SHRIMP U-Pb dating of detrital zircons in paragneiss from Oki-Dogo Island, western Japan

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We obtained the radiometric ages of detrital zircons from two samples of paragneiss from Oki-Dogo Island, Japan, from the $^{238}\text{U}/^{206}\text{Pb}$ ratio and isotopic composition of Pb determined using a Sensitive High-Resolution Ion MicroProbe (SHRIMP II). The zircons show two main age clusters around 2200 Ma and 1800 Ma, with some discordant ages. One zircon grain has a rim with a concordant age of 236 ± 3 Ma, which is consistent with the age of peak metamorphism in the Hida Metamorphic Belt. The modal proportions of zircon ages from Oki-Dogo Island are clearly different from those for paragneiss of the Hida Terrane. This indicates that the Oki Gneiss is derived from an Early Proterozoic rock and is different from the Hida Gneiss in terms of provenance and/or the depositional age of the parent sediment.

Keywords: Oki Islands, Paragneiss, Provenance, Detrital zircon, U-Pb age

INTRODUCTION

The Hida Belt is located in the northern part of southwest Japan, and consists of low- to medium-P/T gneisses that were metamorphosed at approximately 240 to 250 Ma (Ishizaka and Yamaguchi, 1969; Ota and Itaya, 1989; Suzuki and Adachi, 1991). The gneisses were once considered to form the basement of the Japanese Islands, which originally formed during the Precambrian (Sato, 1968). Otofujii et al. (1983) demonstrated from paleomagnetic data that the Sea of Japan opened during the Middle Miocene, and many researchers consider that the Hida Metamorphic Belt was formed by continental collision between the Sino-Korean and Yangtze Massifs, as determined from lithofacies analysis (Hiroi, 1981; Maruyama and Seno, 1986; Isozaki and Maruyama, 1991; Ree, 1996), or between the Sino-Korean and Siberia Massifs (Arakawa et al., 2000). These interpretations require that part of the Hida Belt was connected to the Ogcheon Belt (Hiroi, 1981) or the Imjingang Belt (Ree et al., 1996)

prior to the opening of the Sea of Japan (Fig. 1).

The gneiss on Oki-Dogo Island is considered to be a western extension of the Hida Gneiss on the basis of similarities in both lithofacies and metamorphic age. Whole-rock isochron ages in excess of 1800 Ma have been reported for the Oki Gneiss (Tanaka and Hoshino, 1987), and are interpreted to represent the age of the source rocks. Such old ages have not previously been reported for gneisses of the Hida district (cf., Ota and Itaya, 1989). In contrast, Suzuki and Adachi (1994) analyzed the ages of zircon and monazite grains from paragneisses on Oki-Dogo Island using an electron microprobe analyzer and concluded that the depositional age of the parent sediments is less than 350 Ma. Sano et al. (2000) analyzed zircons in paragneisses from the Amo area, Hida district, using SHRIMP II, and on the basis of age variations from 240 to 3000 Ma concluded that the depositional age of the parent sediment was approximately 250 Ma.

To clarify the depositional age of the parent rocks of paragneisses on Oki-Dogo Island, we analyzed zircons from two paragneiss samples and measured U-Pb ages using SHRIMP II equipment installed at Hiroshima University, Japan. The closure temperature of the U-Pb system in zircon is higher than 900 °C, and the system usually remains closed under low- to medium-grade metamorphism (Lee et al., 1997; Sano et al., 1999; Cherniak

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Figure 1. (a) Generalized tectonic map of East Asia (after Zhao et al., 2000). (b) Locality map of Oki-Dogo Island, Hida district, the Imjingang Belt, and the Ogcheon Belt. Abbreviations: NM, Nangrim Massif; IB, Imjingang Belt; GM, Gyeonggi Massif; OB, Ogcheon Belt; YM, Yeongnam Massif; GB, Gyeongsang Basin; ISTL, Itoigawa-Shizuoka Tectonic Line; MTL, Median Tectonic Line.

and Watson, 2000). As the Hida gneiss was metamorphosed under conditions of the amphibolite and lower granulite facies (Suzuki, 1977), the ages of detrital zircons in these rocks have not been significantly disturbed during metamorphism and therefore provide information

on the upper age limit of the deposition and provenance of the parent rock.

