		-6.9	1678 $\pm$ 41		1762 $\pm$ 51		1863 $\pm$ 28	
nd1-50	1.23	0.15	0.1146 $\pm$ 0.0017		0.2988 $\pm$ 0.0073		4.722 $\pm$ 0.135		-7.1	1685 $\pm$ 41		1771 $\pm$ 51		1874 $\pm$ 28	
nd1-66	0.63	n.d	0.1134 $\pm$ 0.0019		0.2999 $\pm$ 0.0074		4.690 $\pm$ 0.140		-5.4	1691 $\pm$ 42		1765 $\pm$ 53		1855 $\pm$ 31	
nd1-7	0.26	n.d	0.1179 $\pm$ 0.0024		0.3001 $\pm$ 0.0135		4.880 $\pm$ 0.240		-7.1	1692 $\pm$ 76		1799 $\pm$ 89		1926 $\pm$ 38	
nd1-18	0.12	0.04	0.1151 $\pm$ 0.0026		0.3041 $\pm$ 0.0100		4.826 $\pm$ 0.193		-4.1	1712 $\pm$ 56		1789 $\pm$ 72		1882 $\pm$ 43	
nd1-62	0.21	n.d	0.1170 $\pm$ 0.0018		0.3052 $\pm$ 0.0075		4.925 $\pm$ 0.143		-7.2	1717 $\pm$ 42		1806 $\pm$ 53		1912 $\pm$ 29	
nd1-1	0.51	n.d	0.1155 $\pm$ 0.0025		0.3069 $\pm$ 0.0138		4.887 $\pm$ 0.244		-2.5	1726 $\pm$ 78		1800 $\pm$ 90		1888 $\pm$ 41	
nd1-59	0.23	n.d	0.1157 $\pm$ 0.0017		0.3085 $\pm$ 0.0076		4.923 $\pm$ 0.142		-5.1	1733 $\pm$ 43		1806 $\pm$ 52		1892 $\pm$ 28	
nd1-13	0.24	n.d	0.1172 $\pm$ 0.0030		0.3099 $\pm$ 0.0156		5.008 $\pm$ 0.283		-2.2	1740 $\pm$ 88		1821 $\pm$ 103		1915 $\pm$ 49	
nd1-55	0.18	0.13	0.1138 $\pm$ 0.0017		0.3102 $\pm$ 0.0076		4.865 $\pm$ 0.139		-2.8	1742 $\pm$ 43		1796 $\pm$ 51		1861 $\pm$ 27	
nd1-44	0.18	n.d	0.1144 $\pm$ 0.0024		0.3107 $\pm$ 0.0071		4.900 $\pm$ 0.151		-2.7	1744 $\pm$ 40		1802 $\pm$ 55		1870 $\pm$ 39	
nd1-56	0.29	n.d	0.1155 $\pm$ 0.0017		0.3184 $\pm$ 0.0078		5.069 $\pm$ 0.144		-2.0	1782 $\pm$ 43		1831 $\pm$ 52		1888 $\pm$ 27	
nd1-36	1.11	n.d	0.1151 $\pm$ 0.0025		0.3232 $\pm$ 0.0068		5.127 $\pm$ 0.154			1805 $\pm$ 38		1840 $\pm$ 55		1881 $\pm$ 40	
nd1-60	0.39	0.03	0.1162 $\pm$ 0.0018		0.3238 $\pm$ 0.0080		5.190 $\pm$ 0.151		-0.9	1808 $\pm$ 45		1851 $\pm$ 54		1899 $\pm$ 29	
nd1-27	0.43	0.01	0.1275 $\pm$ 0.0030		0.3355 $\pm$ 0.0110		5.898 $\pm$ 0.238		-4.8	1865 $\pm$ 61		1961 $\pm$ 79		2064 $\pm$ 48	
nd1-20	0.85	0.13	0.1232 $\pm$ 0.0030		0.3538 $\pm$ 0.0117		6.011 $\pm$ 0.246			1953 $\pm$ 64		1977 $\pm$ 81		2004 $\pm$ 49	
nd1-47	0.38	n.d	0.1221 $\pm$ 0.0025		0.3724 $\pm$ 0.0085		6.271 $\pm$ 0.193			2041 $\pm$ 46		2014 $\pm$ 62		1988 $\pm$ 41	
nd1-3	0.70	n.d	0.1459 $\pm$ 0.0029		0.4039 $\pm$ 0.0182		8.128 $\pm$ 0.399			2187 $\pm$ 98		2245 $\pm$ 110		2299 $\pm$ 45	
nd1-65	0.38	0.05	0.1480 $\pm$ 0.0023		0.4253 $\pm$ 0.0105		8.677 $\pm$ 0.252			2284 $\pm$ 56		2305 $\pm$ 67		2323 $\pm$ 35	
nd1-39	0.47	0.08	0.1814 $\pm$ 0.0037		0.4298 $\pm$ 0.0098		10.752 $\pm$ 0.329		-11.0	2305 $\pm$ 52		2502 $\pm$ 76		2666 $\pm$ 54	
nd1-11	0.95	n.d	0.1754 $\pm$ 0.0046		0.4935 $\pm$ 0.0249		11.933 $\pm$ 0.677			2586 $\pm$ 130		2599 $\pm$ 147		2610 $\pm$ 68	
nd1-61	0.43	7.44	0.1191 $\pm$ 0.0018		0.5391 $\pm$ 0.0133		8.852 $\pm$ 0.256			2780 $\pm$ 69		2323 $\pm$ 67		1943 $\pm$ 29	
nd1-5	0.52	n.d	0.2703 $\pm$ 0.0053		0.5768 $\pm$ 0.0261		21.496 $\pm$ 1.060		-5.9	2936 $\pm$ 133		3161 $\pm$ 156		3308 $\pm$ 65	

Table 1. Continued

Sample Code	Th/U	²⁰⁶ Pb/ ²³⁸ U (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
<i>Northern Nakdong Fm. (n=89)</i>															
0629-3-55	0.81	n.d	0.0527 ± 0.0018		0.0191 ± 0.0005		0.139 ± 0.006		-0.5	122.0 ± 3.5		132.0 ± 5.9		317 ± 11.0	
0629-3-25	1.25	n.d	0.0483 ± 0.0019		0.0240 ± 0.0005		0.160 ± 0.007			152.8 ± 3.2		150.6 ± 6.7		115 ± 4.5	
0629-3-100	0.74	n.d	0.0536 ± 0.0041		0.0247 ± 0.0006		0.182 ± 0.015			157.1 ± 3.6		170.0 ± 13.6		355 ± 27.2	
0629-3-54	1.05	n.d	0.0559 ± 0.0029		0.0247 ± 0.0007		0.190 ± 0.011		-2.8	157.1 ± 4.7		176.8 ± 10.7		450 ± 23.6	
0629-3-21	0.89	n.d	0.0486 ± 0.0031		0.0247 ± 0.0006		0.166 ± 0.011			157.3 ± 3.5		155.5 ± 10.4		129 ± 8.1	
0629-3-35	1.04	n.d	0.0504 ± 0.0030		0.0253 ± 0.0005		0.176 ± 0.011			161.2 ± 3.5		164.7 ± 10.5		216 ± 13.0	
0629-3-62	0.96	n.d	0.0513 ± 0.0034		0.0253 ± 0.0011		0.179 ± 0.014			161.3 ± 7.1		167.3 ± 13.3		254 ± 16.7	
0629-3-6	0.67	n.d	0.0466 ± 0.0031		0.0255 ± 0.0012		0.164 ± 0.013			162.4 ± 7.8		154.0 ± 12.5		28 ± 1.8	
0629-3-36	0.69	n.d	0.0474 ± 0.0038		0.0256 ± 0.0006		0.167 ± 0.014			163.2 ± 3.7		157.2 ± 13.3		68 ± 5.5	
0629-3-98	1.01	n.d	0.0490 ± 0.0022		0.0259 ± 0.0005		0.175 ± 0.009			164.6 ± 3.5		163.4 ± 8.0		147 ± 6.5	
0629-3-45	0.90	n.d	0.0500 ± 0.0020		0.0262 ± 0.0005		0.180 ± 0.008			166.4 ± 3.1		168.3 ± 7.3		195 ± 7.6	
0629-3-2	0.66	n.d	0.0536 ± 0.0037		0.0268 ± 0.0013		0.198 ± 0.017			170.6 ± 8.3		183.8 ± 15.4		357 ± 24.4	
0629-3-82	2.07	n.d	0.0553 ± 0.0028		0.0269 ± 0.0009		0.205 ± 0.012		-0.9	171.4 ± 5.5		189.7 ± 11.3		425 ± 21.5	
0629-3-65	0.32	n.d	0.0530 ± 0.0027		0.0270 ± 0.0012		0.198 ± 0.013			172.1 ± 7.5		183.1 ± 12.3		329 ± 16.8	
0629-3-77	0.30	n.d	0.0486 ± 0.0014		0.0271 ± 0.0007		0.182 ± 0.007			172.5 ± 4.5		169.7 ± 6.6		131 ± 3.8	
0629-3-51	0.29	n.d	0.0487 ± 0.0017		0.0272 ± 0.0008		0.182 ± 0.008			172.8 ± 4.9		170.1 ± 7.7		134 ± 4.7	
0629-3-61	1.36	n.d	0.0479 ± 0.0029		0.0276 ± 0.0012		0.182 ± 0.014			175.7 ± 7.7		170.1 ± 12.8		93 ± 5.7	
0629-3-89	0.25	n.d	0.0473 ± 0.0016		0.0282 ± 0.0009		0.184 ± 0.008			179.0 ± 5.6		171.1 ± 7.8		65 ± 2.2	
0629-3-29	1.29	n.d	0.0438 ± 0.0023		0.0288 ± 0.0006		0.174 ± 0.010			182.8 ± 3.9		162.8 ± 9.2			
0629-3-75	0.33	n.d	0.0482 ± 0.0015		0.0309 ± 0.0008		0.206 ± 0.008			196.5 ± 5.1		189.9 ± 7.8		110 ± 3.4	
0629-3-10	1.61	n.d	0.0508 ± 0.0017		0.0313 ± 0.0015		0.219 ± 0.012			198.4 ± 9.3		200.9 ± 11.5		231 ± 7.5	
0629-3-19	0.67	n.d	0.0534 ± 0.0018		0.0331 ± 0.0013		0.244 ± 0.012			210.0 ± 8.0		221.4 ± 11.3		344 ± 11.7	
0629-3-13	0.06	0.28	0.0505 ± 0.0017		0.0345 ± 0.0013		0.240 ± 0.012			218.4 ± 8.3		218.5 ± 11.1		220 ± 7.4	
0629-3-57	1.30	n.d	0.0518 ± 0.0015		0.0345 ± 0.0010		0.247 ± 0.010			218.8 ± 6.2		223.8 ± 9.1		278 ± 8.2	
0629-3-66	0.49	n.d	0.0496 ± 0.0039		0.0354 ± 0.0016		0.242 ± 0.022			224.5 ± 10.1		220.3 ± 19.9		177 ± 13.9	
0629-3-22	0.07	n.d	0.0517 ± 0.0022		0.0355 ± 0.0007		0.253 ± 0.012			225.0 ± 4.7		229.3 ± 10.8		274 ± 11.5	
0629-3-37	2.63	n.d	0.0514 ± 0.0033		0.0360 ± 0.0008		0.255 ± 0.017			228.0 ± 5.0		230.6 ± 15.6		258 ± 16.5	
0629-3-47	1.03	n.d	0.0507 ± 0.0016		0.0363 ± 0.0007		0.254 ± 0.009			229.8 ± 4.1		229.6 ± 8.5		229 ± 7.4	
0629-3-71	0.02	n.d	0.0497 ± 0.0018		0.0365 ± 0.0010		0.250 ± 0.011			231.2 ± 6.1		226.9 ± 10.1		183 ± 6.6	
0629-3-27	1.01	n.d	0.0549 ± 0.0019		0.0365 ± 0.0007		0.276 ± 0.011		-0.8	231.2 ± 4.7		247.7 ± 9.8		407 ± 13.8	
0629-3-11	0.84	0.01	0.0559 ± 0.0019		0.0371 ± 0.0014		0.286 ± 0.015			234.7 ± 9.0		255.4 ± 13.2		451 ± 15.7	
0629-3-59	1.60	n.d	0.0537 ± 0.0027		0.0371 ± 0.0011		0.275 ± 0.016			234.9 ± 6.9		246.4 ± 14.5		358 ± 18.3	
0629-3-56	1.27	n.d	0.0501 ± 0.0020		0.0405 ± 0.0012		0.280 ± 0.014			256.0 ± 7.4		250.5 ± 12.4		200 ± 8.1	
0629-3-12	0.26	0.27	0.0515 ± 0.0018		0.0415 ± 0.0016		0.294 ± 0.015			261.9 ± 10.0		262.0 ± 13.5		263 ± 9.1	
0629-3-34	0.19	n.d	0.0572 ± 0.0044		0.0417 ± 0.0010		0.329 ± 0.027			263.6 ± 6.1		288.9 ± 23.3		499 ± 38.6	
0629-3-91	0.19	n.d	0.0486 ± 0.0073		0.0434 ± 0.0012		0.291 ± 0.044			273.7 ± 7.3		259.1 ± 39.4		129 ± 19.3	
0629-3-87	0.91	0.60	0.0603 ± 0.0023		0.0586 ± 0.0018		0.487 ± 0.024		-1.3	366.9 ± 11.6		403.0 ± 20.0		617 ± 23.7	
0629-3-18	0.74	n.d	0.0570 ± 0.0019		0.0680 ± 0.0026		0.534 ± 0.027			424.0 ± 16.2		434.7 ± 21.9		492 ± 16.1	
0629-3-88	0.57	n.d	0.0555 ± 0.0024		0.0685 ± 0.0022		0.524 ± 0.028			427.2 ± 13.5		427.7 ± 22.7		431 ± 18.4	
0629-3-92	0.63	n.d	0.0556 ± 0.0021		0.0712 ± 0.0015		0.546 ± 0.024			443.5 ± 9.3		442.2 ± 19.3		436 ± 16.6	
0629-3-97	1.12	0.73	0.0640 ± 0.0013		0.0817 ± 0.0016		0.720 ± 0.020		-3.8	506.0 ± 10.1		550.9 ± 15.6		742 ± 14.7	
0629-3-83	1.04	n.d	0.0761 ± 0.0048		0.1109 ± 0.0037		1.163 ± 0.083		-4.0	677.9 ± 22.6		783.5 ± 55.6		1098 ± 69	
0629-3-64	1.34	n.d	0.0656 ± 0.0016		0.1156 ± 0.0050		1.045 ± 0.052			705.3 ± 30.3		726.5 ± 36.0		793 ± 19.5	
0629-3-68	0.93	n.d	0.0655 ± 0.0016		0.1243 ± 0.0053		1.123 ± 0.055			755.4 ± 32.4		764.4 ± 37.6		791 ± 19.0	
0629-3-3	0.62	0.33	0.0778 ± 0.0012		0.1349 ± 0.0063		1.447 ± 0.071		-1.3	815.5 ± 37.8		908.4 ± 44.4		1142 ± 18	
0629-3-5	0.80	n.d	0.0635 ± 0.0030		0.1375 ± 0.0066		1.203 ± 0.080			830.4 ± 39.6		802.1 ± 53.4		725 ± 33.7	

Table 1. Continued

Sample Code	Th/U	²⁰⁶ Pb/ ²³⁸ U (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
0629-3-4	0.92	n.d	0.0646 ± 0.0024		0.1427 ± 0.0067		1.272 ± 0.076			860.0 ± 40.6		833.2 ± 49.7		763 ± 27.9	
0629-3-33	0.69	0.66	0.0788 ± 0.0019		0.1875 ± 0.0038		2.038 ± 0.064		-1.0	1108 ± 22		1128 ± 35		1169 ± 28	
0629-3-70	0.84	0.09	0.0817 ± 0.0017		0.1892 ± 0.0081		2.131 ± 0.102		-4.2	1117 ± 48		1159 ± 55		1238 ± 26	
0629-3-95	0.60	n.d	0.0820 ± 0.0020		0.2019 ± 0.0041		2.283 ± 0.072		-0.5	1186 ± 24		1207 ± 38		1246 ± 30	
0629-3-99	0.71	n.d	0.0790 ± 0.0019		0.2068 ± 0.0042		2.252 ± 0.071			1212 ± 25		1197 ± 38		1172 ± 28	
0629-3-52	0.81	n.d	0.1125 ± 0.0019		0.2824 ± 0.0078		4.381 ± 0.143		-10.0	1604 ± 44		1709 ± 56		1841 ± 32	
0629-3-20	0.77	0.03	0.1020 ± 0.0020		0.2834 ± 0.0107		3.986 ± 0.169			1609 ± 61		1631 ± 69		1661 ± 32	
0629-3-8	0.77	0.09	0.1096 ± 0.0017		0.2859 ± 0.0133		4.323 ± 0.212		-4.3	1621 ± 75		1698 ± 83		1794 ± 28	
0629-3-46	1.28	n.d	0.1082 ± 0.0022		0.2888 ± 0.0052		4.309 ± 0.116		-4.2	1636 ± 29		1695 ± 46		1770 ± 36	
0629-3-96	0.10	0.11	0.1139 ± 0.0019		0.2901 ± 0.0058		4.555 ± 0.117		-9.6	1642 ± 33		1741 ± 45		1863 ± 31	
0629-3-79	1.14	0.55	0.1091 ± 0.0024		0.2912 ± 0.0076		4.380 ± 0.149		-3.4	1647 ± 43		1709 ± 58		1785 ± 39	
0629-3-32	0.43	n.d	0.1082 ± 0.0022		0.2915 ± 0.0058		4.350 ± 0.125		-3.1	1649 ± 33		1703 ± 49		1770 ± 36	
0629-3-40	0.07	0.81	0.1204 ± 0.0016		0.2935 ± 0.0057		4.873 ± 0.113		-14.9	1659 ± 32		1798 ± 42		1963 ± 26	
0629-3-69	0.27	n.d	0.1139 ± 0.0022		0.2949 ± 0.0126		4.633 ± 0.217		-5.4	1666 ± 71		1755 ± 82		1863 ± 36	
0629-3-26	0.65	n.d	0.1129 ± 0.0018		0.2959 ± 0.0058		4.606 ± 0.116		-6.8	1671 ± 33		1750 ± 44		1847 ± 29	
0629-3-24	1.34	n.d	0.1062 ± 0.0028		0.2979 ± 0.0063		4.361 ± 0.149			1681 ± 36		1705 ± 58		1735 ± 46	
0629-3-23	0.91	n.d	0.1166 ± 0.0019		0.2979 ± 0.0059		4.788 ± 0.121		-9.6	1681 ± 33		1783 ± 45		1905 ± 30	
0629-3-74	0.15	n.d	0.1117 ± 0.0019		0.3014 ± 0.0077		4.641 ± 0.143		-3.2	1698 ± 44		1757 ± 54		1827 ± 31	
0629-3-38	1.01	n.d	0.1068 ± 0.0045		0.3033 ± 0.0070		4.465 ± 0.215			1708 ± 39		1724 ± 83		1746 ± 74	
0629-3-58	0.63	0.15	0.1116 ± 0.0018		0.3043 ± 0.0084		4.684 ± 0.150		-2.1	1713 ± 47		1764 ± 57		1826 ± 30	
0629-3-90	0.85	0.03	0.1112 ± 0.0031		0.3055 ± 0.0096		4.683 ± 0.198			1719 ± 54		1764 ± 75		1819 ± 51	
0629-3-44	0.83	n.d	0.1139 ± 0.0015		0.3072 ± 0.0053		4.823 ± 0.104		-4.8	1727 ± 30		1789 ± 39		1863 ± 24	
0629-3-78	0.80	0.30	0.1097 ± 0.0019		0.3090 ± 0.0079		4.674 ± 0.145			1736 ± 45		1763 ± 55		1795 ± 31	
0629-3-80	0.35	0.04	0.1145 ± 0.0020		0.3118 ± 0.0080		4.922 ± 0.152		-2.6	1750 ± 45		1806 ± 56		1872 ± 32	
0629-3-41	0.21	0.29	0.1135 ± 0.0014		0.3144 ± 0.0054		4.921 ± 0.104		-2.3	1763 ± 30		1806 ± 38		1857 ± 23	
0629-3-9	0.27	n.d	0.1142 ± 0.0018		0.3215 ± 0.0149		5.061 ± 0.248			1797 ± 83		1830 ± 90		1867 ± 30	
0629-3-17	0.64	0.09	0.1160 ± 0.0021		0.3280 ± 0.0124		5.247 ± 0.220			1829 ± 69		1860 ± 78		1896 ± 35	
0629-3-49	0.44	n.d	0.1154 ± 0.0014		0.3316 ± 0.0057		5.279 ± 0.110			1846 ± 32		1865 ± 39		1887 ± 23	
0629-3-93	0.29	n.d	0.1215 ± 0.0021		0.3347 ± 0.0067		5.607 ± 0.148		-2.5	1861 ± 37		1917 ± 51		1979 ± 34	
0629-3-7	0.53	0.19	0.1073 ± 0.0017		0.3379 ± 0.0157		4.998 ± 0.245			1877 ± 87		1819 ± 89		1754 ± 28	
0629-3-28	1.23	n.d	0.1131 ± 0.0014		0.3397 ± 0.0066		5.298 ± 0.123			1885 ± 37		1869 ± 43		1851 ± 24	
0629-3-76	0.66	0.39	0.1090 ± 0.0019		0.3429 ± 0.0088		5.153 ± 0.161			1901 ± 49		1845 ± 58		1783 ± 32	
0629-3-50	0.56	n.d	0.1194 ± 0.0017		0.3474 ± 0.0060		5.720 ± 0.130			1922 ± 33		1934 ± 44		1948 ± 28	
0629-3-43	0.15	n.d	0.1145 ± 0.0014		0.3477 ± 0.0059		5.487 ± 0.115			1924 ± 33		1899 ± 40		1872 ± 23	
0629-3-67	0.21	0.09	0.1322 ± 0.0024		0.3496 ± 0.0149		6.373 ± 0.297		-3.8	1932 ± 83		2028 ± 94		2128 ± 39	
0629-3-30	0.13	0.02	0.1380 ± 0.0015		0.3541 ± 0.0068		6.736 ± 0.150		-9.5	1954 ± 38		2077 ± 46		2202 ± 25	
0629-3-86	1.58	0.05	0.1479 ± 0.0030		0.3566 ± 0.0109		7.273 ± 0.267		-12.7	1966 ± 60		2145 ± 79		2323 ± 47	
0629-3-48	0.12	0.02	0.1443 ± 0.0015		0.3666 ± 0.0062		7.293 ± 0.143		-10.4	2013 ± 34		2148 ± 42		2280 ± 23	
0629-3-63	0.41	0.21	0.1528 ± 0.0030		0.3687 ± 0.0158		7.768 ± 0.366		-10.9	2023 ± 87		2204 ± 104		2378 ± 46	
0629-3-94	0.41	0.14	0.1713 ± 0.0029		0.4157 ± 0.0083		9.820 ± 0.256		-10.8	2241 ± 45		2418 ± 63		2571 ± 43	
0629-3-39	0.70	0.54	0.1735 ± 0.0024		0.4171 ± 0.0081		9.978 ± 0.238		-11.8	2247 ± 44		2433 ± 58		2592 ± 36	
0629-3-14	0.43	0.59	0.1616 ± 0.0032		0.4476 ± 0.0170		9.976 ± 0.428			2385 ± 91		2432 ± 104		2473 ± 49	
0629-3-60	0.69	0.57	0.1951 ± 0.0032		0.4512 ± 0.0125		12.139 ± 0.391		-11.4	2401 ± 67		2615 ± 84		2786 ± 46	
<i>Southern Hasandong Fm. (n=49)</i>															
hsd2-22	0.53	n.d	0.0505 ± 0.0022		0.0171 ± 0.0005		0.119 ± 0.006			109.0 ± 3.4		114.1 ± 6.1		221 ± 9.6	
hsd2-1	0.52	n.d	0.0476 ± 0.0015		0.0174 ± 0.0010		0.114 ± 0.007			111.2 ± 6.1		109.7 ± 7.0		78 ± 2.5	
hsd2-24	0.52	n.d	0.0468 ± 0.0023		0.0174 ± 0.0005		0.112 ± 0.007			111.4 ± 3.5		108.2 ± 6.3		38 ± 1.9	

