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Petrology and Geochemistry of Jurassic Daejeon and Nonsan Granitoids in the Ogcheon Fold Belt, Korea*

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Abstract: The Jurassic Daejeon and Nonsan granitoids are "S-type" syntectonic calc-alkaline two-mica monzogranite and granodiorite, respectively. With evidences of high CaO, Al_2O_3, LIL/HFS elements, total REE, (Ce/Yb)N and initial ($^{87}Sr/^{86}Sr$) ratio, and no significant Eu anomaly, the primary magmas for the Daejeon and Nonsan granitic rocks are derived from partial melting of the Precambrian granulite (e.g. grey gneisses). But those Jurassic granitoids crystallised from different chemical characteristics of parental magmas which is mainly due to varying degree of partial melting of the granulite (crustal anatexis). The absence of significant anomalous Eu(Eu/Eu*=0.82~1.00) in the Daejeon and Nonsan granitoids could indicate that feldspars, mainly plagioclase, did not separate from the magmas. The parental hydrous magmas could not rise appreciably above their source region before crystallisation. The Jurassic granitoids may be resulted by closing-collision situation and belong to the Hercynotype (Pitcher 1979) such as compressive ductile regime of an intracontinental orogen.

INTRODUCTION

The Jurassic Daejeon and Nonsan granitoids in the Ogcheon Fold Belt transects the Korean peninsula along the Sinian direction with N30°E trend. The granitoids cover an area of about 1,200km² (60km×20km) and show a variety of texture and mineral composition (Fig. 1). The country rocks adjacent to the Jurassic granitoids are Precambrian gneisses at the NW margin of the studied area and metapelitic rocks of unknown age at the SE side.

The detailed geology of the Jurassic Daejeon and Nonsan granitoids was previously mapped at 1:50,000 scale by various geologists (Yuseong geologic quadrangle by Park, et al., 1977; Daejeon quadrangle by Lee, et al., 1980; Ganggyeong quadrangle by Lee, et al., 1980; Nonsan quadrangle by Chang & Hwang, 1980).

The Precambrian gneisses around the grani-

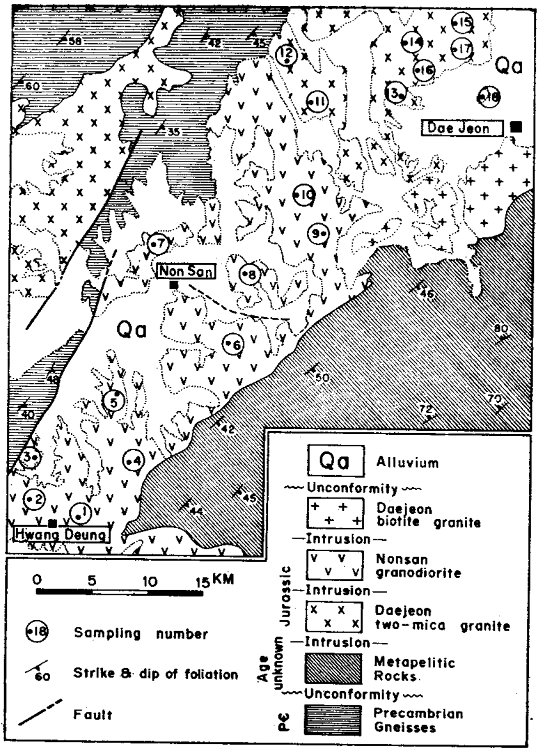

Fig. 1 The sample location of the Daejeon and Nonsan granitic rocks (Modified from Geological map of Korea, 1973).

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** Korea Institute of Energy and Resources (KIER) toids were radiometrically dated by Hurley et al (1973), they have obtained Rb/Sr whole rock ages of 1,330~1,985Ma at the northern part of the studied area.

The age of initial sedimentation of the metapelitic rocks is still controversial; late proterozoic is proposed by Reedman and Um (1975), and Cambro-Ordovician by Son (1970).

The granitoids appear to have intruded the Precambrian gneisses and the metapelitic rocks in the Ogcheon Fold Belt during and/or after the Daebo orogeny—mid to late Jurassic (Lee, 1971).