Figure 2. Geological map of Oki-Dogo Island (after Hoshino, 1979), showing sample locations.

GEOLOGICAL SETTING

Oki-Dogo Island is the largest of the Oki Islands located in the Sea of Japan. The gneisses on Oki-Dogo Island are associated with granitoids and are widely covered by Tertiary sediments and Quaternary volcanics (Fig. 2). The Oki gneisses consist mainly of pelitic to psammitic gneiss and migmatites intercalated in places with basic gneiss. The equilibrium temperature of the gneiss, estimated from Fe-Mg partitioning coefficients between orthopyroxene and clinopyroxene in two-pyroxene amphibolite, is approximately 800 °C (Hoshino, 1979). Previously reported K-Ar ages of biotite are 165 Ma and 173 Ma (Shibata and Nozawa, 1978), while a Rb-Sr biotite age of 187 Ma has also been reported (Hayase and Ishizaka, 1967). Sm-Nd whole-rock ages have been determined for amphibolite (1980 ± 180 Ma) and paragneiss (1960 ± 820 Ma; Tanaka and Hoshino, 1987). The ages of monazites and zircons in paragneisses determined by the U-Th-total Pb chemical isochron method (CHIME) show broad ranges in age from 250 to 1700 Ma and 350 to 3000 Ma, respectively (Suzuki and Adachi, 1994).

SAMPLES AND ANALYTICAL METHODS

Two paragneiss samples, DO-3 and DO-9, were selected

for analysis from the collection of rock specimens housed at the National Science Museum, Tokyo, Japan. The registration numbers of the samples are 130692 and 130698, respectively. DO-3 was collected from the main area of the Oki gneiss, while DO-9 was collected from an area close to a basalt vent.

Zircon grains were separated from the samples by standard crushing and heavy-liquid techniques, and then handpicked. Zircon grains from the samples and the zircon standard QNGG, with a TIMS U/Pb age of 1850 ± 2 Ma (2σ), were cemented in an epoxy resin and polished until their centers were largely exposed on a flat surface. U-Pb dating was performed using a SHRIMP II installed at Hiroshima University, Japan. Instrumental conditions and measurement procedures are described in Sano et al. (2000). The spot size of the primary ion beam was about 20 μ m. Both back-scattered images and cathodoluminescence images were used to select sites for SHRIMP analysis. The $^{206}\text{Pb}/^{238}\text{U}$ ratios of the samples were calibrated using the empirical relationship described by Claoue-Long et al. (1995). In this procedure, it is essential to subtract initial Pb from measured Pb to estimate the age accurately. The measured $^{206}\text{Pb}/^{204}\text{Pb}$ ratio was used for the correction of initial Pb, whose isotopic composition was assumed using a single-stage model (Compston et al., 1984).

Table 1. $^{207}\text{Pb}/^{206}\text{Pb}$, $^{238}\text{U}/^{206}\text{Pb}$, and Th/U ratios, F-value, radiometric $^{238}\text{U}/^{206}\text{Pb}$ ages, $^{207}\text{Pb}^*/^{206}\text{Pb}^*$ ages,