Table 1. Continued

Sample Code	Th/U	²⁰⁶ Pbc ^(a) (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc ^(b) (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
hsd2-25	0.57	n.d	0.0497 ± 0.0021		0.0176 ± 0.0005		0.120 ± 0.006			112.2 ± 3.5		115.5 ± 6.0		184 ± 7.6	
hsd2-56	0.28	n.d	0.0486 ± 0.0024		0.0185 ± 0.0009		0.124 ± 0.009			118.0 ± 6.0		118.5 ± 8.4		129 ± 6.3	
hsd2-57	1.26	n.d	0.0497 ± 0.0021		0.0192 ± 0.0010		0.131 ± 0.009			122.6 ± 6.2		125.4 ± 8.3		179 ± 7.7	
hsd2-44	3.04	n.d	0.0446 ± 0.0057		0.0193 ± 0.0007		0.118 ± 0.016			122.9 ± 4.7		113.7 ± 15.2			
hsd2-50	1.20	n.d	0.0498 ± 0.0039		0.0193 ± 0.0010		0.133 ± 0.012			123.4 ± 6.5		126.6 ± 11.9		186 ± 14.5	
hsd2-18	0.45	n.d	0.0522 ± 0.0021		0.0197 ± 0.0006		0.142 ± 0.007			125.5 ± 3.9		134.4 ± 6.8		295 ± 11.9	
hsd2-48	0.96	n.d	0.0503 ± 0.0031		0.0197 ± 0.0010		0.136 ± 0.011			125.7 ± 6.5		129.9 ± 10.4		207 ± 12.6	
hsd2-49	0.96	n.d	0.0498 ± 0.0031		0.0261 ± 0.0013		0.179 ± 0.014			166.4 ± 8.6		167.5 ± 13.4		184 ± 11.3	
hsd2-2	1.05	3.37	0.0517 ± 0.0009		0.0318 ± 0.0018		0.227 ± 0.013			202.1 ± 11.1		207.6 ± 12.0		271 ± 4.8	
hsd2-40	1.19	n.d	0.0644 ± 0.0019		0.1213 ± 0.0038		1.077 ± 0.046			738.0 ± 23.1		742.4 ± 31.9		756 ± 22.2	
hsd2-27	0.39	n.d	0.0694 ± 0.0019		0.1217 ± 0.0037		1.165 ± 0.048			740.3 ± 22.6		784.4 ± 32.6		913 ± 25.6	
hsd2-65	1.03	0.24	0.0677 ± 0.0019		0.1222 ± 0.0034		1.140 ± 0.045			743.2 ± 20.8		772.5 ± 30.5		859 ± 23.9	
hsd2-62	0.41	0.51	0.0634 ± 0.0014		0.1247 ± 0.0034		1.091 ± 0.039			757.8 ± 20.9		749.0 ± 26.7		723 ± 16.3	
hsd2-33	1.30	n.d	0.0804 ± 0.0020		0.1254 ± 0.0068		1.391 ± 0.083	-3.9		761.6 ± 41.1		885.1 ± 52.6		1209 ± 30	
hsd2-23	0.89	n.d	0.0679 ± 0.0022		0.1279 ± 0.0040		1.197 ± 0.054			776.1 ± 24.0		799.2 ± 36.1		865 ± 28.4	
hsd2-13	0.39	n.d	0.0669 ± 0.0014		0.1297 ± 0.0040		1.197 ± 0.045			786.4 ± 24.4		799.1 ± 30.0		835 ± 17.6	
hsd2-12	0.55	0.30	0.0658 ± 0.0012		0.1336 ± 0.0041		1.213 ± 0.044			808.3 ± 25.0		806.3 ± 28.9		801 ± 14.6	
hsd2-52	0.84	n.d	0.0636 ± 0.0025		0.1337 ± 0.0068		1.173 ± 0.075			808.9 ± 41.2		788.2 ± 50.5		730 ± 28.4	
hsd2-53	0.54	0.24	0.0650 ± 0.0014		0.1347 ± 0.0068		1.208 ± 0.066			814.9 ± 40.9		804.2 ± 43.8		775 ± 16.4	
hsd2-29	0.96	0.19	0.0636 ± 0.0015		0.1385 ± 0.0075		1.214 ± 0.072			836.3 ± 45.0		806.9 ± 47.6		727 ± 17.4	
hsd2-36	0.94	0.65	0.0673 ± 0.0026		0.1399 ± 0.0076		1.299 ± 0.087			844.0 ± 46.0		845.1 ± 56.6		849 ± 33.0	
hsd2-45	1.22	n.d	0.0656 ± 0.0026		0.1431 ± 0.0046		1.294 ± 0.066			862.4 ± 27.7		843.2 ± 43.2		794 ± 31.8	
hsd2-46	0.97	n.d	0.0637 ± 0.0023		0.1458 ± 0.0046		1.281 ± 0.062			877.4 ± 27.9		837.4 ± 40.6		734 ± 26.9	
hsd2-6	0.27	0.11	0.1136 ± 0.0017		0.2737 ± 0.0150		4.288 ± 0.244	-11.9		1560 ± 86		1691 ± 96		1858 ± 28	
hsd2-10	0.11	0.19	0.1162 ± 0.0018		0.2906 ± 0.0090		4.654 ± 0.161	-10.5		1645 ± 51		1759 ± 61		1898 ± 30	
hsd2-55	0.29	0.18	0.1127 ± 0.0016		0.2945 ± 0.0147		4.574 ± 0.238	-4.2		1664 ± 83		1744 ± 91		1843 ± 27	
hsd2-15	0.04	n.d	0.1149 ± 0.0018		0.2968 ± 0.0091		4.704 ± 0.162	-7.3		1676 ± 52		1768 ± 61		1879 ± 29	
hsd2-54	1.28	1.49	0.0940 ± 0.0023		0.2981 ± 0.0151		3.865 ± 0.218			1682 ± 85		1606 ± 90		1509 ± 37	
hsd2-11	0.54	n.d	0.1138 ± 0.0019		0.3000 ± 0.0093		4.705 ± 0.164	-5.2		1691 ± 52		1768 ± 62		1861 ± 30	
hsd2-26	0.54	0.54	0.1064 ± 0.0022		0.3005 ± 0.0091		4.410 ± 0.161			1694 ± 51		1714 ± 63		1740 ± 36	
hsd2-42	1.10	0.14	0.1024 ± 0.0022		0.3041 ± 0.0094		4.292 ± 0.161			1712 ± 53		1692 ± 63		1668 ± 36	
hsd2-20	0.04	n.d	0.1170 ± 0.0023		0.3044 ± 0.0092		4.912 ± 0.177	-6.4		1713 ± 52		1804 ± 65		1912 ± 38	
hsd2-67	0.98	0.05	0.1162 ± 0.0016		0.3046 ± 0.0083		4.879 ± 0.149	-6.5		1714 ± 47		1799 ± 55		1899 ± 26	
hsd2-8	0.01	0.08	0.1139 ± 0.0018		0.3111 ± 0.0096		4.885 ± 0.170	-1.9		1746 ± 54		1800 ± 63		1863 ± 30	
hsd2-43	1.08	n.d	0.1042 ± 0.0026		0.3148 ± 0.0098		4.521 ± 0.181			1764 ± 55		1735 ± 69		1700 ± 43	
hsd2-5	0.41	0.03	0.1146 ± 0.0018		0.3149 ± 0.0173		4.975 ± 0.284			1765 ± 97		1815 ± 104		1874 ± 29	
hsd2-34	0.98	n.d	0.1148 ± 0.0024		0.3206 ± 0.0172		5.074 ± 0.293			1792 ± 96		1832 ± 106		1877 ± 40	
hsd2-66	0.20	n.d	0.1139 ± 0.0015		0.3319 ± 0.0090		5.211 ± 0.157			1847 ± 50		1854 ± 56		1863 ± 24	
hsd2-60	0.21	0.06	0.1242 ± 0.0016		0.3329 ± 0.0091		5.701 ± 0.171	-4.9		1852 ± 50		1931 ± 58		2018 ± 26	
hsd2-17	0.23	n.d	0.1337 ± 0.0022		0.3507 ± 0.0108		6.463 ± 0.225	-5.9		1938 ± 60		2041 ± 71		2147 ± 35	
hsd2-58	0.45	n.d	0.1448 ± 0.0019		0.3815 ± 0.0104		7.616 ± 0.230	-5.6		2083 ± 57		2187 ± 66		2286 ± 30	
hsd2-7	1.33	0.13	0.1544 ± 0.0023		0.4030 ± 0.0221		8.582 ± 0.488	-2.7		2183 ± 120		2295 ± 131		2396 ± 35	
hsd2-14	0.79	0.02	0.1613 ± 0.0025		0.4290 ± 0.0132		9.540 ± 0.328	-2.6		2301 ± 71		2391 ± 82		2470 ± 38	
hsd2-61	1.24	0.33	0.1595 ± 0.0022		0.4454 ± 0.0122		9.798 ± 0.299			2375 ± 65		2416 ± 74		2451 ± 33	
hsd2-63	0.42	n.d	0.1844 ± 0.0027		0.4678 ± 0.0129		11.894 ± 0.370	-4.5		2474 ± 68		2596 ± 81		2693 ± 39	
hsd2-41	0.05	0.01	0.2793 ± 0.0057		0.5806 ± 0.0179		22.362 ± 0.825	-8.5		2951 ± 91		3199 ± 118		3360 ± 68	