FIELD RELATIONS

Foliation in the Precambrian gneisses (N35°~40°E/40°~60°SE) is generally parallel with the Sinian direction, and mafic and felsic parts alternate regularly as a banded structure. The main mineral constituents of the Precambrian rock are plagioclase, quartz, biotite and muscovite, with garnet and magnetite as accessory minerals. Feldspar and garnet are found as porphyroblasts. The contact between the Jurassic granitoids and the Precambrian rock is poorly exposed.

Metapelitic rocks consist of micaschist interbedded with quartzite, black slate, and crystalline limestone. Petrographic study of the metapelitic rocks by Lee et al (1980) reveals that the rocks were affected by low grade regional metamorphism (greenschist facies) during the Daebo orogeny. Those rocks were thermally metamorphosed again to amphibole-hornfels by the Jurassic granite intrusion (Lee et al., 1980). But, no significant contact metamorphic aureoles are observed in the country rocks adjacent to the Jurassic Daejeon and Nonsan granitoids. The main direction of foliation in the metapelitic rocks in N30°~75°E/40°~50°SE, but in some places is up to 70°~80°NW dip owing to repeat by isoclinal folds. The contact between the metapelitic rocks and the granitoids is generally sharp.

The Jurassic granitoids in the studied area can be divided into three different rock types; (1) The first type is a medium grained Daejeon two-mica foliated granite which is locally distributed in the northern part of the Daejeon (Fig. 1). Choo et al (1982) has radiometrically dated the Daejeon two-mica granite as 190Ma by Rb/Sr two point age (whole rock and biotite) with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7176. (2) The second type is a medium to coarse grained and slightly foliated, porphyroblastic biotite granodiorite with megacrysts of K-feldspar (up to 3cm in length) which is exposed over most of the Nonsan. Kim (1971) and Choo (1971) dated the Nonsan granodiorite as 153Ma and 158Ma, respectively by K/Ar method on biotites. Recent Rb/Sr whole rock age on the granodiorite from the Hwangdeung by Kim and Wendt (1982, Pers. Comm.) shows 167Ma with an initial $^{87}Sr/^{86}Sr$ value of 0.7104. (3) The third type is a coarse grained biotite granite which is located in the southern part of the Daejeon. The Daejeon biotite granite also has been dated as 163~175Ma by Rb/Sr two point age (whole rock and biotite) with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7095~0.7107 (Choo et al., 1982).

The main foliation of the studied granitoids is generally N20°~30°E which is parallel to the Ogcheon Fold Belt. The following is a summary of the field sequence: 1) The Daejeon two-mica granite appears to be homogeneous and intruded the country rocks in the NE part of the studied area. 2) The first phase of Nonsan granodiorite, which is abundant in the Hwangdeung, intruded with incorporation of mafic xenoliths. The size of xenoliths is up to 30cm in length with an average of 20cm. They are subangular, deformed and slightly digested by the granitic melt which suggest relatively local derivation. 3) The second phase of granodiorite, which includes the first phase of the granodiorite as xenoliths, intruded throughout the Nonsan. The megacrysts of K-feldspar, which shows an average of 2cm in length, were grown again during the intrusion of the second phase of granodiorite. Both magmatic and metasomatic origins have been proposed for regrowth of the K-feldspar megacrysts, but the former is preferred since the megacrysts are generally poikilitic and enclosing other magmatic mineral species (e.g. biotite). 4) The coarse grained Daejeon biotite granite intruded as last phase in the studied area at the southern part of the Daejeon. 5) The first phase of aplite cut through the foliation of the granodiorites. Folding of primary foliation suggests deformation while the granitic rocks are still hot(syntectonic intrusions). The alignment of the K-feldspar megacrysts and of the mafic xenoliths is parallel to the foliation of biotite, which implies a certain extent of compression. The schlierens are abundant only in the NE side of the Nonsan granodiorite and oriented parallel to the biotite foliation. 6) The second phase of aplite, pegmatite and dolerite intruded, undeformed and aligned with the Sinian direction as postdeformation phases. 7) The granitoids were possibly uplifted before final crystallisation of the magmas with evidences of predominant horizontal joints which is mainly due to release of load pressure.