Labels	$^{207}\text{Pb}/^{206}\text{Pb}$	F - value ¹⁾	$^{238}\text{U}/^{206}\text{Pb}$	Th/U	$^{238}\text{U}/^{206}\text{Pb}$ age ²⁾ (Ma)	$^{207}\text{Pb}^*/^{206}\text{Pb}^*$ age ²⁾ (Ma)	Disc. ³⁾ (%)
Sample DO-3							
DO3.01.1	0.1041±0.0040	0.00017±0.00051	3.37±0.15	0.25	1675±66	1598±64	-4.8±2.7
DO3.02.1	0.1115±0.0022	0.00009±0.00031	3.21±0.12	0.75	1748±57	1822±36	4.1±1.5
DO3.02.2	0.0992±0.0029	0.00034±0.00038	5.02±0.18	0.01	1171±39	1605±54	27.0±12.8
DO3.03.1	0.1181±0.0014	0.00176±0.00077	3.08±0.08	0.52	1812±40	1907±24	5.0±1.3
DO3.03.2	0.1116±0.0026	<0.00001	3.64±0.21	0.11	1566±79	1810±45	13.5±7.6
DO3.03.3	0.1050±0.0013	0.00037±0.00011	4.09±0.17	0.01	1408±52	1709±23	17.6±7.0
DO3.04.1	0.1078±0.0025	0.00050±0.00030	3.12±0.19	0.15	1793±95	1756±43	-2.1±1.2
DO3.05.1	0.1104±0.0019	0.00006±0.00005	3.30±0.05	0.09	1705±23	1805±31	5.5±1.2
DO3.07.1	0.1761±0.0067	<0.00001	1.80±0.06	0.27	2853±81	2617±62	-9.0±3.3
DO3.08.1	0.1180±0.0010	0.00028±0.00026	2.78±0.06	0.16	1977±39	1923±16	-2.9±0.6
DO3.09.1	0.1130±0.0047	0.00033±0.00028	3.13±0.11	0.13	1787±57	1845±74	3.2±1.6
DO3.11.1	0.1182±0.0015	0.00019±0.00015	3.09±0.05	0.22	1805±28	1926±23	6.3±1.2
DO3.12.1	0.1130±0.0024	<0.00001	2.97±0.05	0.17	1868±25	1848±38	-1.1±0.3
DO3.12.2	0.1120±0.0043	0.00040±0.00017	4.66±0.25	0.01	1253±62	1738±62	27.9±17.0
DO3.13.1	0.1205±0.0035	<0.00001	3.62±0.17	0.19	1574±65	1963±53	19.8±9.8
DO3.14.1	0.1112±0.0020	0.00030±0.00012	2.91±0.04	0.48	1905±25	1814±33	-5.0±1.1
DO3.15.1	0.1126±0.0072	0.00036±0.00024	3.41±0.19	0.35	1656±82	1737±109	4.6±3.7
DO3.16.1	0.1123±0.0011	0.00001±0.00055	3.43±0.02	0.95	1648±10	1837±19	10.3±1.2
DO3.17.1	0.1114±0.0010	0.00020±0.00009	3.16±0.03	0.38	1773±14	1820±17	2.6±0.3
DO3.17.2	0.1092±0.0030	0.00056±0.00024	3.66±0.09	0.01	1555±35	1779±49	12.6±4.5
DO3.18.1	0.1151±0.0025	0.00000±0.00003	3.12±0.08	0.43	1792±38	1881±39	4.7±1.4
DO3.19.1	0.1068±0.0025	<0.00001	3.28±0.12	0.11	1716±53	1745±42	1.7±0.7
DO3.19.2	0.0531±0.0010	0.00191±0.00182	26.82±0.35	0.02	236±3	263±83	10.5±33.0
DO3.20.1	0.1123±0.0056	<0.00001	3.85±0.23	0.19	1490±80	1838±88	18.9±13.6
DO3.20.2	0.1060±0.0012	0.00004±0.00006	4.29±0.10	0.02	1351±28	1731±20	21.9±5.3
DO3.21.1	0.1141±0.0011	<0.00001	2.81±0.02	0.13	1964±14	1866±17	-5.2±0.6
DO3.22.1	0.1298±0.0036	0.00064±0.00020	3.68±0.07	0.14	1548±25	2088±48	25.9±7.3
DO3.22.2	0.1094±0.0040	0.00025±0.00021	4.07±0.14	0.01	1415±44	1877±61	24.6±11.1
DO3.23.1	0.1137±0.0038	0.00058±0.00032	3.18±0.05	0.16	1761±27	1874±67	6.0±2.4
DO3.24.1	0.1087±0.0007	0.00019±0.00005	3.09±0.03	0.31	1808±17	1778±10	-1.7±0.2
DO3.24.2	0.1076±0.0020	0.00022±0.00018	3.01±0.07	0.30	1851±39	1722±17	-7.5±1.7
DO3.24.3	0.1063±0.0038	0.00005±0.00002	5.01±0.11	0.01	1174±23	1736±64	32.4±13.5
DO3.25.1	0.1079±0.0017	<0.00001	5.16±0.18	0.01	1143±37	1764±28	35.2±12.6
DO3.26.1	0.1133±0.0011	0.00009±0.00016	3.20±0.05	0.18	1754±23	1851±18	5.2±0.9
DO3.27.1	0.1518±0.0039	<0.00001	2.13±0.06	0.84	2481±56	2366±44	-4.9±1.4
DO3.28.1	0.1356±0.0010	0.00033±0.00024	2.56±0.06	0.34	2124±43	2169±13	2.1±0.4
DO3.28.2	0.1156±0.0026	0.00056±0.00023	3.12±0.07	0.11	1790±34	1933±32	7.4±1.9
DO3.29.1	0.1155±0.0010	0.00006±0.00029	3.36±0.07	0.20	1680±30	1887±15	11.0±2.2
DO3.30.1	0.1049±0.0038	0.00029±0.00029	6.40±0.20	0.04	935±27	1725±63	45.8±21.3