Table 1. Continued

Sample Code	Th/U	²⁰⁶ Pb/ ²³⁸ U ^(a) (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc ^(b) (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
<i>Central Hasandong Fm. (n=77)</i>															
grh-23	0.85	n.d	0.0505 ± 0.0013		0.0172 ± 0.0003		0.120 ± 0.004			110.1 ± 2.0		115.1 ± 3.6		221 ± 5.6	
grh-24	0.74	n.d	0.0488 ± 0.0028		0.0176 ± 0.0004		0.119 ± 0.007			112.7 ± 2.4		113.9 ± 6.9		140 ± 7.9	
grh-44	1.07	n.d	0.0477 ± 0.0028		0.0183 ± 0.0007		0.121 ± 0.009			117.1 ± 4.7		115.7 ± 8.2		87 ± 5.1	
grh-93	1.65	n.d	0.0435 ± 0.0037		0.0187 ± 0.0006		0.112 ± 0.010			119.5 ± 3.9		108.0 ± 9.7			
grh-50	3.08	n.d	0.0554 ± 0.0055		0.0188 ± 0.0004		0.143 ± 0.015			120.1 ± 2.5		136.1 ± 13.9		427 ± 42.6	
grh-46	1.56	n.d	0.0562 ± 0.0041		0.0189 ± 0.0004		0.146 ± 0.011		-4.4	120.6 ± 2.3		138.7 ± 10.5		462 ± 33.8	
grh-55	1.20	n.d	0.0462 ± 0.0038		0.0198 ± 0.0004		0.126 ± 0.011			126.6 ± 2.4		120.8 ± 10.2		8 ± 0.7	
grh-71	1.07	n.d	0.0571 ± 0.0036		0.0249 ± 0.0005		0.196 ± 0.013		-5.1	158.3 ± 3.2		181.6 ± 12.1		497 ± 31.5	
grh-12	0.78	n.d	0.0523 ± 0.0039		0.0249 ± 0.0008		0.180 ± 0.015			158.8 ± 5.2		167.8 ± 13.6		298 ± 22.0	
grh-4	0.82	n.d	0.0490 ± 0.0018		0.0254 ± 0.0008		0.172 ± 0.008			161.9 ± 4.9		160.9 ± 7.8		147 ± 5.5	
grh-59	0.83	n.d	0.0536 ± 0.0020		0.0257 ± 0.0005		0.190 ± 0.008		-1.6	163.3 ± 3.1		176.4 ± 7.3		356 ± 13.1	
grh-19	0.89	1.97	0.0504 ± 0.0023		0.0261 ± 0.0005		0.181 ± 0.009			165.8 ± 3.4		169.0 ± 8.4		214 ± 9.6	
grh-81	0.59	n.d	0.0492 ± 0.0024		0.0264 ± 0.0005		0.179 ± 0.009			167.8 ± 3.4		166.9 ± 8.8		156 ± 7.5	
grh-84	0.48	0.38	0.0508 ± 0.0021		0.0265 ± 0.0005		0.186 ± 0.008			168.5 ± 3.3		172.8 ± 7.8		234 ± 9.5	
grh-97	1.00	n.d	0.0514 ± 0.0026		0.0272 ± 0.0007		0.193 ± 0.011			172.7 ± 4.2		178.8 ± 9.9		260 ± 13.0	
grh-6	0.78	n.d	0.0496 ± 0.0026		0.0334 ± 0.0010		0.228 ± 0.014			211.5 ± 6.7		208.6 ± 12.8		176 ± 9.2	
grh-99	0.69	n.d	0.0511 ± 0.0019		0.0345 ± 0.0008		0.243 ± 0.011			218.9 ± 5.2		221.3 ± 9.7		247 ± 9.1	
grh-11	0.07	n.d	0.0500 ± 0.0018		0.0354 ± 0.0011		0.244 ± 0.012			224.4 ± 6.9		221.8 ± 10.5		195 ± 7.0	
grh-56	0.53	n.d	0.0556 ± 0.0096		0.0358 ± 0.0010		0.275 ± 0.048			226.9 ± 6.3		246.6 ± 43.1		438 ± 75.6	
grh-62	0.06	n.d	0.0516 ± 0.0021		0.0359 ± 0.0007		0.256 ± 0.011			227.6 ± 4.4		231.1 ± 10.4		267 ± 10.8	
grh-76	0.80	n.d	0.0577 ± 0.0035		0.0365 ± 0.0008		0.290 ± 0.018		-2.6	231.2 ± 5.0		258.7 ± 16.5		517 ± 31.0	
grh-60	0.49	n.d	0.0581 ± 0.0031		0.0367 ± 0.0008		0.294 ± 0.017		-4.0	232.5 ± 4.8		261.7 ± 15.1		533 ± 28.8	
grh-39	0.04	n.d	0.0477 ± 0.0023		0.0375 ± 0.0015		0.247 ± 0.016			237.3 ± 9.5		223.9 ± 14.2		86 ± 4.2	
grh-22	0.54	n.d	0.0541 ± 0.0012		0.0656 ± 0.0012		0.489 ± 0.014			409.8 ± 7.6		404.4 ± 11.6		374 ± 8.2	
grh-100	0.36	n.d	0.0644 ± 0.0025		0.0683 ± 0.0016		0.606 ± 0.028		-5.5	425.8 ± 10.2		481.1 ± 21.9		755 ± 29.3	
grh-92	1.09	0.93	0.0641 ± 0.0024		0.0873 ± 0.0026		0.771 ± 0.037			539.4 ± 16.1		580.3 ± 27.8		745 ± 28.0	
grh-47	1.72	n.d	0.0649 ± 0.0029		0.1023 ± 0.0018		0.916 ± 0.044			627.9 ± 10.9		660.3 ± 31.4		773 ± 34.3	
grh-77	0.08	n.d	0.0701 ± 0.0019		0.1140 ± 0.0022		1.102 ± 0.037		-2.9	695.7 ± 13.2		754.3 ± 25.0		933 ± 25.4	
grh-18	1.65	n.d	0.0713 ± 0.0023		0.1158 ± 0.0023		1.137 ± 0.043		-3.1	706.1 ± 13.9		771.2 ± 29.1		965 ± 31.0	
grh-94	1.21	n.d	0.0679 ± 0.0029		0.1201 ± 0.0036		1.124 ± 0.059			730.9 ± 22.1		765.0 ± 40.1		867 ± 37.1	
grh-79	0.60	n.d	0.0661 ± 0.0021		0.1221 ± 0.0024		1.114 ± 0.042			742.9 ± 14.5		760.0 ± 28.5		811 ± 25.9	
grh-64	0.87	0.07	0.0651 ± 0.0018		0.1287 ± 0.0024		1.154 ± 0.038			780.2 ± 14.4		779.3 ± 25.4		777 ± 20.9	
grh-5	0.85	n.d	0.0674 ± 0.0018		0.1295 ± 0.0039		1.203 ± 0.048			785.1 ± 23.4		802.1 ± 32.0		850 ± 22.6	
grh-10	0.91	n.d	0.0675 ± 0.0029		0.1297 ± 0.0041		1.206 ± 0.064			786.2 ± 24.6		803.5 ± 42.4		852 ± 36.3	
grh-30	1.41	n.d	0.0691 ± 0.0026		0.1319 ± 0.0073		1.258 ± 0.084			798.9 ± 44.0		826.8 ± 55.4		903 ± 34.4	
grh-20	1.36	n.d	0.0647 ± 0.0025		0.1338 ± 0.0027		1.192 ± 0.053			809.3 ± 16.5		797.0 ± 35.2		764 ± 29.9	
grh-26	0.81	n.d	0.0755 ± 0.0029		0.1351 ± 0.0074		1.407 ± 0.094			816.9 ± 45.0		892.0 ± 59.6		1084 ± 41	
grh-29	0.14	n.d	0.0653 ± 0.0020		0.1388 ± 0.0076		1.251 ± 0.079			838.1 ± 45.9		823.8 ± 51.8		786 ± 24.2	
grh-52	0.96	n.d	0.0695 ± 0.0015		0.1428 ± 0.0022		1.368 ± 0.036			860.4 ± 13.1		875.2 ± 22.9		913 ± 19.4	
grh-70	0.67	n.d	0.0796 ± 0.0023		0.2014 ± 0.0033		2.210 ± 0.073			1183 ± 19		1184 ± 39		1187 ± 34	
grh-3	0.82	n.d	0.0780 ± 0.0022		0.2051 ± 0.0062		2.206 ± 0.091			1203 ± 36		1183 ± 49		1148 ± 33	
grh-68	0.44	0.09	0.1108 ± 0.0031		0.2679 ± 0.0044		4.091 ± 0.132		-13.6	1530 ± 25		1652 ± 54		1813 ± 51	
grh-7	1.07	0.49	0.1112 ± 0.0034		0.2774 ± 0.0085		4.253 ± 0.183		-8.7	1578 ± 48		1684 ± 72		1819 ± 55	
grh-43	0.53	0.26	0.1102 ± 0.0030		0.2850 ± 0.0112		4.331 ± 0.208		-4.6	1616 ± 64		1699 ± 82		1804 ± 49	
grh-58	0.14	n.d	0.1171 ± 0.0029		0.2895 ± 0.0053		4.676 ± 0.144		-12.0	1639 ± 30		1763 ± 54		1913 ± 47	
grh-57	0.18	n.d	0.1182 ± 0.0029		0.2994 ± 0.0055		4.881 ± 0.151		-9.6	1689 ± 31		1799 ± 55		1930 ± 48	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ ^(a) (%)	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2 σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	Disc ^(b) (%)	^{238}U - ^{206}Pb age (Ma)	Error 2 σ	^{235}U - ^{207}Pb age (Ma)	Error 2 σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2 σ
grh-86	0.25	0.18	0.1170 $\pm$ 0.0041		0.3023 $\pm$ 0.0090		4.876 $\pm$ 0.223		-5.4	1703 $\pm$ 50		1798 $\pm$ 82		1911 $\pm$ 66	
grh-38	0.04	0.08	0.1187 $\pm$ 0.0033		0.3030 $\pm$ 0.0119		4.960 $\pm$ 0.238		-6.5	1706 $\pm$ 67		1813 $\pm$ 87		1938 $\pm$ 53	
grh-37	0.16	0.15	0.1116 $\pm$ 0.0030		0.3049 $\pm$ 0.0120		4.693 $\pm$ 0.224			1716 $\pm$ 67		1766 $\pm$ 84		1827 $\pm$ 50	
grh-83	0.64	n.d	0.1130 $\pm$ 0.0027		0.3065 $\pm$ 0.0058		4.776 $\pm$ 0.146		-2.8	1723 $\pm$ 33		1781 $\pm$ 55		1849 $\pm$ 45	
grh-21	0.35	0.03	0.1132 $\pm$ 0.0013		0.3068 $\pm$ 0.0055		4.789 $\pm$ 0.104		-4.3	1725 $\pm$ 31		1783 $\pm$ 39		1852 $\pm$ 22	
grh-54	1.03	n.d	0.1071 $\pm$ 0.0031		0.3077 $\pm$ 0.0052		4.542 $\pm$ 0.153			1729 $\pm$ 29		1739 $\pm$ 59		1750 $\pm$ 51	
grh-33	0.89	n.d	0.1037 $\pm$ 0.0039		0.3118 $\pm$ 0.0173		4.459 $\pm$ 0.300			1750 $\pm$ 97		1723 $\pm$ 116		1692 $\pm$ 64	
grh-98	0.43	0.11	0.1124 $\pm$ 0.0029		0.3119 $\pm$ 0.0072		4.832 $\pm$ 0.166		-0.1	1750 $\pm$ 40		1790 $\pm$ 62		1839 $\pm$ 47	
grh-89	0.82	0.11	0.1120 $\pm$ 0.0040		0.3157 $\pm$ 0.0094		4.876 $\pm$ 0.226			1768 $\pm$ 53		1798 $\pm$ 83		1833 $\pm$ 65	
grh-45	0.63	0.06	0.1122 $\pm$ 0.0031		0.3173 $\pm$ 0.0125		4.911 $\pm$ 0.238			1777 $\pm$ 70		1804 $\pm$ 87		1836 $\pm$ 52	
grh-65	0.20	n.d	0.1132 $\pm$ 0.0028		0.3177 $\pm$ 0.0058		4.959 $\pm$ 0.154			1778 $\pm$ 33		1812 $\pm$ 56		1852 $\pm$ 46	
grh-63	0.39	n.d	0.1303 $\pm$ 0.0033		0.3179 $\pm$ 0.0059		5.711 $\pm$ 0.180		-13.3	1779 $\pm$ 33		1933 $\pm$ 61		2103 $\pm$ 54	
grh-66	0.45	0.09	0.1125 $\pm$ 0.0031		0.3182 $\pm$ 0.0052		4.935 $\pm$ 0.159			1781 $\pm$ 29		1808 $\pm$ 58		1840 $\pm$ 51	
grh-74	0.52	0.03	0.1117 $\pm$ 0.0033		0.3190 $\pm$ 0.0053		4.912 $\pm$ 0.165			1785 $\pm$ 30		1804 $\pm$ 61		1827 $\pm$ 53	
grh-36	0.30	0.19	0.1166 $\pm$ 0.0032		0.3204 $\pm$ 0.0126		5.151 $\pm$ 0.247			1792 $\pm$ 71		1845 $\pm$ 88		1905 $\pm$ 52	
grh-48	0.63	n.d	0.1151 $\pm$ 0.0019		0.3216 $\pm$ 0.0048		5.105 $\pm$ 0.116		-1.4	1798 $\pm$ 27		1837 $\pm$ 42		1882 $\pm$ 32	
grh-51	0.56	1.27	0.1145 $\pm$ 0.0018		0.3229 $\pm$ 0.0048		5.100 $\pm$ 0.110		-0.7	1804 $\pm$ 27		1836 $\pm$ 40		1873 $\pm$ 29	
grh-28	0.04	n.d	0.1169 $\pm$ 0.0032		0.3254 $\pm$ 0.0178		5.243 $\pm$ 0.320			1816 $\pm$ 99		1860 $\pm$ 114		1909 $\pm$ 52	
grh-31	0.19	0.11	0.1164 $\pm$ 0.0032		0.3348 $\pm$ 0.0183		5.374 $\pm$ 0.329			1861 $\pm$ 102		1881 $\pm$ 115		1903 $\pm$ 52	
grh-15	0.70	n.d	0.1228 $\pm$ 0.0034		0.3397 $\pm$ 0.0103		5.752 $\pm$ 0.237			1885 $\pm$ 57		1939 $\pm$ 80		1998 $\pm$ 56	
grh-35	0.46	0.71	0.1130 $\pm$ 0.0032		0.3400 $\pm$ 0.0186		5.297 $\pm$ 0.326			1887 $\pm$ 103		1868 $\pm$ 115		1848 $\pm$ 52	
grh-72	0.45	0.11	0.1216 $\pm$ 0.0035		0.3447 $\pm$ 0.0057		5.780 $\pm$ 0.190			1909 $\pm$ 31		1943 $\pm$ 64		1981 $\pm$ 56	
grh-69	0.25	n.d	0.1198 $\pm$ 0.0035		0.3533 $\pm$ 0.0058		5.836 $\pm$ 0.195			1950 $\pm$ 32		1952 $\pm$ 65		1954 $\pm$ 57	
grh-78	0.39	0.09	0.1195 $\pm$ 0.0029		0.3534 $\pm$ 0.0067		5.822 $\pm$ 0.179			1951 $\pm$ 37		1950 $\pm$ 60		1949 $\pm$ 47	
grh-1	0.50	n.d	0.1393 $\pm$ 0.0034		0.3557 $\pm$ 0.0106		6.832 $\pm$ 0.261		-7.4	1962 $\pm$ 58		2090 $\pm$ 80		2219 $\pm$ 53	
grh-17	1.13	0.40	0.1450 $\pm$ 0.0020		0.3637 $\pm$ 0.0067		7.269 $\pm$ 0.167		-11.0	1999 $\pm$ 37		2145 $\pm$ 49		2288 $\pm$ 32	
grh-49	0.70	n.d	0.1308 $\pm$ 0.0024		0.3715 $\pm$ 0.0057		6.700 $\pm$ 0.159		-0.1	2036 $\pm$ 31		2073 $\pm$ 49		2109 $\pm$ 38	
grh-73	0.56	n.d	0.1410 $\pm$ 0.0044		0.3722 $\pm$ 0.0064		7.237 $\pm$ 0.258		-4.7	2040 $\pm$ 35		2141 $\pm$ 76		2240 $\pm$ 70	
grh-25	0.19	n.d	0.1436 $\pm$ 0.0015		0.3930 $\pm$ 0.0071		7.781 $\pm$ 0.161		-3.5	2137 $\pm$ 38		2206 $\pm$ 46		2272 $\pm$ 23	
grh-27	0.34	0.09	0.1578 $\pm$ 0.0042		0.4227 $\pm$ 0.0231		9.199 $\pm$ 0.559			2273 $\pm$ 124		2358 $\pm$ 143		2433 $\pm$ 65	
grh-96	0.58	n.d	0.1595 $\pm$ 0.0040		0.4482 $\pm$ 0.0104		9.857 $\pm$ 0.334			2387 $\pm$ 55		2421 $\pm$ 82		2451 $\pm$ 61	
<i>Northern Hasandong Fm. (n=74)</i>															
hsd1-94	1.26	n.d	0.0483 $\pm$ 0.0058		0.0261 $\pm$ 0.001		0.174 $\pm$ 0.0			166.3 $\pm$ 5.3		162.8 $\pm$ 20.3		112 $\pm$ 13.5	
hsd1-87	2.25	n.d	0.0553 $\pm$ 0.0056		0.0267 $\pm$ 0.0008		0.203 $\pm$ 0.021			169.7 $\pm$ 5.4		188.0 $\pm$ 19.8		425 $\pm$ 42.7	
hsd1-76	0.42	n.d	0.0529 $\pm$ 0.0015		0.0271 $\pm$ 0.0006		0.198 $\pm$ 0.007		-0.3	172.2 $\pm$ 3.8		183.0 $\pm$ 6.5		326 $\pm$ 9.2	
hsd1-88	0.41	n.d	0.0495 $\pm$ 0.0013		0.0271 $\pm$ 0.0007		0.185 $\pm$ 0.007			172.2 $\pm$ 4.4		172.3 $\pm$ 6.3		174 $\pm$ 4.5	
hsd1-46	0.68	0.85	0.0542 $\pm$ 0.0021		0.0271 $\pm$ 0.0014		0.202 $\pm$ 0.013			172.2 $\pm$ 8.9		187.1 $\pm$ 12.0		379 $\pm$ 14.6	
hsd1-81	1.29	n.d	0.0444 $\pm$ 0.0026		0.0273 $\pm$ 0.0007		0.167 $\pm$ 0.011			173.4 $\pm$ 4.1		156.9 $\pm$ 10.0			
hsd1-80	0.42	n.d	0.0504 $\pm$ 0.0013		0.0273 $\pm$ 0.0006		0.190 $\pm$ 0.006			173.7 $\pm$ 3.8		176.5 $\pm$ 5.8		214 $\pm$ 5.3	
hsd1-93	0.31	n.d	0.0570 $\pm$ 0.0015		0.0273 $\pm$ 0.001		0.215 $\pm$ 0.0		-6.9	173.8 $\pm$ 4.5		197.5 $\pm$ 7.2		492 $\pm$ 12.8	
hsd1-97	0.13	n.d	0.0500 $\pm$ 0.0013		0.0274 $\pm$ 0.001		0.189 $\pm$ 0.0			174.0 $\pm$ 4.5		175.5 $\pm$ 6.5		196 $\pm$ 5.2	
hsd1-85	0.44	n.d	0.0507 $\pm$ 0.0012		0.0275 $\pm$ 0.0007		0.192 $\pm$ 0.007			175.0 $\pm$ 4.4		178.6 $\pm$ 6.1		227 $\pm$ 5.3	
hsd1-90	0.32	n.d	0.0498 $\pm$ 0.0013		0.0276 $\pm$ 0.0007		0.189 $\pm$ 0.007			175.4 $\pm$ 4.5		176.2 $\pm$ 6.5		188 $\pm$ 5.0	
hsd1-73	0.50	n.d	0.0512 $\pm$ 0.0014		0.0276 $\pm$ 0.0006		0.195 $\pm$ 0.007			175.4 $\pm$ 3.8		180.5 $\pm$ 6.4		249 $\pm$ 6.9	
hsd1-75	0.67	n.d	0.0552 $\pm$ 0.0013		0.0277 $\pm$ 0.0006		0.210 $\pm$ 0.007		-4.6	175.9 $\pm$ 3.8		193.9 $\pm$ 6.2		421 $\pm$ 9.8	
hsd1-36	0.36	n.d	0.0504 $\pm$ 0.0017		0.0277 $\pm$ 0.0014		0.193 $\pm$ 0.012			176.2 $\pm$ 8.8		178.9 $\pm$ 10.8		215 $\pm$ 7.4	