PETROGRAPHY

Daejeon two-mica granite

Quartz occurs anhedral to subhedral grains and up to 3mm with an average length of 1mm. Quartz crystals are slightly fractured with normal extinctions and rarely seen undulatory extinctions. Myrmekitic intergrowth around the quartz and feldspar is observed in many places. Alkali-feldspar shows subhedral tabular shapes and up to 3mm in length with mean of 1mm. Microline is dominant with cross-hatched twinning. Plagioclase forms generally as subhedral crystals and its grain sizes range up to 3mm with an average of 1.5mm in length. The plagioclase is identified as oligoclase. Parallel twinning is dominant in the plagioclase, but faintly zoned structures are also observed. Biotite occurs as subhedral and tabular grains up to 1.5mm. The biotite frequently displays poikilitic textures with inclusions of apatite, zircon, sphene and opaques. Muscovite, which has a mean length of 0.5mm, is mainly as primary(magmatic) origin since the muscovite formed well-crystallised grains and intergrown with biotite.

Nonan granodiorite

Quartz is observed as anhedral to subedral grains up to 5mm in long length an average of 2mm. The crystals are slightly fractured and show mostly normal extinction. Poikilitic quartz with inclusions of enhedral sphene and biotite laths is found in many places. Myrmekite is abundant in the granodiorite. The myrmekitic quartz shows no preferred orientation, but converge perpendicular to an outwardly convex boundary, widen inward, then terminate in blunt lobes. Myrmekite may form by sodium and calcium metasomatism of alkali-feldspar, or possibly by exsolution. If a solution with a higher(Na+Ca)/K activity ratio than that required for equilibrium with alkali-feldspar is present, ionic exchange rapidly produces plagioclase and excess silica which is precipitated essentially in places as quartz blobs. The string type of perthitic microcline is dominant in the Nonsan granodiorite as subhedral grains. Plagioclase shows subhedral columnar shape with up to 4mm in long length. The plagioclase is known as oligoclase(An 18~30) and shows zonnation in some places, but, mostly parallel twinning. Poikilitic biotite with inclusions of zircon, apatite and sphene is abundant. Iron oxide occurs as subrounded grains up to 0.3mm across and often surrounded by biotite crystals. Zircon occurs as subhedral grains with an average length of 0.02mm and it is noticeable particularly by its pleochroic haloes in biotite. Apatite is found as irregularly oriented needle-shapes in biotite. Spene occurs predominantly in the Nonsan granodiorite as euhedral to subhedral diamond-shaped grains (up to 1mm in length with an average of 0.5mm) and appears to overgrow biotite crystals.

MODAL ANALYSIS

The modal compositions of the samples from the Jurassic Daejeon and Nonsan granitoids are shown in Table 1. The minerals present in each specimen from the studied area were point-counted frm etched large sections (4cm × 2cm). Alkali-feldspar was stained using the sodium cobalitinitrate method (Bailey & Stevens, 1960). All samples were counted for about 2,000 points and plotted on a quartz-alkali feldspar-plagioclase diagram for classification (Streckeisen, 1976). Total variations are seen to be from granodiorite to monzogranite (Fig. 2).

MINERAL CHEMISTRY

The mineral chemistry of representative samples from the Jurassic granitoids was studied using the energy dispersive electron microprobe. The analytical results are presented for alkali-feldspar, plagioclase and biotite (Table 2, 4, 5). The electron beam is normally incident with an accelerating voltage of 20KV and a specimen current 25~30nA. Fluorescent *X*-ray photons are detected at a take off angle of 40° with a 4mm^2 Si(Li) detector. Further details of analytical techniques are available from Hong (1983).

Analytical results for the exsolved alkali-feldspars are given in Table 2. The numbers of cations K and Na in the perthitic alkali-feldspars do not show any significant trend. A technique for determining geological temperature

Table 1 Modal composition of the Jurassic granitoids (in volume percent).
JN (Jurassic Nonsan granodiorite), JD (Jurassic Daejeon two-mica granite).