and degree of discordance (Disc.) of zircons in samples from Oki-Dogo Island.

Labels	$^{207}\text{Pb}/^{206}\text{Pb}$	F - value ¹⁾	$^{238}\text{U}/^{206}\text{Pb}$	Th/U	$^{238}\text{U}/^{206}\text{Pb}^* \text{ age}^2)$ (Ma)	$^{207}\text{Pb}^*/^{206}\text{Pb}^* \text{ age}^2)$ (Ma)	Disc. ³⁾ (%)
DO3.30.2	0.1124±0.0071	0.00225±0.00117	3.95±0.11	0.25	1450±35	1810±114	19.9±13.3
DO3.30.3	0.1073±0.0028	0.00065±0.00036	5.30±0.11	0.04	1115±22	1745±48	36.1±12.1
DO3.31.1	0.1602±0.0008	0.00087±0.00045	2.44±0.06	0.56	2209±43	2451±10	9.9±2.0
DO3.31.2	0.1092±0.0040	0.00010±0.00005	4.18±0.12	0.06	1382±37	1785±66	22.6±10.3
DO3.32.1	0.1575±0.0014	0.00030±0.00039	2.23±0.02	0.45	2387±20	2427±16	1.6±0.2
DO3.32.2	0.1159±0.0025	0.00059±0.00022	3.32±0.13	0.12	1696±58	1887±39	10.1±4.0
DO3.33.1	0.1104±0.0041	<0.00001	6.97±0.15	0.05	865±17	1807±66	52.1±21.8
DO3.33.2	0.1005±0.0021	0.00009±0.00002	3.14±0.11	0.01	1783±57	1631±38	-9.3±3.7
DO3.34.1	0.1132±0.0008	0.00070±0.00077	3.30±0.09	0.55	1704±42	1843±17	7.6±2.0
DO3.35.1	0.1113±0.0009	0.00022±0.00011	3.18±0.13	0.44	1764±62	1818±15	3.0±1.1
DO3.36.1	0.1107±0.0027	<0.00001	4.08±0.09	0.33	1413±28	1811±46	22.0±7.0
DO3.37.1	0.1157±0.0033	<0.00001	3.34±0.12	0.13	1689±53	1891±52	10.7±4.4
DO3.38.1	0.1136±0.0014	<0.00001	3.49±0.07	0.55	1625±28	1857±22	12.5±2.6
DO3.39.1	0.1124±0.0012	0.00014±0.00031	3.35±0.08	0.16	1684±37	1838±20	8.4±2.1
DO3.40.1	0.1124±0.0015	<0.00001	3.27±0.05	0.41	1719±25	1839±26	6.5±1.3
DO3.41.1	0.1097±0.0013	0.00075±0.00026	4.04±0.06	0.27	1425±18	1785±22	20.2±3.5
DO3.42.1	0.1258±0.0029	0.00046±0.00031	3.00±0.10	0.14	1851±55	2036±41	9.1±3.3
DO3.43.1	0.1130±0.0024	0.00068±0.00013	4.05±0.07	0.01	1422±22	1840±38	22.7±5.8
DO3.44.1	0.1123±0.0062	<0.00001	3.89±0.13	0.12	1475±45	1837±97	19.7±12.0
Sample DO-9							
DO9.01.1	0.1487±0.0021	0.00005±0.00051	2.40±0.09	0.51	2241±69	2330±25	3.8±1.2
DO9.02.1	0.1249±0.0022	<0.00001	3.14±0.07	0.30	1781±33	2028±31	12.2±2.9
DO9.03.1	0.1177±0.0025	<0.00001	2.69±0.08	0.44	2036±49	1922±38	-5.9±1.8