hsd1-37	0.46	n.d	0.0488 $\pm$ 0.0014		0.0278 $\pm$ 0.0014		0.187 $\pm$ 0.011			176.8 $\pm$ 8.8		174.2 $\pm$ 10.1		139 $\pm$ 4.1	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ ^(a) (%)	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2 σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	Disc ^(b) (%)	^{238}U - ^{206}Pb age (Ma)	Error 2 σ	^{235}U - ^{207}Pb age (Ma)	Error 2 σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2 σ
hsd1-62	0.52	0.57	0.0478 ± 0.0013		0.0280 ± 0.0005		0.185 ± 0.006			178.2 ± 3.1		172.0 ± 5.5		88 ± 2.4	
hsd1-64	0.45	n.d	0.0536 ± 0.0015		0.0280 ± 0.0005		0.207 ± 0.007		-2.0	178.3 ± 3.1		191.3 ± 6.3		355 ± 9.9	
hsd1-92	0.15	n.d	0.0494 ± 0.0021		0.0281 ± 0.001		0.191 ± 0.0			178.6 ± 4.8		177.7 ± 9.0		167 ± 7.2	
hsd1-61	0.46	n.d	0.0514 ± 0.0013		0.0284 ± 0.0010		0.201 ± 0.009			180.3 ± 6.5		186.1 ± 8.3		261 ± 6.8	
hsd1-52	0.64	n.d	0.0470 ± 0.0025		0.0284 ± 0.0015		0.184 ± 0.014			180.4 ± 9.4		171.4 ± 12.8		50 ± 2.7	
hsd1-9	0.69	n.d	0.0507 ± 0.0017		0.0286 ± 0.0007		0.200 ± 0.008			181.7 ± 4.5		185.0 ± 7.6		227 ± 7.5	
hsd1-68	0.40	0.01	0.0521 ± 0.0017		0.0287 ± 0.0005		0.206 ± 0.008			182.2 ± 3.2		190.2 ± 6.9		292 ± 9.3	
hsd1-14	0.60	n.d	0.0493 ± 0.0014		0.0287 ± 0.0007		0.195 ± 0.007			182.6 ± 4.5		181.1 ± 6.7		163 ± 4.5	
hsd1-3	0.36	n.d	0.0536 ± 0.0010		0.0288 ± 0.0005		0.213 ± 0.006		-2.3	183.1 ± 3.3		195.9 ± 5.2		353 ± 6.8	
hsd1-15	0.35	n.d	0.0510 ± 0.0018		0.0290 ± 0.0007		0.204 ± 0.009			184.3 ± 4.6		188.5 ± 8.1		242 ± 8.4	
hsd1-57	0.45	n.d	0.0531 ± 0.0012		0.0290 ± 0.0011		0.212 ± 0.009			184.4 ± 6.7		195.6 ± 8.4		333 ± 7.7	
hsd1-34	0.44	n.d	0.0503 ± 0.0017		0.0290 ± 0.0014		0.201 ± 0.012			184.5 ± 9.2		186.3 ± 11.2		211 ± 7.0	
hsd1-4	0.54	0.52	0.0498 ± 0.0011		0.0291 ± 0.0005		0.199 ± 0.006			184.6 ± 3.4		184.6 ± 5.2		184 ± 3.9	
hsd1-53	0.50	n.d	0.0551 ± 0.0020		0.0291 ± 0.0015		0.221 ± 0.014			184.9 ± 9.5		202.9 ± 12.8		418 ± 15.2	
hsd1-72	0.55	n.d	0.0503 ± 0.0022		0.0291 ± 0.0007		0.202 ± 0.010			184.9 ± 4.2		186.6 ± 9.2		208 ± 9.1	
hsd1-8	0.33	n.d	0.0507 ± 0.0013		0.0292 ± 0.0007		0.204 ± 0.007			185.7 ± 4.6		188.9 ± 6.7		230 ± 5.8	
hsd1-95	0.51	0.40	0.0494 ± 0.0018		0.0293 ± 0.001		0.200 ± 0.0			186.3 ± 4.9		184.8 ± 8.2		165 ± 5.9	
hsd1-31	0.48	0.53	0.0453 ± 0.0012		0.0294 ± 0.0015		0.184 ± 0.010			186.9 ± 9.3		171.3 ± 9.7			
hsd1-23	1.01	0.50	0.0541 ± 0.0014		0.0294 ± 0.0010		0.219 ± 0.010			187.0 ± 6.6		201.4 ± 8.9		375 ± 10.0	
hsd1-42	0.32	n.d	0.0508 ± 0.0014		0.0295 ± 0.0012		0.206 ± 0.010			187.2 ± 7.8		190.4 ± 9.5		232 ± 6.2	
hsd1-12	0.28	n.d	0.0496 ± 0.0012		0.0295 ± 0.0007		0.202 ± 0.007			187.2 ± 4.6		186.5 ± 6.5		179 ± 4.4	
hsd1-7	0.33	n.d	0.0501 ± 0.0012		0.0296 ± 0.0005		0.204 ± 0.006			187.8 ± 3.5		188.6 ± 5.6		200 ± 4.6	
hsd1-20	0.36	n.d	0.0511 ± 0.0013		0.0296 ± 0.0010		0.209 ± 0.009			188.1 ± 6.6		192.3 ± 8.3		245 ± 6.1	
hsd1-26	0.19	n.d	0.0495 ± 0.0009		0.0297 ± 0.0010		0.203 ± 0.008			188.8 ± 6.6		187.5 ± 7.4		173 ± 3.1	
hsd1-29	0.73	n.d	0.0521 ± 0.0034		0.0299 ± 0.0015		0.215 ± 0.018			190.2 ± 9.6		197.7 ± 16.4		289 ± 19.0	
hsd1-25	0.59	0.08	0.0504 ± 0.0016		0.0301 ± 0.0011		0.209 ± 0.010			191.2 ± 6.8		193.0 ± 9.2		215 ± 6.8	
hsd1-32	0.52	n.d	0.0503 ± 0.0026		0.0303 ± 0.0015		0.210 ± 0.015			192.5 ± 9.6		193.9 ± 13.9		210 ± 10.7	
hsd1-33	0.64	n.d	0.0657 ± 0.0035		0.0307 ± 0.0015		0.278 ± 0.020		-13.3	194.7 ± 9.8		248.8 ± 18.3		796 ± 42.8	
hsd1-35	1.14	n.d	0.0507 ± 0.0029		0.0332 ± 0.0017		0.232 ± 0.018			210.4 ± 10.6		211.6 ± 16.0		226 ± 12.8	
hsd1-77	1.35	n.d	0.0527 ± 0.0018		0.0334 ± 0.0007		0.242 ± 0.010			211.7 ± 4.7		220.5 ± 8.9		315 ± 10.6	
hsd1-24	1.28	n.d	0.0584 ± 0.0031		0.0344 ± 0.0013		0.277 ± 0.018		-2.9	218.1 ± 8.0		248.2 ± 15.9		544 ± 28.7	
hsd1-99	0.33	0.65	0.0590 ± 0.0011		0.0344 ± 0.001		0.280 ± 0.0		-8.6	218.1 ± 5.6		250.5 ± 8.0		566 ± 10.9	
hsd1-6	0.61	n.d	0.0512 ± 0.0021		0.0347 ± 0.0007		0.245 ± 0.011			220.1 ± 4.3		222.8 ± 10.3		252 ± 10.5	
hsd1-83	0.55	3.44	0.0462 ± 0.0009		0.0348 ± 0.0009		0.221 ± 0.007			220.6 ± 5.6		203.1 ± 6.5		6 ± 0.1	
hsd1-82	1.15	0.16	0.0528 ± 0.0011		0.0352 ± 0.0009		0.256 ± 0.008			222.8 ± 5.6		231.3 ± 7.5		320 ± 6.6	
hsd1-96	1.38	n.d	0.0547 ± 0.0016		0.0354 ± 0.001		0.267 ± 0.0		-0.4	224.4 ± 5.8		240.4 ± 9.3		400 ± 11.6	
hsd1-44	1.92	n.d	0.0536 ± 0.0014		0.0359 ± 0.0015		0.266 ± 0.013			227.5 ± 9.5		239.3 ± 11.7		357 ± 9.0	
hsd1-39	0.54	n.d	0.0520 ± 0.0012		0.0359 ± 0.0015		0.258 ± 0.012			227.6 ± 9.5		232.8 ± 11.2		286 ± 6.7	
hsd1-60	0.36	n.d	0.0515 ± 0.0015		0.0359 ± 0.0013		0.255 ± 0.012			227.7 ± 8.3		230.8 ± 10.6		263 ± 7.4	
hsd1-91	1.24	n.d	0.0502 ± 0.0014		0.0360 ± 0.0009		0.250 ± 0.010			228.1 ± 5.9		226.2 ± 8.7		206 ± 5.9	
hsd1-22	0.91	n.d	0.0513 ± 0.0014		0.0369 ± 0.0013		0.261 ± 0.012			233.6 ± 8.3		235.4 ± 10.5		254 ± 6.8	
hsd1-2	1.25	n.d	0.0500 ± 0.0009		0.0372 ± 0.0007		0.256 ± 0.007			235.3 ± 4.3		231.6 ± 5.9		195 ± 3.5	
hsd1-43	0.15	n.d	0.0517 ± 0.0013		0.0373 ± 0.0016		0.266 ± 0.013			235.9 ± 9.9		239.2 ± 11.7		272 ± 6.9	
hsd1-56	0.55	0.96	0.0544 ± 0.0011		0.0374 ± 0.0014		0.280 ± 0.012			236.5 ± 8.5		250.7 ± 10.3		387 ± 7.6	
hsd1-41	0.92	n.d	0.0649 ± 0.0014		0.0388 ± 0.0016		0.347 ± 0.016		-13.2	245.5 ± 10.3		302.6 ± 14.3		770 ± 16.8	
hsd1-47	0.57	0.04	0.1154 ± 0.0033		0.2959 ± 0.0151		4.708 ± 0.276		-4.5	1671 ± 85		1769 ± 104		1886 ± 54	
hsd1-28	0.78	0.21	0.1266 ± 0.0018		0.3032 ± 0.0150		5.293 ± 0.272		-13.6	1707 ± 85		1868 ± 96		2052 ± 28	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ (%)	$^{207}\text{Pb}/^{235}\text{U}$	Error 2σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2σ	Disc (%)	^{238}U - ^{206}Pb age (Ma)	Error 2σ	^{235}U - ^{207}Pb age (Ma)	Error 2σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2σ
hsd1-40	0.52	0.10	0.1270 ± 0.0019		0.3073 ± 0.0128		5.379 ± 0.239		-13.1	1727 ± 72		1881 ± 84		2057 ± 31	
hsd1-55	0.19	1.28	0.1144 ± 0.0019		0.3101 ± 0.0112		4.893 ± 0.195		-2.1	1741 ± 63		1801 ± 72		1872 ± 31	
hsd1-70	1.98	n.d	0.1144 ± 0.0027		0.3188 ± 0.0054		5.030 ± 0.145		-0.8	1784 ± 30		1824 ± 52		1872 ± 43	
hsd1-13	0.36	n.d	0.1158 ± 0.0018		0.3249 ± 0.0079		5.188 ± 0.151		-0.3	1814 ± 44		1851 ± 54		1893 ± 30	
hsd1-18	0.29	n.d	0.1248 ± 0.0018		0.3383 ± 0.0119		5.823 ± 0.221		-2.8	1878 ± 66		1950 ± 74		2027 ± 30	
hsd1-58	0.05	0.20	0.1213 ± 0.0021		0.3386 ± 0.0122		5.665 ± 0.226			1880 ± 68		1926 ± 77		1977 ± 34	
hsd1-66	0.23	n.d	0.1330 ± 0.0029		0.3485 ± 0.0059		6.389 ± 0.177		-6.8	1927 ± 32		2031 ± 56		2138 ± 47	
hsd1-19	0.14	n.d	0.1220 ± 0.0017		0.3500 ± 0.0123		5.890 ± 0.223			1935 ± 68		1960 ± 74		1987 ± 28	
hsd1-71	0.37	n.d	0.1385 ± 0.0031		0.3535 ± 0.0060		6.749 ± 0.190		-9.0	1951 ± 33		2079 ± 58		2209 ± 50	
hsd1-1	0.90	0.21	0.1662 ± 0.0018		0.4135 ± 0.0075		9.477 ± 0.200		-9.9	2231 ± 40		2385 ± 50		2520 ± 27	
hsd1-10	1.26	n.d	0.1625 ± 0.0024		0.4927 ± 0.0120		11.043 ± 0.313			2582 ± 63		2527 ± 72		2483 ± 36	
hsd1-5	0.64	0.45	0.2724 ± 0.0028		0.7223 ± 0.0132		27.132 ± 0.569			3505 ± 64		3388 ± 71		3321 ± 34	
<i>Southern Jinju Fm. (n=79)</i>															
jj1-35	1.31	n.d	0.0499 ± 0.0028		0.0171 ± 0.0007		0.118 ± 0.008			109.4 ± 4.3		113.0 ± 7.8		190 ± 10.8	
jj1-50	1.64	n.d	0.0464 ± 0.0030		0.0171 ± 0.0007		0.110 ± 0.008			109.5 ± 4.2		105.6 ± 7.9		19 ± 1.2	
jj1-18	1.08	n.d	0.0492 ± 0.0017		0.0176 ± 0.0006		0.120 ± 0.006			112.7 ± 4.0		114.7 ± 5.7		157 ± 5.5	
jj1-9	1.26	n.d	0.0490 ± 0.0024		0.0180 ± 0.0006		0.121 ± 0.007			114.7 ± 3.5		116.2 ± 6.7		148 ± 7.2	
jj1-6	0.25	n.d	0.0501 ± 0.0016		0.0180 ± 0.0002		0.124 ± 0.004			115.1 ± 1.6		119.1 ± 4.0		201 ± 6.2	
jj1-38	2.09	2.26	0.0479 ± 0.0020		0.0180 ± 0.0011		0.119 ± 0.009			115.2 ± 6.9		114.3 ± 8.4		95 ± 4.0	
jj1-96	1.35	n.d	0.0524 ± 0.0017		0.0183 ± 0.0009		0.132 ± 0.008			116.7 ± 5.9		125.9 ± 7.6		304 ± 10.0	
jj1-52	1.31	n.d	0.0508 ± 0.0057		0.0184 ± 0.0008		0.129 ± 0.015			117.6 ± 4.9		123.2 ± 14.7		233 ± 26.1	
jj1-13	1.54	n.d	0.0450 ± 0.0046		0.0190 ± 0.0007		0.118 ± 0.013			121.2 ± 4.2		113.0 ± 12.3			
jj1-91	1.93	n.d	0.0514 ± 0.0017		0.0192 ± 0.0009		0.136 ± 0.008			122.5 ± 5.9		129.5 ± 7.6		260 ± 8.6	
jj1-82	1.16	n.d	0.0567 ± 0.0031		0.0194 ± 0.0010		0.151 ± 0.012		-1.3	123.8 ± 6.7		143.2 ± 11.1		478 ± 26.4	
jj1-100	1.62	n.d	0.0639 ± 0.0034		0.0210 ± 0.0011		0.185 ± 0.014		-14.0	133.8 ± 6.9		172.2 ± 12.8		739 ± 39.8	
jj1-89	0.34	n.d	0.0496 ± 0.0021		0.0244 ± 0.0012		0.167 ± 0.011			155.6 ± 7.5		157.0 ± 10.1		178 ± 7.6	
jj1-81	0.38	n.d	0.0518 ± 0.0017		0.0256 ± 0.0014		0.183 ± 0.011			163.2 ± 8.7		170.7 ± 10.6		277 ± 9.1	
jj1-41	1.48	n.d	0.0493 ± 0.0020		0.0266 ± 0.0016		0.181 ± 0.013			169.1 ± 10.1		168.7 ± 12.2		164 ± 6.5	
jj1-25	0.79	n.d	0.0471 ± 0.0017		0.0276 ± 0.0010		0.179 ± 0.009			175.7 ± 6.3		167.5 ± 8.5		53 ± 1.9	
jj1-16	0.42	n.d	0.0484 ± 0.0016		0.0286 ± 0.0009		0.191 ± 0.008			181.6 ± 5.4		177.1 ± 7.9		118 ± 3.9	
jj1-63	0.33	n.d	0.0507 ± 0.0013		0.0337 ± 0.0009		0.236 ± 0.009			213.7 ± 5.8		214.8 ± 8.0		227 ± 5.8	
jj1-19	2.13	n.d	0.0496 ± 0.0017		0.0353 ± 0.0013		0.242 ± 0.012			223.8 ± 7.9		219.8 ± 10.7		178 ± 6.0	
jj1-98	0.48	0.90	0.0535 ± 0.0017		0.0354 ± 0.0018		0.261 ± 0.016			224.4 ± 11.3		235.6 ± 14.0		349 ± 11.0	
jj1-2	1.06	n.d	0.0522 ± 0.0024		0.0359 ± 0.0006		0.258 ± 0.013			227.6 ± 3.5		233.4 ± 11.4		293 ± 13.5	
jj1-86	0.41	n.d	0.0563 ± 0.0026		0.0457 ± 0.0022		0.355 ± 0.024			288.3 ± 14.0		308.6 ± 20.6		465 ± 21.3	
jj1-23	0.80	n.d	0.0503 ± 0.0017		0.0508 ± 0.0018		0.352 ± 0.017			319.3 ± 11.3		306.1 ± 14.8		208 ± 6.9	
jj1-3	0.68	n.d	0.0500 ± 0.0011		0.0511 ± 0.0007		0.352 ± 0.009			321.5 ± 4.1		306.5 ± 7.6		195 ± 4.1	
jj1-60	0.73	n.d	0.0552 ± 0.0020		0.0672 ± 0.0019		0.511 ± 0.024			419.2 ± 11.7		419.2 ± 19.3		420 ± 15.4	
jj1-40	1.07	n.d	0.0649 ± 0.0024		0.1121 ± 0.0067		1.002 ± 0.071			684.7 ± 41.1		705.0 ± 49.8		771 ± 28.6	
jj1-32	1.05	0.01	0.0665 ± 0.0015		0.1166 ± 0.0044		1.069 ± 0.047			711.0 ± 27.0		738.2 ± 32.5		822 ± 18.4	
jj1-72	0.97	n.d	0.0675 ± 0.0011		0.1205 ± 0.0042		1.122 ± 0.043			733.5 ± 25.7		764.0 ± 29.4		855 ± 13.5	
jj1-73	0.66	n.d	0.0633 ± 0.0022		0.1244 ± 0.0045		1.086 ± 0.054			755.9 ± 27.1		746.7 ± 37.4		720 ± 25.2	
jj1-4	1.48	n.d	0.0677 ± 0.0011		0.1321 ± 0.0016		1.233 ± 0.025			799.9 ± 9.9		815.8 ± 16.2		860 ± 13.4	
jj1-74	1.53	n.d	0.0635 ± 0.0019		0.1326 ± 0.0047		1.161 ± 0.054			802.9 ± 28.6		782.3 ± 36.5		725 ± 21.8	
jj1-42	0.68	n.d	0.0675 ± 0.0014		0.1399 ± 0.0083		1.302 ± 0.082			844.3 ± 50.3		846.8 ± 53.3		854 ± 17.4	
jj1-55	0.12	n.d	0.0736 ± 0.0014		0.1447 ± 0.0054		1.468 ± 0.061			871.2 ± 32.2		917.1 ± 38.1		1030 ± 20	
jj1-61	0.23	n.d	0.0809 ± 0.0016		0.1745 ± 0.0048		1.947 ± 0.066		-12.7	1037 ± 28		1097 ± 37		1221 ± 24	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	Error 2 σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2 σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	Disc (%)	^{238}U - ^{206}Pb age (Ma)	Error 2 σ	^{235}U - ^{207}Pb age (Ma)	Error 2 σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2 σ
jj1-21	0.92	n.d	0.0716 $\pm$ 0.0014		0.1764 $\pm$ 0.0062		1.742 $\pm$ 0.070			1047 $\pm$ 37		1024 $\pm$ 41		976 $\pm$ 20	