	JN. 1	JN. 2	JN. 3	JN. 4	JN. 5	JN. 6	JN. 7	JN. 8	JN. 9
Quartz	30.1	34.1	31.0	31.6	40.9	36.3	32.8	37.8	32.7
K-feldspar	16.6	16.4	17.6	9.3	11.1	15.0	17.6	19.4	10.0
Plagioclase	40.3	39.9	35.4	43.4	35.3	34.5	35.7	40.0	35.9
Biotite	7.9	7.4	13.7	12.8	8.7	11.0	11.8	0.4	20.4
Myrmekite	2.7	1.5	1.1	0.6	2.8	1.3	0.9	0.1	0.2
Muscovite	—	—	0.2	—	—	—	—	2.4	0.7
Sphene	0.6	—	0.1	1.4	0.6	1.1	0.7	—	—
Zircon & Apatite	0.8	—	0.2	0.4	0.4	0.2	0.1	—	—
Opaques	0.9	0.6	0.8	0.5	0.4	0.6	0.5	—	—

	JN. 10	JD. 11	JD. 12	JD. 13	JD. 14	JD. 15	JD. 16	JD. 17	JD. 18
Quartz	25.8	37.1	38.4	29.8	30.2	45.9	32.6	40.7	33.9
K-feldspar	12.1	26.6	21.5	34.0	29.1	12.8	25.3	23.4	27.3
Plagioclase	41.7	24.8	27.7	27.1	33.5	29.3	38.4	26.5	32.6
Biotite	17.8	8.2	7.5	8.2	4.7	8.0	0.5	4.3	3.5
Myrmekite	0.6	2.4	1.9	0.1	1.5	3.4	0.5	3.2	1.8
Muscovite	0.3	0.9	2.8	0.4	0.6	0.7	2.7	1.7	0.8
Sphene	1.4	tr.	tr.	—	—	—	—	—	—
Zircon & Apatite	0.3	—	0.3	—	—	—	—	—	—
Opaques	—	—	—	0.5	0.3	—	—	—	0.1

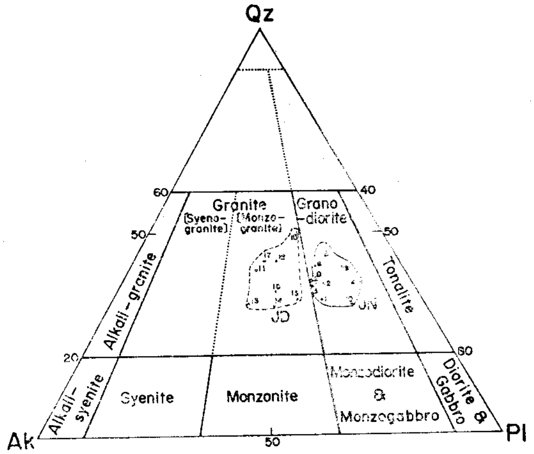

Fig. 2 Modal proportion of quartz (Qz), alkali-feldspar (Ak) and plagioclase (Pl) of the Jurassic Daejeon (JD) and Nonsan (JN) granitic rocks (after Streckeisen, 1976).

base on the distribution of the albite($NaAlSi_3O_8$) component between the two co-existing feldspars is of great practical significance. Details of this geothermometer are described in Stormer (1975) and Powell & Powell (1977). The graphical representation of geothermometer by Stormer (1975) illustrates that the perthites plot in small range which shows little temperature variation over the studied areas. Using Powell & Powell's geothermometer, calculated temperatures for cessation of exsolution in perthitic alkali-feldspars remain within a generally narrow range of about 350°C～450°C at assumed pressure of 0.5～3 kbar for Daejeon two-mica granite and 400°C～475°C at assumed pressure of 5 kbar for Nonsan granodiorite (Table 3). The small temperature variation of the perthites in granitoids could be explained as the country rocks adjacent to the granitic rocks had been under high heat flow regime (Daebo orogeny) during the intrusion and those rocks had cooled down slowly.

Twinned plagioclases are analysed and presented with structural formulae in Table 4. Numbers of cation Ca in plagioclases are higher in the Daejeon two-mica granite (0.320～0.373)

Table 2. Electron microprobe analyses of perthitic alkali-feldspar for the Jurassic Daejeon and Nonsan granitic rocks.

	JN. 1		JN. 4		JN. 5		JN. 6		JD. 17		JD. 18	
	AF	PL	AF	PL	AF	PL	AF	PL	AF	PL	AF	PL
SiO_2	64.931	61.824	63.953	61.308	64.307	60.682	65.116	60.744	64.610	59.590	64.190	59.897
Al_2O_3	18.278	23.370	18.529	24.438	19.123	24.558	18.414	24.349	18.508	25.238	19.008	24.908
FeO(t)	—	0.360	—	0.123	—	0.145	—	—	—	—	—	—
CaO	—	4.851	—	6.270	—	6.262	—	6.068	—	6.942	—	6.779
BaO	0.360	—	0.793	—	0.689	—	0.336	—	0.351	—	0.438	—
Na_2O	0.835	8.599	0.730	8.025	1.154	7.989	0.757	8.158	0.939	7.683	0.776	7.728
K_2O	15.397	0.269	15.032	0.129	14.746	0.173	15.246	0.206	15.019	0.124	15.033	0.278
Total	99.800	99.274	99.037	100.292	100.019	99.809	99.869	99.526	99.427	99.577	99.443	99.589