DO9.04.1	0.1378±0.0017	0.00011±0.00016	2.57±0.07	0.75	2121±46	2199±22	3.6±0.8
DO9.05.1	0.1361±0.0032	0.00008±0.00018	2.23±0.09	0.68	2385±77	2177±40	-9.6±3.6
DO9.06.1	0.1241±0.0013	0.00002±0.00011	2.86±0.08	0.24	1934±48	2015±18	4.0±1.1
DO9.07.1	0.0969±0.0029	0.00357±0.00220	13.73±0.39	0.03	452±12	1509±69	70.1±37.3
DO9.08.1	0.1395±0.0051	0.00086±0.00080	2.36±0.10	0.53	2272±82	2212±63	-2.7±1.2
DO9.09.1	0.1325±0.0065	0.00004±0.00006	2.38±0.08	0.44	2261±68	2131±83	-6.1±3.0
DO9.10.1	0.1395±0.0035	0.00019±0.00126	2.35±0.10	0.61	2287±79	2220±45	-3.0±1.2
DO9.11.1	0.1208±0.0024	0.00014±0.00020	3.58±0.12	0.21	1588±47	1966±35	19.3±6.6
DO9.12.1	0.0732±0.0020	0.00047±0.00034	24.05±0.65	0.01	262±7	1010±55	74.0±44.9
DO9.13.1	0.1438±0.0056	0.00100±0.00067	2.22±0.17	0.74	2396±152	2265±66	-5.8±4.0
DO9.14.1	0.1323±0.0020	0.00002±0.00005	2.92±0.08	0.45	1897±47	2129±26	10.9±3.0
DO9.15.1	0.1326±0.0027	0.00141±0.00126	2.95±0.15	0.44	1878±84	2118±39	11.4±5.5
DO9.16.1	0.1458±0.0015	0.00013±0.00015	2.45±0.08	0.50	2204±59	2296±18	4.0±1.1
DO9.17.1	0.1247±0.0021	<0.00001	3.03±0.11	0.38	1837±58	2024±30	9.2±3.2
DO9.18.1	0.1480±0.0036	0.00098±0.00098	3.06±0.14	0.88	1819±72	2314±42	21.4±9.3
DO9.19.1	0.1365±0.0037	0.00020±0.00032	2.43±0.07	0.27	2224±56	2181±46	-2.0±0.7

Table 1. (Continued)

Labels	$^{207}\text{Pb}/^{206}\text{Pb}$	F - value ¹⁾	$^{238}\text{U}/^{206}\text{Pb}$	Th/U	$^{238}\text{U}/^{206}\text{Pb}$ age ²⁾ (Ma)	$^{207}\text{Pb}^*/^{206}\text{Pb}^*$ age ²⁾ (Ma)	Disc. ³⁾ (%)
DO9.20.1	0.1165±0.0014	<0.00001	3.47±0.08	0.22	1634±32	1904±22	14.2±3.3
DO9.21.1	0.1300±0.0070	0.00257±0.00227	2.96±0.16	0.75	1871±88	2071±97	9.7±6.4
DO9.22.1	0.1300±0.0046	0.00062±0.00059	2.91±0.11	0.09	1902±61	2091±62	9.0±4.0
DO9.23.1	0.1285±0.0021	0.00019±0.00014	2.98±0.06	0.23	1866±30	2076±29	10.1±2.2
DO9.24.1	0.1300±0.0013	0.00011±0.00027	3.26±0.08	0.95	1725±39	2096±18	17.7±4.3
DO9.27.1	0.1218±0.0016	<0.00001	3.46±0.09	0.17	1636±36	1983±24	17.5±4.4

¹⁾ The F-value is defined as 'initial $^{206}\text{Pb}/\text{total } ^{206}\text{Pb}$ '.