jj1-36	0.72	n.d	0.0821 $\pm$ 0.0018		0.1827 $\pm$ 0.0070		2.067 $\pm$ 0.090		-9.0	1081 $\pm$ 41		1138 $\pm$ 50		1247 $\pm$ 27	
jj1-65	0.68	n.d	0.0798 $\pm$ 0.0024		0.1902 $\pm$ 0.0053		2.091 $\pm$ 0.087		-0.1	1122 $\pm$ 31		1146 $\pm$ 47		1191 $\pm$ 36	
jj1-53	0.66	0.14	0.0800 $\pm$ 0.0015		0.1912 $\pm$ 0.0071		2.109 $\pm$ 0.088		-0.4	1128 $\pm$ 42		1152 $\pm$ 48		1197 $\pm$ 23	
jj1-30	0.58	0.44	0.0744 $\pm$ 0.0022		0.1939 $\pm$ 0.0075		1.989 $\pm$ 0.096			1142 $\pm$ 44		1112 $\pm$ 54		1053 $\pm$ 31	
jj1-10	0.92	n.d	0.0798 $\pm$ 0.0022		0.2150 $\pm$ 0.0064		2.367 $\pm$ 0.096			1255 $\pm$ 38		1233 $\pm$ 50		1193 $\pm$ 32	
jj1-94	0.95	n.d	0.0912 $\pm$ 0.0014		0.2283 $\pm$ 0.0114		2.870 $\pm$ 0.150		-2.7	1326 $\pm$ 66		1374 $\pm$ 72		1450 $\pm$ 23	
jj1-64	0.76	n.d	0.0971 $\pm$ 0.0016		0.2535 $\pm$ 0.0069		3.394 $\pm$ 0.107		-3.3	1457 $\pm$ 39		1503 $\pm$ 47		1570 $\pm$ 25	
jj1-99	1.02	n.d	0.1133 $\pm$ 0.0012		0.2805 $\pm$ 0.0140		4.380 $\pm$ 0.224		-10.0	1594 $\pm$ 80		1709 $\pm$ 87		1853 $\pm$ 20	
jj1-34	0.17	0.16	0.1129 $\pm$ 0.0017		0.2885 $\pm$ 0.0109		4.490 $\pm$ 0.182		-7.6	1634 $\pm$ 62		1729 $\pm$ 70		1847 $\pm$ 28	
jj1-79	0.60	0.19	0.1125 $\pm$ 0.0020		0.2895 $\pm$ 0.0153		4.490 $\pm$ 0.251		-5.0	1639 $\pm$ 87		1729 $\pm$ 97		1841 $\pm$ 33	
jj1-24	0.87	n.d	0.1134 $\pm$ 0.0021		0.2908 $\pm$ 0.0102		4.547 $\pm$ 0.179		-7.3	1645 $\pm$ 58		1740 $\pm$ 69		1856 $\pm$ 34	
jj1-57	0.42	n.d	0.1135 $\pm$ 0.0017		0.2916 $\pm$ 0.0079		4.562 $\pm$ 0.142		-8.1	1649 $\pm$ 45		1742 $\pm$ 54		1856 $\pm$ 28	
jj1-48	0.77	n.d	0.1059 $\pm$ 0.0034		0.2988 $\pm$ 0.0114		4.365 $\pm$ 0.219			1685 $\pm$ 64		1706 $\pm$ 85		1731 $\pm$ 56	
jj1-77	0.70	0.13	0.1123 $\pm$ 0.0018		0.2988 $\pm$ 0.0158		4.628 $\pm$ 0.255		-2.0	1686 $\pm$ 89		1754 $\pm$ 97		1838 $\pm$ 29	
jj1-85	1.05	n.d	0.1156 $\pm$ 0.0027		0.3020 $\pm$ 0.0145		4.813 $\pm$ 0.257		-3.6	1701 $\pm$ 82		1787 $\pm$ 95		1889 $\pm$ 45	
jj1-80	0.54	0.05	0.1214 $\pm$ 0.0019		0.3057 $\pm$ 0.0161		5.117 $\pm$ 0.282		-7.9	1720 $\pm$ 91		1839 $\pm$ 101		1977 $\pm$ 31	
jj1-70	0.57	n.d	0.1167 $\pm$ 0.0016		0.3059 $\pm$ 0.0107		4.922 $\pm$ 0.185		-5.8	1721 $\pm$ 60		1806 $\pm$ 68		1907 $\pm$ 26	
jj1-59	0.41	0.03	0.1146 $\pm$ 0.0018		0.3074 $\pm$ 0.0083		4.856 $\pm$ 0.153		-4.0	1728 $\pm$ 47		1795 $\pm$ 57		1874 $\pm$ 30	
jj1-27	0.83	n.d	0.1134 $\pm$ 0.0022		0.3124 $\pm$ 0.0110		4.883 $\pm$ 0.196		-0.3	1752 $\pm$ 62		1799 $\pm$ 72		1855 $\pm$ 36	
jj1-75	0.69	n.d	0.1147 $\pm$ 0.0015		0.3126 $\pm$ 0.0109		4.943 $\pm$ 0.184		-2.1	1754 $\pm$ 61		1810 $\pm$ 67		1875 $\pm$ 24	
jj1-33	0.44	n.d	0.1156 $\pm$ 0.0019		0.3129 $\pm$ 0.0119		4.987 $\pm$ 0.206		-2.1	1755 $\pm$ 66		1817 $\pm$ 75		1889 $\pm$ 31	
jj1-47	0.86	0.03	0.1163 $\pm$ 0.0021		0.3169 $\pm$ 0.0117		5.081 $\pm$ 0.209		-1.5	1775 $\pm$ 66		1833 $\pm$ 75		1900 $\pm$ 34	
jj1-95	0.49	n.d	0.1166 $\pm$ 0.0012		0.3185 $\pm$ 0.0159		5.118 $\pm$ 0.260		-0.8	1782 $\pm$ 89		1839 $\pm$ 94		1905 $\pm$ 19	
jj1-17	0.46	0.03	0.1134 $\pm$ 0.0019		0.3240 $\pm$ 0.0095		5.068 $\pm$ 0.170			1809 $\pm$ 53		1831 $\pm$ 62		1856 $\pm$ 31	
jj1-22	0.23	n.d	0.1133 $\pm$ 0.0021		0.3279 $\pm$ 0.0115		5.123 $\pm$ 0.202			1828 $\pm$ 64		1840 $\pm$ 73		1854 $\pm$ 34	
jj1-49	0.77	n.d	0.1201 $\pm$ 0.0022		0.3312 $\pm$ 0.0122		5.482 $\pm$ 0.226		-0.6	1844 $\pm$ 68		1898 $\pm$ 78		1958 $\pm$ 35	
jj1-54	0.19	n.d	0.1397 $\pm$ 0.0025		0.3318 $\pm$ 0.0123		6.389 $\pm$ 0.262		-14.5	1847 $\pm$ 68		2031 $\pm$ 83		2223 $\pm$ 39	
jj1-45	0.41	0.03	0.1244 $\pm$ 0.0018		0.3329 $\pm$ 0.0198		5.708 $\pm$ 0.349		-1.5	1852 $\pm$ 110		1933 $\pm$ 118		2020 $\pm$ 29	
jj1-97	0.70	n.d	0.1147 $\pm$ 0.0011		0.3332 $\pm$ 0.0166		5.271 $\pm$ 0.268			1854 $\pm$ 92		1864 $\pm$ 95		1876 $\pm$ 18	
jj1-44	0.60	0.04	0.1131 $\pm$ 0.0018		0.3355 $\pm$ 0.0200		5.235 $\pm$ 0.323			1865 $\pm$ 111		1858 $\pm$ 115		1851 $\pm$ 30	
jj1-51	0.63	0.13	0.1200 $\pm$ 0.0026		0.3362 $\pm$ 0.0125		5.563 $\pm$ 0.240			1868 $\pm$ 70		1910 $\pm$ 82		1957 $\pm$ 42	
jj1-71	0.11	n.d	0.1405 $\pm$ 0.0018		0.3381 $\pm$ 0.0118		6.547 $\pm$ 0.244		-13.9	1877 $\pm$ 66		2052 $\pm$ 77		2233 $\pm$ 29	
jj1-11	0.18	0.32	0.1119 $\pm$ 0.0019		0.3411 $\pm$ 0.0100		5.263 $\pm$ 0.177			1892 $\pm$ 55		1863 $\pm$ 63		1831 $\pm$ 30	
jj1-84	0.70	0.09	0.1400 $\pm$ 0.0031		0.3476 $\pm$ 0.0166		6.711 $\pm$ 0.353		-8.6	1923 $\pm$ 92		2074 $\pm$ 109		2228 $\pm$ 49	
jj1-37	0.33	n.d	0.1338 $\pm$ 0.0020		0.3489 $\pm$ 0.0132		6.436 $\pm$ 0.261		-6.0	1929 $\pm$ 73		2037 $\pm$ 83		2149 $\pm$ 32	
jj1-43	1.82	0.01	0.1136 $\pm$ 0.0018		0.3507 $\pm$ 0.0209		5.492 $\pm$ 0.338			1938 $\pm$ 115		1899 $\pm$ 117		1858 $\pm$ 29	
jj1-39	0.23	0.15	0.1311 $\pm$ 0.0019		0.3593 $\pm$ 0.0214		6.496 $\pm$ 0.398			1979 $\pm$ 118		2045 $\pm$ 125		2113 $\pm$ 31	
jj1-78	0.97	0.02	0.1275 $\pm$ 0.0021		0.3647 $\pm$ 0.0193		6.411 $\pm$ 0.355			2005 $\pm$ 106		2034 $\pm$ 113		2064 $\pm$ 34	
jj1-69	0.45	n.d	0.1583 $\pm$ 0.0024		0.3743 $\pm$ 0.0132		8.169 $\pm$ 0.314		-13.6	2049 $\pm$ 72		2250 $\pm$ 86		2438 $\pm$ 38	
jj1-46	0.50	0.02	0.1574 $\pm$ 0.0027		0.3838 $\pm$ 0.0142		8.328 $\pm$ 0.340		-10.2	2094 $\pm$ 77		2267 $\pm$ 92		2428 $\pm$ 42	
jj1-68	0.49	0.01	0.1575 $\pm$ 0.0022		0.4072 $\pm$ 0.0143		8.843 $\pm$ 0.333		-5.3	2202 $\pm$ 77		2322 $\pm$ 87		2430 $\pm$ 33	
jj1-5	0.69	0.03	0.1517 $\pm$ 0.0023		0.4086 $\pm$ 0.0052		8.546 $\pm$ 0.169		-4.2	2209 $\pm$ 28		2291 $\pm$ 45		2365 $\pm$ 36	
jj1-12	0.43	0.18	0.1522 $\pm$ 0.0028		0.4113 $\pm$ 0.0121		8.630 $\pm$ 0.298		-1.9	2221 $\pm$ 65		2300 $\pm$ 79		2371 $\pm$ 43	
jj1-28	2.10	n.d	0.1584 $\pm$ 0.0030		0.4366 $\pm$ 0.0167		9.538 $\pm$ 0.407			2336 $\pm$ 89		2391 $\pm$ 102		2440 $\pm$ 47	
<i>Central Jinju Fm. (n=79)</i>															
jj2-70	0.81	n.d	0.0554 $\pm$ 0.0052		0.0166 $\pm$ 0.0006		0.127 $\pm$ 0.013			106.2 $\pm$ 3.7		121.3 $\pm$ 12.2		430 $\pm$ 40.6	
jj2-87	1.26	n.d	0.0545 $\pm$ 0.0035		0.0171 $\pm$ 0.0006		0.128 $\pm$ 0.009		-0.4	109.0 $\pm$ 4.0		122.5 $\pm$ 9.1		394 $\pm$ 25.4	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ (%)	$^{207}\text{Pb}/^{206}\text{Pb}$	Error 2σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2σ	Disc (%)	^{238}U - ^{206}Pb age (Ma)	Error 2σ	^{235}U - ^{207}Pb age (Ma)	Error 2σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2σ
jj2-74	2.13	n.d	0.0494 ± 0.0040		0.0173 ± 0.0004		0.118 ± 0.010			110.5 ± 2.9		113.1 ± 9.6		169 ± 13.7	
jj2-51	1.19	n.d	0.0480 ± 0.0025		0.0180 ± 0.0007		0.119 ± 0.008			115.0 ± 4.6		114.3 ± 7.6		99 ± 5.3	
jj2-98	0.99	0.24	0.0483 ± 0.0027		0.0181 ± 0.0008		0.120 ± 0.009			115.6 ± 5.1		115.4 ± 8.2		113 ± 6.3	
jj2-58	1.04	n.d	0.0495 ± 0.0040		0.0181 ± 0.0007		0.124 ± 0.011			115.8 ± 4.7		118.4 ± 10.8		172 ± 14.0	
jj2-43	2.05	n.d	0.0573 ± 0.0053		0.0187 ± 0.0006		0.148 ± 0.015		-2.3	119.6 ± 4.0		140.2 ± 13.8		505 ± 46.8	
jj2-41	1.05	n.d	0.0505 ± 0.0039		0.0190 ± 0.0006		0.132 ± 0.011			121.3 ± 3.9		126.1 ± 10.6		218 ± 16.9	
jj2-26	2.13	n.d	0.0516 ± 0.0038		0.0195 ± 0.0007		0.139 ± 0.011			124.6 ± 4.4		132.0 ± 10.8		269 ± 19.8	
jj2-83	0.92	n.d	0.0514 ± 0.0021		0.0199 ± 0.0007		0.141 ± 0.008			126.8 ± 4.4		133.7 ± 7.2		260 ± 10.8	
jj2-94	0.36	n.d	0.0506 ± 0.0016		0.0263 ± 0.0011		0.183 ± 0.010			167.3 ± 7.1		170.9 ± 9.1		221 ± 7.0	
jj2-49	1.37	n.d	0.0528 ± 0.0031		0.0268 ± 0.0011		0.195 ± 0.014			170.7 ± 6.8		181.0 ± 12.8		319 ± 18.5	
jj2-92	0.27	n.d	0.0543 ± 0.0020		0.0269 ± 0.0009		0.202 ± 0.010			171.3 ± 5.9		186.6 ± 9.4		385 ± 14.2	
jj2-34	1.35	n.d	0.0552 ± 0.0023		0.0284 ± 0.0009		0.216 ± 0.011		-1.4	180.4 ± 5.5		198.7 ± 10.3		423 ± 17.6	
jj2-75	1.04	n.d	0.0504 ± 0.0045		0.0349 ± 0.0009		0.242 ± 0.022			220.9 ± 6.0		220.4 ± 20.4		215 ± 19.0	
jj2-50	0.67	n.d	0.0468 ± 0.0022		0.0351 ± 0.0014		0.227 ± 0.014			222.2 ± 8.8		207.3 ± 12.7		42 ± 2.0	
jj2-38	1.32	n.d	0.0509 ± 0.0014		0.0351 ± 0.0010		0.246 ± 0.010			222.4 ± 6.5		223.4 ± 9.1		235 ± 6.6	
jj2-44	0.71	n.d	0.0552 ± 0.0018		0.0355 ± 0.0011		0.270 ± 0.012		-0.3	225.1 ± 6.7		242.9 ± 10.6		419 ± 13.3	
jj2-32	0.06	n.d	0.0533 ± 0.0021		0.0390 ± 0.0012		0.286 ± 0.014			246.5 ± 7.5		255.6 ± 12.6		341 ± 13.2	
jj2-86	0.86	n.d	0.0572 ± 0.0021		0.0609 ± 0.0021		0.480 ± 0.024			381.2 ± 13.1		398.1 ± 20.0		498 ± 18.3	
jj2-96	0.85	n.d	0.0513 ± 0.0035		0.0642 ± 0.0029		0.454 ± 0.037			400.9 ± 17.9		379.9 ± 30.7		254 ± 17.1	
jj2-9	1.02	n.d	0.0550 ± 0.0020		0.0643 ± 0.0036		0.488 ± 0.033			401.7 ± 22.4		403.3 ± 26.9		413 ± 15.2	
jj2-54	0.06	n.d	0.0562 ± 0.0014		0.0709 ± 0.0028		0.550 ± 0.026			441.7 ± 17.1		445.0 ± 20.7		463 ± 11.9	
jj2-85	0.89	n.d	0.0654 ± 0.0033		0.0861 ± 0.0031		0.777 ± 0.048			532.6 ± 19.0		583.6 ± 35.9		788 ± 39.5	
jj2-6	0.43	1.94	0.0660 ± 0.0008		0.0931 ± 0.0037		0.847 ± 0.035		-0.2	573.8 ± 22.6		622.9 ± 25.6		806 ± 9.4	
jj2-17	1.59	n.d	0.0696 ± 0.0017		0.1190 ± 0.0066		1.142 ± 0.069			724.8 ± 40.2		773.4 ± 46.8		917 ± 22.1	
jj2-95	1.25	n.d	0.0671 ± 0.0024		0.1357 ± 0.0058		1.255 ± 0.071			820.4 ± 35.3		825.6 ± 46.5		840 ± 30.4	
jj2-29	0.61	n.d	0.0732 ± 0.0025		0.1378 ± 0.0042		1.392 ± 0.064			832.5 ± 25.3		885.3 ± 40.6		1020 ± 35	
jj2-45	1.16	1.06	0.0845 ± 0.0023		0.1499 ± 0.0044		1.746 ± 0.070		-6.4	900.5 ± 26.6		1026 ± 41		1304 ± 36	
jj2-35	1.04	0.28	0.0714 ± 0.0017		0.1622 ± 0.0048		1.596 ± 0.061			968.9 ± 28.7		968.6 ± 37.2		969 ± 23.6	
jj2-30	0.48	n.d	0.0799 ± 0.0021		0.1662 ± 0.0050		1.831 ± 0.073			991.1 ± 29.6		1,056.7 ± 42.2		1195 ± 32	
jj2-19	0.71	n.d	0.0834 ± 0.0025		0.1923 ± 0.0063		2.210 ± 0.098		-6.1	1134 ± 37		1184 ± 52		1278 ± 38	
jj2-89	0.68	n.d	0.0805 ± 0.0023		0.1953 ± 0.0067		2.167 ± 0.097			1150 ± 39		1170 ± 53		1209 ± 35	
jj2-12	0.22	0.04	0.1140 ± 0.0015		0.2676 ± 0.0148		4.206 ± 0.238		-14.9	1529 ± 84		1675 ± 95		1865 ± 24	
jj2-3	0.54	n.d	0.1117 ± 0.0014		0.2702 ± 0.0106		4.161 ± 0.172		-13.0	1542 ± 61		1666 ± 69		1827 ± 23	
jj2-88	0.16	0.37	0.1165 ± 0.0020		0.2722 ± 0.0091		4.372 ± 0.166		-17.2	1552 ± 52		1707 ± 65		1904 ± 33	
jj2-97	0.09	0.08	0.1141 ± 0.0021		0.2735 ± 0.0116		4.303 ± 0.199		-13.3	1558 ± 66		1694 ± 78		1866 ± 35	
jj2-25	0.32	n.d	0.1131 ± 0.0023		0.2738 ± 0.0088		4.269 ± 0.161		-13.0	1560 ± 50		1687 ± 64		1850 ± 37	
jj2-60	0.23	0.10	0.1107 ± 0.0025		0.2741 ± 0.0103		4.182 ± 0.184		-9.6	1562 ± 59		1671 ± 74		1811 ± 41	
jj2-100	0.03	0.02	0.1140 ± 0.0021		0.2802 ± 0.0119		4.403 ± 0.204		-10.6	1592 ± 67		1713 ± 79		1864 ± 35	
jj2-55	0.19	n.d	0.1132 ± 0.0020		0.2819 ± 0.0109		4.399 ± 0.186		-9.8	1601 ± 62		1712 ± 72		1852 ± 32	
jj2-14	0.21	0.01	0.1154 ± 0.0016		0.2820 ± 0.0156		4.486 ± 0.256		-10.6	1601 ± 88		1728 ± 99		1886 ± 27	
jj2-36	0.34	n.d	0.1140 ± 0.0028		0.2843 ± 0.0085		4.470 ± 0.172		-9.8	1613 ± 48		1725 ± 66		1865 ± 46	
jj2-62	0.29	0.32	0.1117 ± 0.0027		0.2973 ± 0.0113		4.577 ± 0.206		-2.4	1678 ± 64		1745 ± 79		1827 ± 44	
jj2-99	0.20	0.39	0.1135 ± 0.0022		0.3042 ± 0.0129		4.761 ± 0.221		-2.2	1712 ± 72		1778 ± 83		1857 ± 35	
jj2-82	1.01	n.d	0.1041 ± 0.0030		0.3072 ± 0.0065		4.411 ± 0.158			1727 ± 37		1714 ± 61		1699 ± 49	
jj2-93	0.55	n.d	0.1161 ± 0.0022		0.3074 ± 0.0130		4.921 ± 0.229		-3.4	1728 ± 73		1806 ± 84		1897 ± 37	
jj2-71	1.24	0.42	0.1056 ± 0.0031		0.3089 ± 0.0092		4.497 ± 0.187			1735 ± 52		1730 ± 72		1725 ± 50	
jj2-84	1.12	n.d	0.1131 ± 0.0023		0.3097 ± 0.0105		4.828 ± 0.191		-0.8	1739 ± 59		1790 ± 71		1850 ± 38	