Recalculated on 8 oxygens

	JN. 1 AF	JN. 1 PL	JN. 4 AF	JN. 4 PL	JN. 5 AF	JN. 5 PL	JN. 6 AF	JN. 6 PL	JD. 17 AF	JD. 17 PL	JD. 18 AF	JD. 18 PL
Si	3.003	2.763	2.987	2.717	2.970	2.705	3.004	2.713	2.995	2.667	2.977	2.680
Al	0.997	1.231	1.020	1.277	1.041	1.290	1.002	1.282	1.011	1.331	1.039	1.314
Fe	—	0.013	—	0.005	—	0.005	—	—	—	—	—	—
Ca	—	0.232	—	0.298	—	0.299	—	0.290	—	0.333	—	0.325
Ba	0.007	—	0.015	—	0.012	—	0.006	—	0.006	—	0.008	—
Na	0.075	0.745	0.066	0.689	0.103	0.690	0.068	0.706	0.084	0.666	0.070	0.670
K	0.909	0.015	0.896	0.007	0.869	0.010	0.897	0.012	0.888	0.007	0.889	0.016

Table 3 Temperatures of cessation of exsolution at the various pressures for the Jurassic Daejeon and Nonsan granitic rocks (after Powell & Powell 1977).

	Mineral	X_{NA}	X_K	T°C			
				1Kb	3Kb	5Kb	7Kb
JN. 1	AF	0.075	0.909	387	406	426	445
	PL	0.745	0.015				
JN. 4	AF	0.066	0.896	366	384	400	421
	PL	0.689	0.007				
JN. 5	AF	0.103	0.869	434	455	475	496
	PL	0.690	0.010				
JN. 6	AF	0.068	0.897	368	387	405	424
	PL	0.706	0.012				
JD. 17	AF	0.084	0.888	411	431	450	471
	PL	0.666	0.007				
JD. 18	AF	0.070	0.889	375	394	413	431
	PL	0.670	0.016				

Table 4 Plagioclase analyses for the Jurassic Daejeon and Nonsan granitic rocks.

	JN. 1	JN. 4	JN. 5	JN. 6	JD. 11	JD. 17	JD. 18
SiO_2	62.385	61.238	62.287	59.943	58.846	60.502	60.210
Al_2O_3	23.547	24.769	23.998	25.995	25.801	24.972	25.732
FeO(t)	—	—	0.125	—	—	—	—
CaO	5.005	6.585	5.559	5.984	7.769	6.708	7.189
Na_2O	8.748	8.086	8.305	8.263	7.187	7.739	7.555
K_2O	0.259	0.139	0.198	0.138	0.098	—	0.151
Total	99.943	100.817	100.472	100.323	99.699	99.921	100.837
Recalculated on 8 oxygens							
Si	2.766	2.703	2.749	2.659	2.635	2.691	2.661
Al	1.231	1.289	1.249	1.359	1.362	1.309	1.340
Fe	—	—	0.005	—	—	—	—
Ca	0.238	0.311	0.263	0.284	0.373	0.320	0.340
Na	0.752	0.692	0.711	0.710	0.624	0.667	0.647
K	0.015	0.008	0.011	0.008	0.006	—	0.008
Mole proportion (%)							
Or	1.5	0.8	1.1	0.8	0.6	—	0.8
Ab	74.8	68.4	72.2	70.9	62.2	67.6	65.0
An	23.7	30.8	26.7	28.3	37.2	32.4	34.2

than in the Nonsan granodiorite (0.238~0.311). And, the number of cation alkalis in plagioclase is higher in the Nonsan granodiorite relative to the Daejeon two-mica granite. Plagioclase shows a total compositional range An 32-37 for the Daejeon twomica granite and An 24-30 for the Nonsan granodiorite. But, the whole-rock geochemical results show that the Daejeon two-mica granite is more chemically evolved than the Nonsan granodiorite in terms of magmatic differentiation. This is mainly because of fact either the abundance of plagioclase in the Nonsan granodiorite is higher (38% in modal volume) than in the Daejeon two-mica granite (30% in mode) or the mafic minerals are abundant in the Nonsan granodiorite (12% in volume) compare to the Daejeon two-mica granite (7% in volume) whereas cation Ca can be accomodated not only in the plagioclase but in the mafic minerals.