²⁾ $^{206}\text{Pb}^*$ and $^{207}\text{Pb}^*$ mean radiometric ^{206}Pb and ^{207}Pb , respectively.

³⁾ The degree of discordance for an analyzed area represents the chronological difference between the two ages determined by the Pb-Pb and U-Pb methods, and is defined as $[1 - (^{238}\text{U}/^{206}\text{Pb}^* \text{ age}) / (^{207}\text{Pb}^*/^{206}\text{Pb}^* \text{ age})] \times 100$ (%) (e.g., Biao et al., 1996).

RESULTS

Table 1 lists zircon data in terms of $^{207}\text{Pb}/^{206}\text{Pb}$, $^{238}\text{U}/^{206}\text{Pb}$, and Th/U ratios; F value (initial $^{206}\text{Pb}/\text{total } ^{206}\text{Pb}$); radiometric $^{238}\text{U}/^{206}\text{Pb}^*$ ages; $^{207}\text{Pb}^*/^{206}\text{Pb}^*$ ages; and degree of discordance. The degree of discordance for an analyzed area indicates the chronological difference between the two ages determined by the Pb-Pb and U-Pb methods, and is defined as $\{1 - (^{238}\text{U}/^{206}\text{Pb}^* \text{ age}) / (^{207}\text{Pb}^*/^{206}\text{Pb}^* \text{ age})\} \times 100$ (%) (e.g., Biao et al., 1996). The magnitude of discordance indicates the degree of disturbance of the U-Pb system within a sample. Subnumbers in Table 1 such as DO3.02.1 and DO3.02.2 indicate different pit positions within a grain, as shown in Figure 3.

Figure 4 shows Tera-Wasserberg concordia diagrams for the two gneiss samples. The ages of zircons in paragneiss sample DO-3 cluster in the range 1600 to 2000 Ma (Fig. 4a). This cluster includes a number of discordant points with younger ages. The oldest zircon plotted on the concordia curve is 2600 Ma, while the youngest is 236 ± 3 Ma, obtained from a zircon rim. All zircon age data for DO-9, except for two points, plot in a cluster ranging from 1900 to 2400 Ma (Fig. 4b). Data points in this cluster are closer to the concordia curve than those for DO-3. All data points for samples DO-3 and DO-9 fall within a triangular area on the concordia diagram with apexes of approximately 240 Ma, 1600 Ma, and 2800 Ma (Fig. 4).

Figure 5 shows three kinds of probability distribution diagrams for samples DO-3 and DO-9: U-Pb age, Pb-Pb age, and Pb-Pb age ($-10 < \text{Disc} (\%) < 10$). 'Disc (%)' is the degree of discordance for an analyzed area and indicates the chronological difference between the two ages determined by the Pb-Pb and U-Pb methods; this is defined as $\{1 - (^{238}\text{U}/^{206}\text{Pb}^* \text{ age}) / (^{207}\text{Pb}^*/^{206}\text{Pb}^* \text{ age})\} \times 100$ (%) (e.g., Biao et al., 1996). All analytical data were used for the distribution diagrams of both the U-Pb and Pb-Pb

Figure 3. Secondary electron images (SEIs; after analysis) and cathodoluminescence images of zircon grains from sample DO-3. Pits on SEIs are analytical sites for SHRIMP dating. Scale bars are 10 μm across.

ages. In addition to uncertainty in the discordant data, error margins for U-Pb and Pb-Pb ages are large for older and younger ages, respectively. In contrast, the plot of Pb-Pb ages ($-10 < \text{Disc} (\%) < 10$) provides the most probable age distribution for the samples, as the data are on or near the concordia line.