Table 1. Continued

Sample Code	Th/U	²⁰⁶ Pbc ^(a) (%)	²⁰⁷ Pb/ ²⁰⁶ Pb	Error 2σ	²⁰⁶ Pb/ ²³⁸ U	Error 2σ	²⁰⁷ Pb/ ²³⁵ U	Error 2σ	Disc ^(b) (%)	²³⁸ U- ²⁰⁶ Pb age (Ma)	Error 2σ	²³⁵ U- ²⁰⁷ Pb age (Ma)	Error 2σ	²⁰⁷ Pb- ²⁰⁶ Pb age (Ma)	Error 2σ
jj2-7	0.84	n.d	0.1147 ± 0.0016		0.3098 ± 0.0122		4.899 ± 0.205		-2.3	1740 ± 69		1802 ± 75		1875 ± 26	
jj2-22	0.48	n.d	0.1128 ± 0.0024		0.3147 ± 0.0101		4.894 ± 0.188			1764 ± 57		1801 ± 69		1845 ± 39	
jj2-78	0.22	n.d	0.1163 ± 0.0026		0.3153 ± 0.0064		5.057 ± 0.152		-3.2	1767 ± 36		1829 ± 55		1901 ± 42	
jj2-4	0.60	0.01	0.1162 ± 0.0015		0.3197 ± 0.0126		5.122 ± 0.213		-0.9	1788 ± 70		1840 ± 76		1899 ± 25	
jj2-59	0.45	n.d	0.1144 ± 0.0026		0.3199 ± 0.0121		5.045 ± 0.223			1789 ± 68		1827 ± 81		1871 ± 43	
jj2-39	0.22	0.02	0.1148 ± 0.0026		0.3200 ± 0.0094		5.065 ± 0.188			1790 ± 52		1830 ± 68		1877 ± 43	
jj2-90	0.20	n.d	0.1149 ± 0.0020		0.3212 ± 0.0108		5.090 ± 0.193			1795 ± 60		1834 ± 70		1880 ± 33	
jj2-1	0.90	0.07	0.1153 ± 0.0015		0.3225 ± 0.0127		5.127 ± 0.213			1802 ± 71		1841 ± 77		1886 ± 25	
jj2-91	0.65	n.d	0.1153 ± 0.0024		0.3249 ± 0.0110		5.164 ± 0.205			1814 ± 61		1847 ± 73		1884 ± 39	
jj2-72	0.25	0.03	0.1198 ± 0.0026		0.3261 ± 0.0094		5.386 ± 0.194		-2.2	1819 ± 53		1883 ± 68		1954 ± 42	
jj2-42	0.27	n.d	0.1131 ± 0.0026		0.3311 ± 0.0097		5.164 ± 0.192			1844 ± 54		1847 ± 69		1850 ± 43	
jj2-66	0.84	0.39	0.1365 ± 0.0030		0.3341 ± 0.0097		6.288 ± 0.230		-12.0	1858 ± 54		2017 ± 74		2184 ± 49	
jj2-57	0.23	0.14	0.1122 ± 0.0025		0.3363 ± 0.0127		5.201 ± 0.228			1869 ± 70		1853 ± 81		1836 ± 41	
jj2-64	0.15	0.15	0.1156 ± 0.0026		0.3370 ± 0.0127		5.372 ± 0.237			1872 ± 71		1880 ± 83		1890 ± 43	
jj2-24	0.40	n.d	0.1313 ± 0.0027		0.3396 ± 0.0109		6.149 ± 0.233		-6.8	1885 ± 60		1997 ± 76		2116 ± 43	
jj2-61	0.67	0.43	0.1094 ± 0.0026		0.3477 ± 0.0132		5.245 ± 0.235			1923 ± 73		1860 ± 83		1790 ± 43	
jj2-21	0.57	n.d	0.1392 ± 0.0028		0.3486 ± 0.0112		6.693 ± 0.254		-9.5	1928 ± 62		2072 ± 79		2218 ± 45	
jj2-10	0.75	0.11	0.1311 ± 0.0018		0.3554 ± 0.0196		6.424 ± 0.366		-0.8	1960 ± 108		2035 ± 116		2113 ± 29	
jj2-63	0.05	n.d	0.1195 ± 0.0026		0.3610 ± 0.0136		5.949 ± 0.259			1987 ± 75		1968 ± 86		1950 ± 43	
jj2-46	0.78	0.12	0.1506 ± 0.0028		0.3632 ± 0.0141		7.541 ± 0.323		-11.8	1997 ± 77		2178 ± 93		2353 ± 43	
jj2-65	0.46	0.05	0.1372 ± 0.0030		0.3661 ± 0.0138		6.926 ± 0.302		-2.9	2011 ± 76		2102 ± 92		2193 ± 48	
jj2-52	0.33	n.d	0.1299 ± 0.0022		0.3805 ± 0.0147		6.818 ± 0.287			2079 ± 80		2088 ± 88		2098 ± 35	
jj2-28	0.60	n.d	0.1475 ± 0.0034		0.3874 ± 0.0115		7.877 ± 0.294		-4.4	2111 ± 62		2217 ± 83		2318 ± 53	
jj2-23	0.62	n.d	0.1439 ± 0.0029		0.4043 ± 0.0129		8.023 ± 0.302			2189 ± 70		2234 ± 84		2275 ± 45	
jj2-2	0.68	0.18	0.1629 ± 0.0020		0.4063 ± 0.0160		9.122 ± 0.375		-7.8	2198 ± 87		2350 ± 97		2486 ± 30	
jj2-37	0.72	0.04	0.1620 ± 0.0037		0.4149 ± 0.0123		9.265 ± 0.346		-5.2	2237 ± 66		2365 ± 88		2477 ± 56	
jj2-53	0.52	n.d	0.1709 ± 0.0029		0.4269 ± 0.0165		10.059 ± 0.425		-6.2	2292 ± 88		2440 ± 103		2567 ± 44	
jj2-18	0.49	n.d	0.1762 ± 0.0037		0.4270 ± 0.0137		10.373 ± 0.397		-8.6	2292 ± 74		2469 ± 94		2618 ± 54	
jj2-20	0.86	0.36	0.1571 ± 0.0034		0.4464 ± 0.0144		9.671 ± 0.374		0.0	2379 ± 77		2404 ± 93		2425 ± 52	
jj2-81	0.50	n.d	0.1824 ± 0.0039		0.5095 ± 0.0102		12.814 ± 0.373		0.0	2654 ± 53		2666 ± 78		2675 ± 57	
<i>Northern Jinju Fm. (n=81)</i>															
0630-9-92	0.85	n.d	0.0547 ± 0.0015		0.0166 ± 0.0003		0.125 ± 0.004		-7.4	106.0 ± 1.9		119.7 ± 4.0		402 ± 11.4	
0630-9-76	0.65	0.43	0.0575 ± 0.0018		0.0249 ± 0.0010		0.198 ± 0.010		-5.9	158.6 ± 6.1		183.1 ± 9.1		513 ± 16.3	
0630-9-93	0.35	n.d	0.0485 ± 0.0017		0.0257 ± 0.0005		0.172 ± 0.007			163.8 ± 2.9		161.4 ± 6.4		126 ± 4.5	
0630-9-3	0.15	n.d	0.0473 ± 0.0015		0.0264 ± 0.0009		0.172 ± 0.008			167.7 ± 5.9		161.0 ± 7.5		64 ± 2.0	
0630-9-17	0.62	0.70	0.0468 ± 0.0012		0.0265 ± 0.0003		0.171 ± 0.005			168.5 ± 2.2		160.3 ± 4.7		41 ± 1.1	
0630-9-5	0.49	0.06	0.0497 ± 0.0016		0.0270 ± 0.0009		0.185 ± 0.009			171.6 ± 6.0		172.1 ± 8.2		179 ± 5.8	
0630-9-14	0.32	n.d	0.0504 ± 0.0016		0.0274 ± 0.0004		0.190 ± 0.007			174.5 ± 2.4		177.0 ± 6.3		212 ± 6.9	
0630-9-19	0.35	n.d	0.0512 ± 0.0019		0.0277 ± 0.0004		0.195 ± 0.008			175.8 ± 2.5		181.0 ± 7.1		249 ± 9.1	
0630-9-60	0.45	n.d	0.0546 ± 0.0019		0.0279 ± 0.0010		0.210 ± 0.010		-0.1	177.2 ± 6.3		193.3 ± 9.6		396 ± 13.7	
0630-9-91	1.01	n.d	0.0551 ± 0.0042		0.0284 ± 0.0006		0.216 ± 0.017			180.4 ± 4.0		198.3 ± 15.6		417 ± 31.5	
0630-9-79	0.28	n.d	0.0509 ± 0.0019		0.0284 ± 0.0011		0.199 ± 0.011			180.5 ± 7.0		184.5 ± 10.0		237 ± 9.0	
0630-9-90	0.67	0.34	0.0480 ± 0.0021		0.0284 ± 0.0005		0.188 ± 0.009			180.7 ± 3.4		175.1 ± 8.4		100 ± 4.4	
0630-9-42	0.27	n.d	0.0491 ± 0.0013		0.0289 ± 0.0016		0.196 ± 0.012			183.6 ± 10.4		181.4 ± 11.3		154 ± 4.1	
0630-9-98	0.75	n.d	0.0514 ± 0.0042		0.0290 ± 0.0007		0.205 ± 0.017			184.2 ± 4.6		189.7 ± 16.1		259 ± 20.9	
0630-9-10	1.09	n.d	0.0490 ± 0.0016		0.0291 ± 0.0010		0.197 ± 0.009			185.1 ± 6.5		182.3 ± 8.7		147 ± 4.7	
0630-9-99	1.40	0.68	0.0493 ± 0.0032		0.0294 ± 0.0007		0.200 ± 0.014			186.7 ± 4.4		185.0 ± 12.8		164 ± 10.6	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ (%) ^(a)	$^{207}\text{Pb}/^{206}\text{Pb}$	Error 2 σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2 σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	Disc (%) ^(b)	^{238}U - ^{206}Pb age (Ma)	Error 2 σ	^{235}U - ^{207}Pb age (Ma)	Error 2 σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2 σ
0630-9-25	0.88	n.d	0.0524 $\pm$ 0.0028		0.0294 $\pm$ 0.0005		0.213 $\pm$ 0.012			186.9 $\pm$ 3.3		195.7 $\pm$ 11.1		303 $\pm$ 16.3	
0630-9-7	1.88	n.d	0.0540 $\pm$ 0.0050		0.0295 $\pm$ 0.0011		0.220 $\pm$ 0.022			187.6 $\pm$ 7.2		201.7 $\pm$ 20.3		371 $\pm$ 34.5	
0630-9-37	0.61	0.65	0.0490 $\pm$ 0.0035		0.0298 $\pm$ 0.0006		0.201 $\pm$ 0.015			189.2 $\pm$ 3.9		186.1 $\pm$ 13.8		148 $\pm$ 10.6	
0630-9-35	0.42	n.d	0.0482 $\pm$ 0.0034		0.0298 $\pm$ 0.0006		0.198 $\pm$ 0.015			189.5 $\pm$ 3.9		183.8 $\pm$ 13.6		112 $\pm$ 8.0	
0630-9-84	0.82	n.d	0.0487 $\pm$ 0.0031		0.0300 $\pm$ 0.0012		0.201 $\pm$ 0.015			190.5 $\pm$ 7.6		186.3 $\pm$ 14.0		134 $\pm$ 8.5	
0630-9-88	0.53	n.d	0.0513 $\pm$ 0.0034		0.0301 $\pm$ 0.0006		0.213 $\pm$ 0.015			191.0 $\pm$ 4.0		195.8 $\pm$ 13.7		254 $\pm$ 17.0	
0630-9-86	0.63	n.d	0.0566 $\pm$ 0.0032		0.0302 $\pm$ 0.0006		0.236 $\pm$ 0.014		-3.1	192.0 $\pm$ 3.9		215.0 $\pm$ 13.0		475 $\pm$ 27.1	
0630-9-40	0.70	n.d	0.0512 $\pm$ 0.0044		0.0302 $\pm$ 0.0007		0.213 $\pm$ 0.019			192.0 $\pm$ 4.2		196.3 $\pm$ 17.3		249 $\pm$ 21.2	
0630-9-100	1.61	n.d	0.0498 $\pm$ 0.0024		0.0304 $\pm$ 0.0007		0.209 $\pm$ 0.011			193.2 $\pm$ 4.3		192.7 $\pm$ 10.1		187 $\pm$ 8.9	
0630-9-12	0.66	n.d	0.0516 $\pm$ 0.0024		0.0304 $\pm$ 0.0005		0.217 $\pm$ 0.010			193.3 $\pm$ 2.9		199.1 $\pm$ 9.6		269 $\pm$ 12.3	
0630-9-57	0.98	n.d	0.0524 $\pm$ 0.0038		0.0305 $\pm$ 0.0011		0.220 $\pm$ 0.018			193.6 $\pm$ 7.2		202.2 $\pm$ 16.6		305 $\pm$ 22.3	
0630-9-32	0.56	n.d	0.0524 $\pm$ 0.0049		0.0305 $\pm$ 0.0007		0.220 $\pm$ 0.021			193.7 $\pm$ 4.4		202.1 $\pm$ 19.4		302 $\pm$ 28.1	
0630-9-69	0.52	n.d	0.0537 $\pm$ 0.0045		0.0305 $\pm$ 0.0012		0.226 $\pm$ 0.021			193.8 $\pm$ 7.4		206.9 $\pm$ 19.0		359 $\pm$ 30.1	
0630-9-22	0.47	n.d	0.0512 $\pm$ 0.0037		0.0306 $\pm$ 0.0006		0.216 $\pm$ 0.016			194.1 $\pm$ 3.7		198.4 $\pm$ 14.7		251 $\pm$ 17.9	
0630-9-2	0.79	n.d	0.0498 $\pm$ 0.0037		0.0306 $\pm$ 0.0011		0.211 $\pm$ 0.017			194.6 $\pm$ 7.2		194.0 $\pm$ 16.0		188 $\pm$ 13.8	
0630-9-38	0.56	n.d	0.0557 $\pm$ 0.0046		0.0307 $\pm$ 0.0007		0.236 $\pm$ 0.020			195.2 $\pm$ 4.3		215.2 $\pm$ 18.6		440 $\pm$ 36.7	
0630-9-50	1.02	n.d	0.0493 $\pm$ 0.0019		0.0308 $\pm$ 0.0010		0.209 $\pm$ 0.011			195.3 $\pm$ 6.2		192.8 $\pm$ 9.7		163 $\pm$ 6.4	
0630-9-41	0.53	n.d	0.0429 $\pm$ 0.0037		0.0308 $\pm$ 0.0018		0.183 $\pm$ 0.019			195.8 $\pm$ 11.4		170.3 $\pm$ 17.8			
0630-9-43	0.58	n.d	0.0517 $\pm$ 0.0030		0.0309 $\pm$ 0.0018		0.220 $\pm$ 0.018			196.2 $\pm$ 11.3		202.2 $\pm$ 16.5		274 $\pm$ 15.9	
0630-9-47	0.78	n.d	0.0448 $\pm$ 0.0030		0.0309 $\pm$ 0.0010		0.191 $\pm$ 0.014			196.2 $\pm$ 6.5		177.5 $\pm$ 13.3			
0630-9-77	0.49	n.d	0.0487 $\pm$ 0.0029		0.0309 $\pm$ 0.0012		0.208 $\pm$ 0.015			196.4 $\pm$ 7.8		191.7 $\pm$ 13.7		135 $\pm$ 8.0	
0630-9-73	0.47	n.d	0.0473 $\pm$ 0.0027		0.0310 $\pm$ 0.0011		0.202 $\pm$ 0.014			196.6 $\pm$ 7.0		186.8 $\pm$ 12.6		65 $\pm$ 3.7	
0630-9-70	0.97	n.d	0.0507 $\pm$ 0.0021		0.0311 $\pm$ 0.0011		0.217 $\pm$ 0.012			197.3 $\pm$ 6.9		199.7 $\pm$ 10.8		229 $\pm$ 9.5	
0630-9-21	0.71	n.d	0.0503 $\pm$ 0.0036		0.0312 $\pm$ 0.0006		0.216 $\pm$ 0.016			197.9 $\pm$ 3.8		198.7 $\pm$ 14.6		208 $\pm$ 14.7	
0630-9-74	1.66	n.d	0.0496 $\pm$ 0.0028		0.0312 $\pm$ 0.0011		0.214 $\pm$ 0.014			198.3 $\pm$ 7.1		196.7 $\pm$ 13.0		178 $\pm$ 9.9	
0630-9-85	0.79	n.d	0.0459 $\pm$ 0.0033		0.0313 $\pm$ 0.0013		0.198 $\pm$ 0.016			198.5 $\pm$ 8.0		183.4 $\pm$ 15.0			
0630-9-20	0.70	n.d	0.0505 $\pm$ 0.0044		0.0316 $\pm$ 0.0006		0.220 $\pm$ 0.020			200.4 $\pm$ 3.9		201.7 $\pm$ 18.0		218 $\pm$ 19.0	
0630-9-6	2.11	n.d	0.0490 $\pm$ 0.0030		0.0316 $\pm$ 0.0012		0.214 $\pm$ 0.015			200.6 $\pm$ 7.3		196.7 $\pm$ 14.0		151 $\pm$ 9.2	
0630-9-80	0.62	n.d	0.0508 $\pm$ 0.0028		0.0320 $\pm$ 0.0013		0.224 $\pm$ 0.015			202.9 $\pm$ 8.0		205.3 $\pm$ 14.0		234 $\pm$ 13.0	
0630-9-66	0.61	n.d	0.0578 $\pm$ 0.0037		0.0320 $\pm$ 0.0012		0.255 $\pm$ 0.019		-1.4	203.3 $\pm$ 7.5		230.8 $\pm$ 17.1		521 $\pm$ 33.6	
0630-9-68	0.46	n.d	0.0549 $\pm$ 0.0040		0.0339 $\pm$ 0.0013		0.257 $\pm$ 0.021			214.8 $\pm$ 8.0		231.9 $\pm$ 18.9		409 $\pm$ 29.7	
0630-9-24	0.39	0.12	0.0539 $\pm$ 0.0014		0.0370 $\pm$ 0.0006		0.275 $\pm$ 0.008		-0.5	234.0 $\pm$ 3.7		246.4 $\pm$ 7.6		367 $\pm$ 9.7	
0630-9-54	0.85	n.d	0.0556 $\pm$ 0.0019		0.0377 $\pm$ 0.0012		0.289 $\pm$ 0.013			238.3 $\pm$ 7.5		257.6 $\pm$ 12.0		437 $\pm$ 15.1	
0630-9-58	1.16	n.d	0.0550 $\pm$ 0.0030		0.0393 $\pm$ 0.0014		0.298 $\pm$ 0.020			248.7 $\pm$ 9.1		265.1 $\pm$ 17.3		413 $\pm$ 22.4	
0630-9-36	1.41	n.d	0.0514 $\pm$ 0.0021		0.0394 $\pm$ 0.0007		0.279 $\pm$ 0.013			249.3 $\pm$ 4.6		250.1 $\pm$ 11.4		258 $\pm$ 10.8	
0630-9-65	0.86	n.d	0.0537 $\pm$ 0.0014		0.0407 $\pm$ 0.0014		0.302 $\pm$ 0.013			257.4 $\pm$ 9.1		267.8 $\pm$ 11.7		361 $\pm$ 9.3	
0630-9-28	0.65	n.d	0.0611 $\pm$ 0.0034		0.0415 $\pm$ 0.0008		0.350 $\pm$ 0.020		-7.6	262.1 $\pm$ 4.8		304.4 $\pm$ 17.6		643 $\pm$ 35.3	
0630-9-46	0.83	n.d	0.0519 $\pm$ 0.0031		0.0421 $\pm$ 0.0014		0.301 $\pm$ 0.020			266.0 $\pm$ 8.7		267.5 $\pm$ 18.2		282 $\pm$ 16.8	
0630-9-8	0.78	n.d	0.0505 $\pm$ 0.0038		0.0424 $\pm$ 0.0016		0.295 $\pm$ 0.025			267.4 $\pm$ 10.0		262.6 $\pm$ 22.3		220 $\pm$ 16.8	
0630-9-26	0.73	n.d	0.1125 $\pm$ 0.0019		0.2778 $\pm$ 0.0043		4.311 $\pm$ 0.099		-13.0	1580 $\pm$ 24		1695 $\pm$ 39		1841 $\pm$ 31	
0630-9-97	0.99	1.58	0.1139 $\pm$ 0.0032		0.2800 $\pm$ 0.0060		4.397 $\pm$ 0.156		-11.6	1591 $\pm$ 34		1712 $\pm$ 61		1863 $\pm$ 53	
0630-9-4	0.37	n.d	0.1136 $\pm$ 0.0023		0.2909 $\pm$ 0.0101		4.557 $\pm$ 0.182		-7.2	1646 $\pm$ 57		1741 $\pm$ 70		1859 $\pm$ 37	
0630-9-18	0.50	0.06	0.1146 $\pm$ 0.0021		0.2936 $\pm$ 0.0038		4.637 $\pm$ 0.103		-9.5	1659 $\pm$ 21		1756 $\pm$ 39		1873 $\pm$ 34	
0630-9-75	0.19	n.d	0.1227 $\pm$ 0.0028		0.2976 $\pm$ 0.0101		5.033 $\pm$ 0.206		-12.8	1679 $\pm$ 57		1825 $\pm$ 75		1996 $\pm$ 45	
0630-9-48	0.48	0.33	0.1107 $\pm$ 0.0019		0.2982 $\pm$ 0.0092		4.550 $\pm$ 0.161		-2.7	1682 $\pm$ 52		1740 $\pm$ 62		1811 $\pm$ 31	
0630-9-64	0.81	0.02	0.1148 $\pm$ 0.0021		0.3005 $\pm$ 0.0106		4.756 $\pm$ 0.189		-5.2	1694 $\pm$ 60		1777 $\pm$ 71		1877 $\pm$ 35	
0630-9-13	0.57	0.10	0.1124 $\pm$ 0.0018		0.3018 $\pm$ 0.0038		4.677 $\pm$ 0.096		-5.2	1700 $\pm$ 21		1763 $\pm$ 36		1839 $\pm$ 30	

Table 1. Continued

Sample Code	Th/U	$^{206}\text{Pb}/^{238}\text{U}$ (%)	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	$^{206}\text{Pb}/^{238}\text{U}$	Error 2 σ	$^{207}\text{Pb}/^{235}\text{U}$	Error 2 σ	Disc (%)	^{238}U - ^{206}Pb age (Ma)	Error 2 σ	^{235}U - ^{207}Pb age (Ma)	Error 2 σ	^{207}Pb - ^{206}Pb age (Ma)	Error 2 σ
0630-9-81	1.04	n.d.	0.1183 $\pm$ 0.0024		0.3027 $\pm$ 0.0115		4.938 $\pm$ 0.212		-7.2	1705 $\pm$ 65		1809 $\pm$ 78		1931 $\pm$ 39	
0630-9-16	0.01	n.d.	0.1148 $\pm$ 0.0018		0.3037 $\pm$ 0.0038		4.804 $\pm$ 0.096		-6.8	1709 $\pm$ 21		1786 $\pm$ 36		1876 $\pm$ 29	
0630-9-9	0.09	0.04	0.1131 $\pm$ 0.0023		0.3065 $\pm$ 0.0106		4.778 $\pm$ 0.191		-1.7	1723 $\pm$ 60		1781 $\pm$ 71		1850 $\pm$ 37	
0630-9-33	0.62	0.07	0.1142 $\pm$ 0.0023		0.3099 $\pm$ 0.0054		4.880 $\pm$ 0.129		-3.5	1740 $\pm$ 30		1799 $\pm$ 48		1868 $\pm$ 37	
0630-9-49	0.19	0.04	0.1156 $\pm$ 0.0017		0.3177 $\pm$ 0.0098		5.065 $\pm$ 0.174		-1.6	1779 $\pm$ 55		1830 $\pm$ 63		1890 $\pm$ 28	
0630-9-53	0.35	0.13	0.1128 $\pm$ 0.0015		0.3186 $\pm$ 0.0098		4.953 $\pm$ 0.166			1783 $\pm$ 55		1811 $\pm$ 61		1845 $\pm$ 25	
0630-9-94	1.08	n.d.	0.1151 $\pm$ 0.0023		0.3230 $\pm$ 0.0057		5.123 $\pm$ 0.136		-0.4	1804 $\pm$ 32		1840 $\pm$ 49		1881 $\pm$ 37	
0630-9-39	0.25	n.d.	0.1167 $\pm$ 0.0018		0.3290 $\pm$ 0.0055		5.292 $\pm$ 0.120		-0.7	1833 $\pm$ 30		1868 $\pm$ 42		1906 $\pm$ 29	
0630-9-59	0.42	n.d.	0.1151 $\pm$ 0.0020		0.3304 $\pm$ 0.0116		5.245 $\pm$ 0.206			1840 $\pm$ 65		1860 $\pm$ 73		1883 $\pm$ 33	
0630-9-78	0.42	0.04	0.1205 $\pm$ 0.0024		0.3327 $\pm$ 0.0126		5.530 $\pm$ 0.237		-0.2	1851 $\pm$ 70		1905 $\pm$ 82		1965 $\pm$ 39	
0630-9-27	0.40	n.d.	0.1286 $\pm$ 0.0017		0.3355 $\pm$ 0.0050		5.946 $\pm$ 0.118		-8.5	1865 $\pm$ 28		1968 $\pm$ 39		2079 $\pm$ 27	
0630-9-11	0.03	0.11	0.1230 $\pm$ 0.0019		0.3431 $\pm$ 0.0042		5.817 $\pm$ 0.114		-2.3	1902 $\pm$ 23		1949 $\pm$ 38		2000 $\pm$ 31	
0630-9-56	0.51	0.16	0.1221 $\pm$ 0.0020		0.3522 $\pm$ 0.0124		5.930 $\pm$ 0.231			1945 $\pm$ 68		1966 $\pm$ 76		1988 $\pm$ 33	
0630-9-96	0.33	n.d.	0.1374 $\pm$ 0.0032		0.3553 $\pm$ 0.0074		6.732 $\pm$ 0.211		-7.3	1960 $\pm$ 41		2077 $\pm$ 65		2195 $\pm$ 52	
0630-9-83	0.43	0.39	0.1200 $\pm$ 0.0025		0.3558 $\pm$ 0.0135		5.887 $\pm$ 0.255			1962 $\pm$ 75		1959 $\pm$ 85		1957 $\pm$ 41	
0630-9-51	0.54	n.d.	0.1422 $\pm$ 0.0024		0.4208 $\pm$ 0.0131		8.252 $\pm$ 0.292			2264 $\pm$ 70		2259 $\pm$ 80		2255 $\pm$ 38	
0630-9-67	0.87	n.d.	0.1552 $\pm$ 0.0039		0.4277 $\pm$ 0.0147		9.153 $\pm$ 0.389			2295 $\pm$ 79		2353 $\pm$ 100		2405 $\pm$ 60	
0630-9-29	0.37	0.03	0.1597 $\pm$ 0.0020		0.4581 $\pm$ 0.0069		10.084 $\pm$ 0.198			2431 $\pm$ 36		2442 $\pm$ 48		2453 $\pm$ 31	

(a) Percentage of ^{206}Pb contributed by common Pb on the basis of ^{204}Pb . Value of common Pb was assumed by Stacey and Kramers (1975) model; n.d.: no detection of ^{204}Pb .

(b) Degree of discordance (%); negative numbers and blanks show normal discordant and concordant within 2 σ of the analytical error, respectively.

Figure 2. Relative probability plot and age histograms for detrital zircon U-Pb ages of the Sindong Group.

(7%), with minor peaks at Early Paleoproterozoic and Early Neoproterozoic (Fig. 2).

Nakdong Formation

Among 300 zircons analyzed, 227 zircon grains yielded concordant or slightly discordant Paleoproterozoic to Lower Cretaceous U-Pb ages (Fig. 3a; Table 1). Zircon U-Pb ages of the Nakdong Formation range from 118 ± 3 Ma to 3494 ± 74 Ma and fall into four main age groups. The zircon age spectrum is dominated by Late Paleopro-

terozoic ages between 1804 and 2013 Ma (29%) with a prominent peak at 1875 Ma, followed by Early Jurassic ages between 172 and 198 Ma (11%) with a peak at 183 Ma, Middle to Late Jurassic ages between 152 and 170 Ma (9%) with a peak at 167 Ma, and by Late Triassic ages between 210 and 235 Ma (7%) with a peak at 227 Ma. Also, there is a notable age cluster in the age range of 2307–2473 Ma (8%).

Nakdong detrital zircons show spatial age variations in the basin (Fig. 3b). The age distribution patterns of the northern and central Nakdong samples are similar but different from that of the southern Nakdong sample. The latter is predominated by Paleoproterozoic and Early Jurassic detrital zircons in that order but lacks Cretaceous, Late Jurassic, Paleozoic, and Neoproterozoic zircons.

Hasandong Formation

A total of 200 zircon grains yielded concordant or slightly discordant Paleoproterozoic to Early Cretaceous U-Pb ages (Fig. 4a). The zircon ages are widely spread, ranging from 109 Ma to 3360 Ma. Most zircons fall into four main age clusters: Jurassic ages between 158 and 194 Ma (27%) with a peak at 177 Ma, Late Paleoproterozoic ages between 1804 and 2027 Ma (22%) with a peak at 1869 Ma, Neoproterozoic ages between 731 and 844 Ma (10%) with a peak at 782 Ma, and Triassic ages between 202 and 245 Ma (9%) with a peak at 227 Ma. Also present is a tight Early Cretaceous age cluster between 109 and 125 Ma.

Like the underlying Nakdong Formation, the age distribution of the Hasandong detrital zircons shows spatial variations in the basin (Fig. 4b). The detrital zircons of the Hasandong samples from the central and southern portions of the basin show similar age spectra, but the

Figure 3. Relative probability plots and age histograms for (a) composite detrital zircon U–Pb ages of the Nakdong Formation and for (b) the Nakdong Formation in three different portions of the Nakdong Trough.

Figure 4. Relative probability plots and age histograms for (a) composite detrital zircon U–Pb ages of the Hasandong Formation and for (b) the Hasandong Formation in three different portions of the Nakdong Trough.

age distribution of detrital zircons from the northern Hasandong sample is distinctive from them as evidenced by the predominance of Early Jurassic zircons followed by Triassic zircons, but lacking Neoproterozoic and Cretaceous zircons.

Jinju Formation

We obtained a total of 239 concordant or slightly discordant detrital zircon ages from the Jinju samples. The zircon ages are also widely spread, ranging from 106 Ma to 3321 Ma (Fig. 5a). The zircon ages fall into four major age groups: Late Paleoproterozoic ages between 1808 and 2000 Ma (30%) with a peak at 1968 Ma, Early Jurassic ages between 189 and 201 Ma (12%) with a peak at 193 Ma, Early–Middle Jurassic ages between 163 and 188 Ma (10%), and Early Cretaceous ages between 106 and 122 Ma (8%) with a peak at 114 Ma. Also present are minor Early Paleoproterozoic age clusters without a prominent peak between 2064 and 2282 Ma (7%) and between 2318 and 2486 Ma (5%).

Like the age distributions of the underlying Hasandong Formation, the age spectrum of the Jinju sample from the northern portion of the basin is separated from those of samples from the central and southern parts (Fig. 5b). Early Jurassic zircons predominate the northern Jinju sample with some Permian zircons, whereas Meso- to Neoproterozoic zircons are lacking, and Cretaceous zircons are scarcely present.

Interpretation and Discussion

As shown in Figure 2, the wide range of ages represents the great variety of Lower Cretaceous to Paleoproterozoic magmatic activities in the source area, indicating that Lower Cretaceous Sindong Group sediments were derived from mixed sources. The Sindong Group contains two dominant populations of 1661–2486 Ma (44.8%) and 153–201 Ma (22.1%) detrital zircons with less abundant Triassic (9.2%), Neoproterozoic (8.7%), and Cretaceous (6.6%) ages. Paleocurrent data indicate Sindong Group sediment derivation from west and northwest (Chang and Kim, 1968; Koh, 1986), most probably from the Yeongnam Massif. Thus, basement rocks and Jurassic plutons of the Yeongnam Massif likely supplied most of the 1661–2486 Ma and 153–201 Ma zircons to the basin. In general, our detrital zircon studies adequately define the geochronology of the Yeongnam Massif.

Source Rock Ages

Mesozoic Zircons

The Mesozoic zircons in the Sindong Group range from 106–249 Ma, representing 37.8% of the analyzed zircons (Figs. 2 and 6a-c). They are first-cycle zircons produced by weathering of igneous rocks in the Yeongnam Massif as evidenced by their euhedral grain shape. The Mesozoic detrital zircons cover more extensive age range than that reported from granitic rocks in the Yeongnam Massif, 169–240 Ma (Cheong and Kim, 2012 and references therein) (Fig. 6e). At present, the presence of Lower Cretaceous igneous rocks is not reported from the Yeongnam Massif. Although Jwa et al. (2008) reported two age groups of Cretaceous granitic rocks in the Yeongnam Massif, 99–

Figure 5. Relative probability plots and age histograms for (a) composite detrital zircon U–Pb ages of the Jinju Formation and for (b) the Jinju Formation in three different portions of the Nakdong Trough.

Figure 6. Age histograms of detrital zircons for (a) Cretaceous, (b) Jurassic, (c) Triassic, (d) Neoproterozoic, (e) combined Triassic–Jurassic, and (f) Paleoproterozoic in age.

102 Ma and 82–83 Ma, they are younger than the observed Lower Cretaceous detrital zircons in this study and the depositional age of the Sindong Group. The Okcheon fold belt to the northwest of the Yeongnam Massif also does not contain Early Cretaceous granitic rocks. The lack of reports on the presence of Lower Cretaceous igneous rocks and granitoids represented by the Sindong Group detrital zircons suggests removal of these igneous rocks in the Yeongnam Massif probably by exhumation.

Spatially, Triassic plutons were likely distributed evenly in the Yeongnam Massif during the deposition of the Sindong Group (Fig. 6c). Like the present distribution of Triassic plutons in the Yeongnam Massif and Okcheon fold belt (Fig. 1), they mostly belong to Late Triassic in age. However, during the Early Cretaceous their exposures in the Yeongnam Massif were relatively minor.

As seen in Figure 2, Jurassic zircons form the dominant contributor to the Sindong Group. Jurassic plutons were distributed heterogeneously both spatially and temporally (Fig. 6b). During the deposition of the Nakdong Formation, Lower Jurassic zircons were mainly delivered to the central and southern portions of the basin, whereas Middle to Upper Jurassic plutons were more abundantly exposed in

the catchments of the northern Nakdong Trough. However, during the deposition of the Hasandong and Jinju formations, the spatial distribution of Jurassic plutons changed drastically opposite to that during the Nakdong Formation deposition. Lower Jurassic plutons with some Middle Jurassic plutons were widely distributed in the catchments of the northern Nakdong Trough, whereas, although minor, Middle to Upper Jurassic plutons existed in the drainage areas of the central and southern portions of the basin. At present, Upper Jurassic plutons are not recorded in the Yeongnam Massif (Fig. 6e) and also in the Okcheon fold belt (cf., Cheong and Kim, 2012). Kim et al. (2005) and Choi et al. (2012) interpreted that Jurassic magmatism in the southern Korean Peninsula was caused by the subduction of the Farallon–Izanagi Plate ridge. The presence of younger Jurassic detrital zircons in the Sindong Group compared to Lower Jurassic plutons in the Yeongnam Massif suggests that the younger Jurassic plutons were emplaced at shallower depths than that of the Jurassic plutons now exposed in the Yeongnam Massif. This interpretation is consistent with that of Kim et al. (2005), who reported different emplacement depths of Jurassic granitoids: the earlier stage of magmatism at deeper depths and the younger stage of magmatism at shallower depths.

Based on hornblende geobarometric calibrations, Cho and Kwon (1994) suggested that the average emplacement depths of Jurassic granites are 12–28 km. This indicates that uplift after Jurassic igneous activity elevated the Jurassic batholith from a depth of 12–28 km to surface, before the deposition of the Sindong Group. K–Ar biotite ages of the Middle Jurassic granitoids indicate that they were uplifted mainly between 150 and 170 Ma in South Korea (Kim et al., 2005), at an uplift rate within the range typical of orogenic areas. The rate of unroofing, or lag time, of the Yeongnam Massif was very rapid, as evidenced by enhanced exhumation of Jurassic deep plutons early in the erosional history of the Yeongnam Massif.

Based on the spatial distribution of Lower Cretaceous detrital zircons in the Nakdong Trough, Lee et al. (2010) interpreted that the magmatic activity was feeble during the Nakdong Formation deposition, the initial phase of the Nakdong Trough filling, and became progressively more active during the deposition of the Hasandong and Jinju formations. However, the locus of Lower Cretaceous magmatic activity was generally confined in the catchments of the Yeongnam Massif for the central and southern portions of the Nakdong Trough (Fig. 6a).

Neoproterozoic–Mesoproterozoic Zircons

Neoproterozoic and Mesoproterozoic detrital zircons comprise 8.7% and 2.7% of the analyzed zircons, respectively (Table 1). Both Neoproterozoic and Mesoproterozoic zircons show rounded to well-rounded shape, suggestive of recycling in origin. Most of the zircons of Neoproterozoic age range from 671 to 846 Ma (Fig. 6d). In general, the source rocks for Neoproterozoic zircons were mainly exposed in the catchments of the central and northern portions of the basin. Neoproterozoic–Mesoproterozoic detrital zircons were reported from Upper Paleozoic quartzites (Park et al., 2011) and post-Ordovician metasediments (Cho et al., 2013) in the central Okcheon fold belt. However, Neoproterozoic zircons from these two sedimentary units are mostly concentrated in the early Neoproterozoic, older than 850 Ma, whereas late Mesoproterozoic ages are within the same range of Sindong Group detrital zircons. There is no known occurrence of potential zircon-bearing rocks within these age ranges in the Yeongnam Massif and also in the Okcheon fold belt, except for several rock bodies in the Okcheon fold belt formed in ca. 750 Ma (Lee et al., 1998; Cho et al., 2004; Choi, 2013). Also, there are no known proba-

ble sources that could provide Grenvillian detrital zircons in the Yeongnam Massif. Thus, further study is necessary to identify their provenance.

Paleoproterozoic Zircons

Paleoproterozoic zircons with the main peak of 1870 Ma constitute the most abundant zircons (44.8%) in the Sindong Group sandstones (Fig. 2). Paleoproterozoic rocks are widely distributed in the Yeongnam Massif, in which 1870 Ma rocks are most abundant not only in the Yeongnam Massif but also in other Precambrian massifs in Korea (Sagong et al., 2003). Spatially, these Paleoproterozoic rocks were more widely distributed in the catchments of the Yeongnam Massif for the northern and central portions of the Nakdong Trough (Fig. 6f).

Provenance Characteristics

Based on the relative proportions of detrital zircon ages, the geology of the catchments for the Sindong Group in the Nakdong Trough was spatially different (Table 2). This interpretation is supported by Lee et al. (2015), who reported the possible existence of different drainage and fluvial system for the Nakdong Trough. The catchments for the northern portion of the Nakdong Trough apparently consisted of rocks of Jurassic >> Paleoproterozoic > Triassic, those for the central portion were composed of Paleoproterozoic > Neoproterozoic ~ Early Cretaceous ~ Jurassic > Triassic, and those for the southern portion were composed of Paleoproterozoic >> Neoproterozoic ~ Early Cretaceous > Jurassic ~ Mesoproterozoic. As zircon is a common constituent of felsic to intermediate igneous rocks and of sedimentary rocks (Marshall, 1967; Morton, 1985) and can survive erosion, transportation, deposition, and diagenesis, it is interpreted that the Sindong detrital zircons do not represent ages of igneous rocks in the immediate source rocks in the Yeongnam Massif. Instead, they may represent mixtures of ages from primary and ultimate source rocks. Lee et al. (2015) reported that source terranes for the Sindong Group have heterogeneous spatial and temporal distribution and were composed mainly of Precambrian basement and Triassic to Jurassic granitic rocks, with minor (meta)sedimentary rocks and syndepositional volcanic rocks. Following this information, a previous study (Lee et al., 2018a, b), and present geology of the Yeongnam Massif, Triassic and Jurassic

Table 2. Results of Kolmogorov–Smirnov (K-S) test run on the detrital zircon age data from the Sindong Group sandstones. P values larger than 0.05 are marked in yellow with bold text

		Nakdong Fm.			Hasandong Fm.			Jinju Fm.		
		Southern	Central	Northern	Southern	Central	Northern	Southern	Central	Northern
Nakdong Fm.	Southern		0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000
	Central	0.000		0.246	0.253	0.874	0.000	0.705	0.239	0.001
	Northern	0.000	0.246		0.063	0.443	0.000	0.340	0.033	0.000
Hasandong Fm.	Southern	0.000	0.253	0.063		0.674	0.000	0.860	0.356	0.000
	Central	0.000	0.874	0.443	0.674		0.000	0.897	0.330	0.000
	Northern	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.146
Jinju Fm.	Southern	0.000	0.705	0.340	0.860	0.897	0.000		0.656	0.000
	Central	0.008	0.239	0.033	0.356	0.330	0.000	0.656		0.000
	Northern	0.000	0.001	0.000	0.000	0.000	0.146	0.000	0.000	

zircons were derived from granitic rocks, Paleoproterozoic zircons from basement rocks, and Early Cretaceous zircons from the syndepositional volcanic rocks. Detrital zircons of other ages might have been derived from recycling of (meta)sedimentary rocks that were distributed in the Yeongnam Massif, whose areal extent was not significant compared to that of basement and Triassic–Lower Cretaceous igneous rocks, all of which are related to the several orogenic events (Sagong et al., 2003; Choi et al., 2012).

Drainage System

Probabilities (p values of the Kolmogorov-Smirnov (K-S) test) > 0.05 indicate that the confidence by which the pair of samples can be statistically distinguished is $\leq 95\%$. Based on p values, the Sindong Group samples were subdivided into three groups: the first group includes northern and central Nakdong samples and central and southern Hasandong and Jinju samples; the second group includes northern Hasandong and northern Jinju samples, and the third includes the southern Nakdong sample. Six samples of the first group show very high p values of paired comparisons. The p values range up to 0.897, and average at a high value of 0.465 (Table 2). These very high p values do not indicate statistically significant differences among the samples, and they strongly suggest that the samples were derived from a common underlying population. Although the probability of the K-S test between the Hasandong and Jinju samples in the northern portion of the basin (the second group) is relatively low ($p = 0.146$), the statistical analysis suggests that these two formations cannot be distinguished as being derived from separate populations (cf., Press et al., 1986).

The dissimilarity among the samples can be visualized to multidimensional scaling (MDS) map (Fig. 7; Vermeesch, 2013; Vermeesch et al., 2016). MDS is a robust superset of principal component analysis, a technique to compare multiple samples by dimension reducing (Vermeesch, 2013). It makes a map plotting the samples according

to their dissimilarity: more similar ones closer, less ones farther. The MDS map of the Sindong Group sandstones analyzed in this study (Fig. 7a) and that of the compiled detrital zircon age data from the previous studies (Kim and Lim, 2017; Lee et al., 2017, 2018a, b; Fig. 7b) with this study yield consistent results with the K-S test, dividing the samples into the same three groups inspite the heterogeneity of individual samples in Figure 7b.

The three distinguished sample groups may represent different geology of catchments, suggesting that during the Sindong Group deposition at least three different drainage systems were developed on the footwall sources.

Northern Nakdong Trough

In the northern portion of the basin, there were at least two different drainage systems: one for the Nakdong Formation and the other for the Hasandong and Jinju formations. This interpretation may be supported by the sedimentological work by Rhee et al. (1988) and Jo and Chough (2001), who studied the Sindong Group in the northwestern corner of the Gyeongsang Basin. They interpreted that the Sindong Group was deposited eastward following the eastward shift in the locus of the sediment deposition without changes in sediment dispersal pattern to south- to southeastward due to tilting or block faulting of the basin floor along the Andong Fault, the northern boundary of the Nakdong Trough, under extensional or transtensional tectonic regime. If this paleogeographic reconstruction of the Nakdong Trough is accepted, the paleofluvial system draining into the northern Nakdong Trough during the Nakdong Formation deposition could not catch up the migrating depocenters to the right and the new paleofluvial system was developed from the north during the deposition of the Hasandong and Jinju formations. This interpretation may partly explain the relatively low p values between the Hasandong and Jinju samples in the northern portion of the basin. After the deposition of

Figure 7. MDS map of (a) the detrital zircon ages of the Sindong Group sandstones in this study and (b) compiled zircon age data from this study and previous studies (Kim and Lim, 2017; Lee et al., 2017; Lee et al., 2018a,b). The more similar samples are located close together, whereas the less same samples farther, making three sample groups identical to those of the K-S test. The solid circles in (b) are the integrated data from the each part of the formation. Note that these integrated data show the same three groups inspite heterogeneity of the data from the individual samples.

the Hasandong Formation, the successive eastward development of the depocenter might have caused adjustment of the paleofluvial system by incorporating slightly different mix of source rocks to the newly formed depocenter for the Jinju Formation deposition. However, the studied section in this study is far south to southeast of the Rhee et al. (1988)'s study area, and thus this scenario may not hold true for this study. Rather, it is interpreted that the Nakdong paleoflow system kept its course through the deposition of the Hasandong and Jinju formations and that the drainage basin became sourced from topographic highs composed more of Jurassic granitoids than that for the Nakdong Formation.

The change in provenance between the Nakdong and Hasandong formations is supported by the nearly two-fold increase in feldspar content among the framework grains (Lee et al., 2015). This was likely caused by strong influences resulting from confluence of dispersal paths draining Jurassic granitoids. In other words, provenance signatures of the paleoflow systems were diluted downstream, as new Jurassic populations are introduced and the system attains second-order. The significantly increasing population of Jurassic age during the Hasandong Formation deposition indicates addition of or expanding Jurassic plutons in its provenance during that time frame. Lee et al. (2015) interpreted that repeated faulting activities occurred in the Yeongnam Massif at the onset of the deposition of each of the Hasandong and Jinju formations in the northern portion, which suggests readjustment of drainage areas during the deposition of the Hasandong and Jinju formations. Alternatively, outcrops of Jurassic granitoids were uncovered by downcutting of the river.

Central Nakdong Trough

The paleofluvial system for the central portion of the basin was different from that for the northern portion of the basin and kept supplying similar detritus continuously during the basin filling. This interpretation suggests that the geology of the drainage basin area did not change temporally. As the p value (0.246) of the Nakdong Formation samples between the northern and central portions of the basin indicates that detrital zircons for both areas were derived from the same underlying population, which suggests that the paleofluvial system for the Nakdong Formation in both areas originated either from common topographic highs or separately in parallel from the mountain ranges composed of similar geology.

Southern Nakdong Trough

For the southern portion of the basin, two different paleofluvial systems are inferred from the K-S test for samples between the Nakdong and Hasandong–Jinju formations. The paleoflow system for the Nakdong Formation drained source terranes composed mainly of Paleoproterozoic rocks with some Jurassic rocks. This interpretation is supported by the present geology of the southwestern Yeongnam Massif, consisting of widespread Paleoproterozoic basement rocks and Jurassic granitoids with sparsely distributed Triassic granitoids (Fig. 1). On the contrary, the paleoflow system for the Hasandong and Jinju formations drained source terranes composed of rocks of mixed Paleoproterozoic, Mesoproterozoic, Neoproterozoic, and Early Cretaceous in age. Lee et al. (2015) reported that Nakdong sandstones are rich in

quartz (av. 73% of framework grains) and metamorphic rock fragments, whereas Hasandong and Jinju sandstones are rich in feldspar and volcanic rock fragments. They also reported the sudden increase in plutonic quartz grain content at the onset of the Hasandong Formation deposition. Since we do not have data from the samples between the studied samples of the Nakdong and Hasandong formations, it is yet clear if the paleofluvial system was the same during the Sindong Group deposition but only with a change in provenance characteristics with time.

Hypotheses for Changes in Drainage Systems of the Nakdong Trough

Four hypotheses can be raised to explain the age separation of detrital zircons between the Nakdong and Hasandong–Jinju formations and similarity of age spectra of the Hasandong and Jinju formations to those of the Sindong Group in the central portion. Spatially, the fault throw was different along the western boundary fault of the Nakdong Trough. There was a large fault throw in the southern segment of the boundary fault as evidenced by the presence of relatively thick (~160 m) gray massive conglomerates in the lower part of the Nakdong Formation (Choi, 1981). As a river continues to drain across the large fault scarps, sediment input from footwall catchments resulting from the incision across the footwall uplifts (e.g., Cowie et al., 2006) would be increased and might dominate the sediment composition.

Considering the common tectonic control for changing drainage patterns (e.g., Hoon et al., 1995) and the extensional origin of basin formation, however, we hypothesize that the fault movements that occurred prior to or syndepositional with the deposition of the Hasandong Formation (Lee et al., 2015) likely explain the drastic changes in detrital zircon age distribution from that of the Nakdong Formation and abrupt increase in plutonic quartz grains at the onset of Hasandong Formation deposition (Lee et al., 2015). The drainage basin seemed to have widened to the source terrane having similar geology to or shared the source terrane for the paleoflow system for the central portion. Alternatively, as relay ramps between fault segments along the basin edge are commonly the entry points of river system into the hanging wall depocenters (Cowie et al., 2006), the paleoriver that supplied detritus to the Nakdong Formation might have drained low gradient hinterland catchments. Sediment supplied during the early rift-initiation stage is well-processed by the low-gradient rivers, resulting in relatively mature composition (Cowie et al., 2006), which may explain the relatively quartz-rich nature of the Nakdong sandstone. Following the faulting and linkage of the fault segments, the paleoriver might have maintained its course during the deposition of the Hasandong and Jinju formations. As a river continues to drain across the active fault scarps, sediment input from footwall catchments resulting from the incision across growing footwall uplifts (Cowie et al., 2006) would be increased and might dominate the sediment composition. In such a case, the ages of detrital zircons of the Hasandong and Jinju formations samples may represent those of footwall rocks. However, this interpretation is less likely considering the presence of considerable amount of lithic fragment in the Nakdong Formation (av. 13% of the framework grains; Lee et al., 2015) and the statistically indistinguishable detrital zircon age spectra of the samples in the central and southern portions as shown by the K–S

test: $p = 0.253$ for the Nakdong Formation in the central portion and the Hasandong Formation in the southern portion and $p = 0.674$ for the Hasandong Formation in both portions.