Figure 4. Tera-Wasserberg U-Pb concordia diagrams for zircons from the paragneiss samples DO-3 (a) and DO-9 (b). $^{207}\text{Pb}^*$ and $^{206}\text{Pb}^*$ indicate radiometric ^{207}Pb and ^{206}Pb , respectively. Solid curves are concordia curves.

DISCUSSION

At first glance, the apparent $^{238}\text{U}-^{206}\text{Pb}^*$ age spectrum of zircons from the Oki gneiss analyzed in this study (solid lines in Fig. 5) corresponds with the CHIME zircon ages (Suzuki and Adachi, 1994) in that both data sets contain a large number of old ages (ca. 1250, 1700, 2000, and 3000 Ma) and a smaller number of young ages (ca. 350 Ma). However, when the data are plotted on Tera-Wasserberg concordia diagrams, it turns out that most of the younger ages are derived from discordant data. Discordant data on the concordia diagram trend toward 300 to 200 Ma. Most of the concordant data range from 1600 to 2000 Ma for DO-3 gneiss and from 1900 to 2400 Ma for DO-9 gneiss, with only one rim analysis yielding a young concordant age of 236 ± 3 Ma in sample DO-3. This 236 Ma age is consistent with a CHIME monazite age that is interpreted to represent the age of metamorphism (Suzuki and Adachi, 1994). Concordant ages for sample DO-3 have a

Figure 5. Probability distribution diagrams of zircon ages from samples DO-3 (a) and DO-9 (b). Distribution curves for U/Pb age, Pb/Pb age, and Pb-Pb age ($-10 < \text{Disc}(\%) < 10$) are represented by fine lines, thick lines, and shaded areas, respectively. The Pb-Pb age ($-10 < \text{Disc}(\%) < 10$) data represent the most probable age distribution for the samples, as the data lie on or near the concordia line.

major peak at 1800 to 1900 Ma and small peaks at 2200 Ma, 2400 Ma, and 2600 Ma (shaded area in Fig. 5a).

Late Archean basement rocks occur widely across the North China Craton, and are mainly 2500 to 2600 Ma in age (Zhao et al., 2001). Although ages of 2400 Ma and 1800 to 2200 Ma are relatively rare in the North China Craton, they are more common in the Trans-North China Orogen (Fig. 1a). Zircon ages of 1600 to 2200 Ma are common in both the Gyeonggi and Yeongnam Massifs, Korea (e.g., Kwon and Jeong, 1990; Truok and Kim, 1996; Kim et al., 1999; Cheong et al., 2000; Lee et al., 2000; Sagong et al., 2003). Given the above age data, it appears that detrital zircons in sample DO-3 were mainly derived from Korean basement rocks, with a minor contribution from the North China Craton. In contrast, detrital zircons in sample DO-9 show a different age distribution, with a continuous distribution from 1900 to 2300 Ma (shaded area in Fig. 5b) and four peaks at 1900, 2000, 2200, and 2400 Ma. Although detrital zircons in sample DO-9 clearly show older ages than those in DO-3, the absence of Archean zircons suggests that the major provenance of the zircons in DO-9 is also the Korean Peninsula.

Sano et al. (2000) measured the U-Pb and Pb-Pb ages of zircons in Hida gneiss from the Aino area, and found that their concordant U-Pb ages are mostly younger

than 400 Ma. The Oki gneiss was previously considered to be an equivalent of the Hida gneiss, but the age distributions of zircons in the two gneisses are clearly different. The Tera-Wasserberg concordia diagrams shown in Figure 4 demonstrate that the lower intercepts of discordant data are around 200 to 300 Ma. If deposition of the parent material of the Oki gneiss occurred after 350 Ma, we would expect concordant core ages younger than 400 Ma. It is unrealistic to expect that concordant core ages in the Oki gneiss were restricted to ages in excess of 1600 Ma because igneous activity occurred across vast areas of East Asia subsequent to 350 Ma (e.g., Wang, 1986; Lee, 1987).