A third hypothesis is that during the Hasandong Formation deposition in the southern portion, the paleoflow system developed in the central portion might have deflected toward the southern portion due to increased fault throw and slip rate that occurred at the onset of the Hasandong Formation. This interpretation is partly supported by the occurrence of relatively thick, amalgamated sandbodies (~6 m thick) in the middle of the Hasandong sequence, which was interpreted to be braided fluvial deposits formed in axial channels flowing south (cf., Egawa and Lee, 2009). A similar faulting activities were suggested at the onset of the Jinju Formation deposition in the central portion by Lee et al. (2015), which suggests that following the above hypothesis the paleoflow system might have deflected back to the central portion and deposited the Jinju Formation there. However, this hypothesis does not explain the dominant sediment of the Hasandong Formation being a deposit of highly sinuous fluvial system (Choi, 1986b), the high p value between the Hasandong and Jinju formations in the southern portion and between the Jinju formations in the central and southern portions (0.860 and 0.656, respectively), and the paleocurrent data for the Jinju Formation in the central portion (Chang and Kim, 1968).

A fourth hypothesis is that after deposition of the Nakdong Formation, the Hasandong and Jinju formations were deposited from the paleoflow system that was bifurcated from the paleofluvial system responsible for the central portion. River bifurcation is a common phenomenon when a stream nears a lake or the ocean forming a distributary channel (channels). In this case, the river bifurcation should have been in the upper reaches of the main paleoflow system of the central portion to deposit thick Hasandong fluvial plain sediments. However, river bifurcation in the upstream is rather uncommon and

compared with the main channel, the suggested distributary channels may not have carried enough sediments to deposit thick Hasandong and Jinju formations in the southern portion.

The schematic diagram depicting the paleodrainage systems for the Sindong Group is shown in Fig. 8. The studied three portions of the basin are envisaged to have received the sediments through respective drainage-basin outlets, whose spatial spacing often tends to be regular on fault blocks (Talling et al., 1997). As the orientation of the volcanic front parallels the strike of the subducting plate, Jurassic granitoids in the Yeongnam Massif are distributed in general with a NE-SW-trending trend (Choi et al., 2012). The Yeongnam Massif to the west of the central portion is composed of complex masses of Triassic and Jurassic granitoids, which may have provided resistant substrate forming ridge crest dividing the drainage basins between the central and southern portions. The same is true for the part of the Yeongnam Massif to the west of the northern portion of the basin. Sediments to the Nakdong Trough were supplied through the orogen-normal oriented valley system from at least three orogen-parallel drainage basins developed in the Yeongnam Massif. Thus, it is inferred that the geology of the Yeongnam Massif was not uniform like the present day: the central Yeongnam Massif was composed of Paleoproterozoic basement rocks and Triassic/Jurassic granitoids with Mesoproterozoic–Neoproterozoic supracrustal rocks, whereas the southwestern Yeongnam Massif was composed mostly of Paleoproterozoic basement rocks with some Jurassic granitoids.

Conclusions

To characterize the sedimentary provenance and paleodrainage system for the Sindong Group, sandstones from three different parts of the Nakdong Trough (northern, central, and southern parts) were collected for detrital zircon U–Pb dating using a LA-ICP-MS technique. Detrital zircons show a wide range of ages from 106 Ma to 3494 Ma with spatial and temporal variations of age population. Based on the K–S statistical test and MDS map, zircon-age populations can be grouped into three sample groups representing respective provenance during the Nakdong Trough filling: (1) northern and central Nakdong sandstones, central and southern Hasandong sandstones, and central and southern Jinju sandstones, (2) northern Hasandong and northern Jinju sandstones, and (3) a southern Nakdong sandstone. The source terranes for the central portion of the basin were composed dominantly of Paleoproterozoic rocks with subordinate Neoproterozoic, Triassic, Jurassic, and Lower Cretaceous rocks. Sandstones from the Nakdong Formation in the northern portion and the Hasandong and Jinju formations in the southern portion of the basin were also derived from the same provenance, but through different paleodrainage system. By the time of the Hasandong For-

Figure 8. Schematic diagram illustrating the development of paleodrainage systems draining into the Nakdong Trough during the Early Cretaceous. The circled numbers in the northern and southern portions of the Yeongnam Massif represent the temporal changes of drainage systems: 1 for the Nakdong Formation and 2 for the Hasandong and Jinju formations.

mation deposition in the northern portion of the basin, the paleodrainage had switched to source terranes composed mainly of Jurassic granitoids with minor Paleoproterozoic rocks and continued supplying detritus to the overlying Jinju Formation. The paleodrainage system for the Nakdong Formation in the southern portion of the basin had proximal sources composed mainly of Paleoproterozoic rocks, but for the Hasandong and Jinju formations the paleodrainage was different from that for the underlying Nakdong Formation and was connecting pluton-parallel to the source terranes for the central portion of the basin after faulting activities at the onset of the Hasandong Formation deposition. Combined with petrographic data of Lee et al. (2015), the spatial and temporal age distribution of detrital zircons of the Sindong Group suggests evolution of paleodrainage patterns in the Yeongnam Massif in association with faulting activities during the deposition of the Sindong Group. Our model posits that at least three Early Cretaceous flows across the Yeongnam Massif funneled into the three different parts of the Nakdong Trough. This interpretation is supported by the apparent belt-like distribution of the stratigraphic units in parallel to each other along the axis of the Nakdong Trough.

Acknowledgments

This study was funded by the National Research Foundation of Korea (NRF-2014R1A2A2A01005404, 2017R1A2B4007877, 2017R1C1B1007653). The authors would like to thank H. Lee, S.K. Hong, I. Seo, and M.K. Lee for providing field and laboratory assistance.

References

- Barth, A.P., Wooden, J.L., Jacobson, C.E., and Probst, K., 2004, U-Pb geochronology and geochemistry of the McCoy Mountains, southeastern California: A Cretaceous retroarc foreland basin. *Geological Society of America Bulletin*, v. 116, pp. 142–153.
- Chang, K.H., 1970, Geology of upper Mesozoic strata, N. Gyeongsang Province, southern Korea (I). *Journal of the Geological Society of Korea*, v. 6, pp. 1–12.
- Chang, K.H., 1975, Cretaceous stratigraphy of Southeast Korea. *Journal of the Geological Society of Korea*, v. 11, pp. 1–23.
- Chang, K.H., 1987, Cretaceous Strata, In: Lee, D.S., (Ed.), *Geology of Korea*, Kyohak-Sa, Seoul, pp. 175–201.
- Chang, K.H., and Kim, H.M., 1968, Cretaceous paleocurrent and sedimentation in northwestern part of Kyongsang basin, southern Korea. *Journal of the Geological Society of Korea*, v. 4, pp. 77–97.
- Cheong, C.S., and Chang, H.W., 1996a, Geochemistry of the Daebo granite batholith in the central Ogcheon belt, Korea: a preliminary report. *Economic and Environmental Geology*, v. 29, pp. 483–493.
- Cheong, C.S., and Chang, H.W., 1996b, Tectono-magmatism, -metamorphism, and -mineralization of the central Ogcheon belt, Korea (1). *Journal of the Geological Society of Korea*, v. 32, pp. 91–116.
- Cheong, C.S., and Kim, N., 2012, Review of radiometric ages for Phanerozoic granitoids in southern Korean Peninsula. *Journal of the Petrological Society of Korea*, v. 21, pp. 173–192.
- Cho, D.L., and Kwon, S.T., 1994, Hornblende geobarometry of the Mesozoic granitoids in South Korea and the evolution of crustal thickness. *Journal of the Geological Society of Korea*, v. 30, pp. 41–61.
- Cho, M., and Kim, H., 2005, Metamorphic evolution of the Ogcheon belt, Korea: a review and new age constraints. *International Geology Review*, v. 47, pp. 41–57.
- Cho, M., Cheong, W., Ernst, W.G., Yi, K., and Kim, J., 2013, SHRIMP U-Pb ages of detrital zircons in metasedimentary rocks of the central Ogcheon fold-thrust belt, Korea: Evidence for tectonic assembly of Paleozoic sedimentary protoliths. *Journal of Asian Earth Sciences*, v. 63, pp. 234–249.
- Cho, M., Kim, T., and Kim, H., 2004, SHRIMP U-Pb zircon age of a felsic meta-tuff in the Ogcheon Metamorphic Belt, Korea: Neoproterozoic (ca. 750 Ma) volcanism. *Journal of the Petrological Society of Korea*, v. 13, pp. 119–125.
- Choi, D.K., 1985, Spores and pollen from the Gyeongsang Supergroup, southeastern Korea and their chronologic and paleoecologic implications. *Journal of Paleontological Society of Korea*, v. 1, pp. 33–50.
- Choi, D.K., and Park, J.B., 1987, Palynology of the Jinju Formation (Lower Cretaceous), Waegwan-Daegu and Jinju areas, Korea. *Journal of Paleontological Society of Korea*, v. 3, pp. 28–43.
- Choi, H.I., 1981, Depositional environments of the Sindong Group in the southwestern part of the Gyeongsang Basin. Ph.D. thesis, Department of Geology, Seoul National University, 144 p.
- Choi, H.I., 1986, Sandstone petrology of the Sindong Group, southwestern part of the Gyeongsang Basin. *Journal of the Geological Society of Korea*, v. 22, pp. 212–223.
- Choi, J.E., 2013, SHRIMP U-Pb age of Seochangri Formation and Geumsusan Formation in Okcheon belt. MSc. thesis, Department of Earth Science Education, Pukyong National University, 58p.
- Choi, S.J., 1987, Study on the Lower Cretaceous charophytes from the upper Gyeongsang Supergroup. *Journal of Paleontological Society of Korea*, v. 3, pp. 79–92.
- Choi, S.J., 1989, Fossil charophytes from the Nagdong Formation in Seonsangun, Gyeongsangbukdo, Korea. *Journal of Paleontological Society of Korea*, v. 5, pp. 28–38.
- Choi, T., and Lee, Y.I., 2011, Thermal histories of Cretaceous basins in Korea: Implications for response of the East Asian continental margin to subduction of the Paleo-Pacific Plate. *Island Arc*, v. 20, pp. 371–385.
- Choi, T., Lee, Y.I., and Orihashi, Y., 2012, Mesozoic detrital zircon U-Pb ages of modern river sediments in Korea: implications for migration of arc magmatism in the Mesozoic East Asian continental margin. *Terra Nova*, v. 24, pp. 156–165.
- Cowie, P.A., Attal, M., Tucker, G.E., Whittaker, A.C., Naylor, M., Ganas, A., and Roberts, G.P., 2006, Investigating the surface process response to fault interaction and linkage using a numerical modelling approach. *Basin Research*, v. 18, pp. 231–266.
- Dickinson, W.R., and Gehrels, G.E., 2003, U-Pb ages of detrital zircons from Permian and Jurassic eolian sandstones of the Colorado Plateau, USA: Paleogeographic implications. *Sedimentary Geology*, v. 163, pp. 29–66.
- Egawa, K., and Lee, Y.I., 2009, Jurassic synorogenic basin filling in western Korea: sedimentary response to inception of the western Circum-Pacific orogeny. *Basin Research*, v. 21, pp. 407–431.
- Gehrels, G.E., and Stewart, J.H., 1998, Detrital zircon U-Pb geochronology of Cambrian to Triassic miogeoclinal and eugeoclinal strata of Sonora, Mexico. *Journal of Geophysical Research*, v. 103, pp. 2471–2487.
- Hong, S.S., 2001, Implication for the emplacement depth of the granites in the Yeongnam Massif, using the aluminum-in-hornblende barometry. *Journal of Petrological Society of Korea*, v. 10, pp. 36–55.
- Hoon, C., Guerrero, J., Sarmiento, G.A., and Lorente, M.A., 1995, Andean tectonics as a cause for changing drainage patterns in Miocene northern South America. *Geology*, v. 23, pp. 237–240.
- Jo, H.R., and Chough, S.K., 2001, Architectural analysis of fluvial sequences in the northwestern part of Kyongsang Basin (Early Cretaceous), SE Korea. *Sedimentary Geology*, v. 144, pp. 307–334.
- Jwa, Y.-J., 2004, Possible source rocks of Mesozoic granites in South Korea: implications for crustal evolution in NE Asia. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, v. 95, pp. 181–198.

- Jwa, Y.J., Orihashi, Y., Kim, H.G., and Sung, K.H., Zircon U-Pb ages of the Mesozoic granites in the central Yeongnam massif: Including newly found Cretaceous granites, Proceedings Joint Geological Sciences Meeting, 2008, The Geological Society of Korea, Abstracts No.2-1, p. 14.
- Kim, C.B. and Lim, H.S., 2017, Absolute dating of fossil localities and rocks designated as natural monument of Korea II, National Research Institute of Cultural Heritage, 192 p.
- Kim, S.W., Oh, C.W., Choi, S.G., Ryu, I.C., and Itaya, T., 2005, Ridge subduction-related Jurassic plutonism in and around the Okcheon Metamorphic Belt, South Korea, and implications for Northeast Asian tectonics. *International Geology Review*, v. 47, pp. 248–269.
- Koh, I.S., 1974, Sedimentary petrology of Nagdong Group (1). *Journal of the Geological Society of Korea*, v. 10, pp. 207–224.
- Koh, I.S., 1986, Study on the source rocks of the Nagdong Group. *Journal of the Geological Society of Korea*, v. 22, no. 3, pp. 233–256.
- Lawton, T.F., Bradford, I.A., Vega, F.J., Gehrels, G.E., and Amato, J.M., 2009, Provenance of Upper Cretaceous–Paleogene sandstones in the foreland basin system of the Sierra Madre Oriental, northeastern Mexico, and its bearing on fluvial systems of the Mexican Laramide Province. *Geological Society of America Bulletin*, v. 121, pp. 820–836.
- Lee, C., Ryu, I.-C., and Shinn, Y.J., 2017, U-Pb ages of detrital zircons in Lower Cretaceous non-marine successions of the Gyeongsang Basin, Northeast Asia: Implications for sediment provenance. *Sedimentary Geology*, v. 353, pp. 125–138.
- Lee, J.I., and Lee, Y.I., 2000, Provenance of the Lower Cretaceous Hayang Group, Gyeongsang Basin, southeastern Korea: Implications for continental-arc volcanism. *Journal of Sedimentary Research*, v. 70, pp. 151–158.
- Lee, K.S., Chang, H.W., and Park, K.H., 1998, Neoproterozoic bimodal volcanism in the central Ogcheon belt, Korea: age and tectonic implication. *Precambrian Research*, v. 89, pp. 47–57.
- Lee, S.M., Kim, H.S., and Oh, I.S., 1986, Metamorphic petrology of Precambrian gneisses in Samcheok–Jukbyeon area. *Journal of the Geological Society of Korea*, v. 22, pp. 257–277.
- Lee, T.-H., Park, K.-H., and Yi, K., 2018a, Nature and evolution of the Cretaceous basins in the eastern margin of Eurasia: A case study of the Gyeongsang Basin, SE Korea. *Journal of Asian Earth Sciences*, v. 166, pp. 19–31.
- Lee, T.-H., Park, K.-H., and Yi, K., 2018b, SHRIMP U-Pb ages of detrital zircons from the Early Cretaceous Nakdong Formation, South East Korea: Timing of initiation of the Gyeongsang Basin and its provenance. *Island Arc*, v. e12258.
- Lee, Y.I., 1999, Stable isotopic composition of calcic paleosols of the Early Cretaceous Hasandong Formation, southeastern Korea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 150, pp. 123–133.
- Lee, Y.I., Choi, T., Lim, H.S., and Orihashi, Y., 2010, Detrital zircon geochronology of the Cretaceous Sindong Group, SE Korea: Implications for depositional age and Early Cretaceous igneous activity. *Island Arc*, v. 19, pp. 647–658.
- Lee, Y.I., and Lim, D.H., 2008, Sandstone diagenesis of the Lower Cretaceous Sindong Group, Gyeongsang Basin, southeastern Korea: Implications for compositional and paleoenvironmental controls. *Island Arc*, v. 17, pp. 152–171.
- Lee, Y.I., Yi, J., and Choi, T., 2015, Provenance analysis of lower Cretaceous Sindong Group sandstones in the Gyeongsang Basin, Korea, using integrated petrography, quartz SEM-cathodoluminescence, and zircon Zr/Hf analysis. *Journal of Sedimentary Research*, v. 85, pp. 529–543.
- Lim, H.S., Lee, Y.I., and Min, K.D., 2003, Thermal history of the Cretaceous Sindong Group, Gyeongsang Basin, Korea based on fission track analysis. *Basin Research*, v. 15, pp. 139–152.
- Link, P.K., Fanning, C.M., and Beranek, L.P., 2005, Reliability and longitudinal change of detrital-zircon age spectra in the Snake River system, Idaho and Wyoming: An example of reproducing the bumpy barcode. *Sedimentary Geology*, v. 182, pp. 101–142.
- Ludwig, K.R., 2003, User's manual for Isoplot 3.00. Berkeley Geochronology Center Special Publication, v. 4, pp. 1–71.
- Noh, J.H., and Park, H.S., 1990, Mineral diagenesis of sandstones from the Kyonsang Supergroup in Goryeong area. *Journal of the Geological Society of Korea*, v. 26, pp. 371–392.
- Rainbird, R.H., McNicoll, V.J., Thériault, R.J., Heaman, L.M., Abbott, J.G., Long, D.G.F., and Thorkelson, D.J., 1997, Pan-continental river system draining Grenville orogeny recorded by U-Pb and Sm-Nd geochronology of Neoproterozoic quartzarenites and mudrocks, northwestern Canada. *The Journal of Geology*, v. 105, pp. 1–17.
- Raines, M.K., Hubbard, S.M., Kukulski, R.B., Leier, A.L., and Gehrels, G.E., 2013, Sedimentary dispersal in an evolving foreland: Detrital zircon geochronology from Upper Jurassic to lowermost Cretaceous strata, Alberta Basin, Canada. *Geological Society of America Bulletin*, v. 125, pp. 741–755.
- Rhee, C.W., Jo, H.R., and Chough, S.K., 1988, An allostratigraphic approach to a non-marine basin: the north-western part of Cretaceous Kyongsang Basin, SE Korea. *Sedimentology*, v. 45, pp. 449–472.
- Roberts, E.M., Stevens, N.J., O'Connor, P.M., Dirks, P.H.G.M., Gottfried, M.D., Clyde, W.C., Armstrong, R.A., Kemp, A.I.S., and Hemming, S., 2012, Initiation of the western branch of the East African Rift coeval with the eastern branch. *Nature Geoscience*, v. 5, pp. 289–294.
- Seo, S.J., 1985, Lower Cretaceous geology and paleontology (Charophyta) of central Kyongsang Basin, Korea. Ph.D. Thesis, Department of Geology, Kyungpook National University, 177 p.
- Shin, S.C., and Jin, M.S., 1995, Isotope age map of plutonic rocks in Korea. Korea Institute of Geology, Mining and Materials.
- Talling, P.J., Stewart, M.D., Stark, C.P., Gupta, S., and Vincent, S.J., 1997, Regular spacing of drainage outlets from linear fault blocks. *Basin Research*, v. 9, pp. 275–302.
- Vermeesch, P., 2013, Multi-sample comparison of detrital age distributions. *Chemical Geology*, v. 341, pp. 140–146.
- Vermeesch, P., Resentini, A., and Garzanti, E., 2016, An R package for statistical provenance analysis. *Sedimentary Geology*, v. 336, pp. 14–25.

Taejin Choi is an assistant professor of sedimentary geology in the Department of Energy and Resources Engineering, Chosun University, Gwangju, Korea. He received his Ph.D. from School of Earth and Environmental Sciences, Seoul National University, Korea. He has studied provenance and thermal history of sedimentary basins in Korea using petrography, geochemistry, and geochronology of detrital minerals.

Hyoun Soo Lim is an associate professor of sedimentary geology in Department of Geological Sciences, Pusan National University, Busan, Korea. He received his Ph.D. from Seoul National University, Korea. His main research focuses on the low-temperature thermochronology, Quaternary geology, paleoclimate, geoarchaeology and polar science. He won the Young Geologist Award (2008) and Academic Award (2019) from the Geological Society of Korea, and the Challenge Award (2009) from the Korea Polar Research Institute. He has served as an associate editor for the Journal of the Geological Society of Korea, and editorial board member for the Geosciences Journal.

Yong Il Lee is emeritus Professor of Geology in the School of Earth and Environmental Sciences at Seoul National University, Seoul, Korea. He holds BSc and MSc degrees in geology from Seoul National University and PhD from the University of Illinois at Urbana-Champaign, Illinois, USA. He served as President of the Geological Society of Korea (2010–2011). He has authored over 200 scientific publications in the fields of sedimentary petrology, diagenesis, sequence stratigraphy, geochemistry, paleogeography, paleoclimatology, and polar sciences. His research on sedimentary geology has been recognized by the Geological Society of Korea with the Best Paper Award (1995) and the Academic Award (2007) and by the National Academy of Sciences of Korea with the Academic Award (2012). He has also won two Medals from the Korean Government: Republic of Korea Order of Science and Technological Merit (2009) and Republic of Korea Order of Service Merit (2018).

Yuji Orihashi is a professor of geology and geochemistry in the Department of Global Environment and Disaster Prevention Sciences, Graduate School of Science and Technology, Hirosaki University, Aomori, Japan. He received his DSc from Graduate School of Science, Hokkaido University, Japan. His scientific work focuses on U-Pb dating by LA-ICPMS and its development of the method. He has served as an editorial board member for Island Arc (until 2019) and as associate editor of Geochemical Journal.