Sm-Nd whole-rock ages for Oki gneiss are 1980 ± 180 Ma for amphibolite and 1960 ± 820 Ma for paragneiss (Tanaka and Hoshino, 1987), which are similar to the average zircon ages for the Oki gneiss. If deposition was younger than 350 Ma, the drainage system would only have supplied detrital minerals to the paragneiss from older geological terranes, without any contribution from younger igneous rocks. As amphibolite was originally an igneous rock, it is reasonable to conclude that the whole-rock Sm-Nd age of 1980 ± 180 Ma indicates the crystallization age of the parent rock. Tanaka and Hoshino (1987) also concluded that the whole-rock age of the paragneiss represents the timing of source rock formation or the depositional age, as the CHUR model age for the paragneiss at Oki is 2.2 to 2.3 Ga. Model ages for the main part of the Hida gneiss are 1.0 to 1.5 Ga (Asano et al., 1990). Compiled Sm-Nd isotopic data for Korean basement rocks indicate a model age for the Gyeonggi Massif mainly in the range 2.5 to 3.0 Ga, with and some young (ca. 1.8 Ga) and old (older than 3.0 Ga) ages. Ages for the Yeongnam Massif show three clusters at around 1.5 Ga, 2.0 to 2.5 Ga, and 2.5 Ga (Cheong et al., 2000). In terms of Sm-Nd isotopic data from Korean basement rocks, the Oki gneiss data are consistent with the 2.0 to 2.5 Ga age cluster of the Yeongnam Massif. This indicates that the parent rocks of the Oki gneiss were related to the Yeongnam Massif rather than gneiss in the Hida area. Considering the relatively old ages of zircons in gneiss and old whole-rock age of associated amphibolite, it is reasonable to conclude that the parent rock of paragneiss on Oki-Dogo Island was deposited during the Proterozoic (ca. 1600 Ma) rather than during the Phanerozoic. Furthermore, it is possible that the Oki gneiss was once part of the Yeongnam Massif.

A number of U-Pb zircon ages have been reported for Precambrian rocks from the Japanese Islands. SHRIMP U-Pb and Pb-Pb ages of zircons from paragneiss clasts in a conglomerate from the Mino Belt, Kamiaso area, mostly yield ages in the range 1840 to

1950 Ma, with some ages in excess of 2400 Ma and as high as 3254 ± 14 Ma (Hidaka et al., 2002). Orthogneiss clasts from the same conglomerate represent the oldest rock in Japan, with whole-rock ages of 1985 ± 25 Ma (Rb-Sr; Shibata and Adachi, 1974) and 2.07 ± 0.06 Ga (Sm-Nd; Shimizu et al., 1996). CHIME zircon ages for the same rock yield dates of 1670 to 2050 Ma and up to 3040 ± 180 Ma (Adachi and Suzuki, 1993). The oldest dated igneous body is 502.5 ± 9.6 Ma; this is a zircon U-Pb (SHRIMP) date for the body of the Hikawa Granitoid, Kyushu (Sakashima et al., 2003). In terms of the K-Ar method, 592 ± 24 Ma (hornblende K-Ar age) for an amphibolite body from the Nomo Peninsula, Kyushu, is the oldest recorded date in Japan (Hattori and Shibata, 1982). Although the gneiss and amphibolite on Oki-Dogo Island underwent metamorphism at around 240 Ma, which is coincident with metamorphism of the main part of the Hida gneiss, it is probable that the parent rocks of the Oki gneiss and amphibolite formed during the Early Proterozoic, and therefore may be the oldest body in Japan.

CONCLUSIONS

- 1) Gneisses on Oki-Dogo Island show a different age distribution of detrital zircons from gneiss in the Hida area.
- 2) The zircon ages of two paragneisses on Oki-Dogo Island are mainly around 1800 Ma and 1900 to 2400 Ma.
- 3) The depositional ages of the parent sediments are not 250 to 350 Ma, but are much older, up to around 1600 Ma.
- 4) In terms of the depositional or igneous age, the Oki gneiss is a candidate for the oldest rock body in the Japanese islands.

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