The analytical results and structural formulae of biotites from the Jurassic granitoids are given in Table 5. The Al_2O_3-total iron-MgO ternary diagram shows that MgO in biotite crystals varies considerably. The content of MgO in biotite is higher in the Nonsan granodiorite relative to the Daejeon two-mica granite. Ionic Mg/(Mg+Fe) ratios in the biotites show that the ratios are higher in the Nonsan granodiorite but ionic Fe/(Fe+Mg) ratios are higher in the Daejeon granitoids, although the ratios show a little variation within each pluton.

WHOLE ROCK CHEMISTRY

Eighteen representative granitic rocks were analysed for major and trace elements by *X*-ray fluorescence spectrometry (XRF) method. Six additional samples were analysed for rare-earth

Table 5 Analyses of biotites from the Jurassic Daejeon and Nonsan granitic rocks.

	JN. 1	JN. 4	JN. 5	JN. 6	JD. 11	JD. 17	JD. 18
SiO_2	35.627	36.371	36.823	36.629	34.789	35.668	35.042
Al_2O_3	15.010	14.784	15.173	15.327	16.128	16.990	17.493
TiO_2	3.214	2.045	1.844	2.015	2.670	2.990	2.763
FeO(t)	21.120	20.494	20.489	20.339	23.949	23.846	22.194
MgO	8.986	10.508	10.591	10.185	6.378	6.720	7.204
MnO	0.210	0.265	0.278	0.346	0.598	0.833	0.247
CaO	—	—	0.087	—	0.115	0.172	0.153
K_2O	9.537	9.537	9.485	9.672	9.455	9.670	8.796
Total	93.704	94.004	94.770	94.512	94.018	96.889	93.892

Recaldulated on 11 oxygens

Si	2.800	2.836	2.841	2.837	2.767	2.746	2.744
Al	1.391	1.359	1.380	1.399	1.512	1.542	1.615
Ti	0.190	0.120	0.107	0.117	0.160	0.173	0.163
Fe	1.388	1.336	1.322	1.317	1.593	1.535	1.454
Mg	1.053	1.221	1.218	1.175	0.756	0.771	0.841
Mn	0.014	0.018	0.018	0.023	0.040	0.054	0.016
Ca	—	—	0.007	—	0.010	0.014	0.013
K	0.956	0.949	0.934	0.956	0.959	0.950	0.879
Ionic Mg/(Mg+Fe)	43.13	47.74	47.95	47.16	32.18	33.43	36.65
Inoic Fe/(Mg+Fe)	0.70	0.66	0.66	0.67	0.79	0.78	0.75

elements by instrumental neutron activation analysis (INAA) using a Ge (Li) low energy photon detector. Details of analytical techniques for major, trace and rare-earth elements are described in Hong (1983).

The analytical results of 11 major oxide elements and CIPW norms are presented in Table 6. The changes in the abundance of major element are shown in the Harker variation diagrams (Fig. 3). The Nonsan granodiorites show a widely scattered in silica content from 63% to 70% in weight (mean value of 67%). The silica content generally increases from NE to SW of the Nonsan granodiorite area. The Daejeon two-mica granite illustrates a small variation from 70% to 72% in weight (average value of 71%). The average ratio of K_2O/Na_2O in the Nonsan granodiorite is 0.88, but in the Daejeon two-mica granite is 1.07.

The Nonsan granodiorite appears to show increases in SiO_2, K_2O, Na_2O, D.I and L.I, and decreases total iron, MnO, TiO_2, Al_2O_3 and P_2O_5. The Daejeon two-mica granite shows very little compositional variations in the major elements but, overall, it is much more chemically evolved than the Nonsan granodiorite (Fig. 3).

The alkalinity ratio (Wright, 1969) and calcium oxide/alkalis against silica diagram (Brown, 1979) show thah the Daejeon and Nonsan granitoids plot within the calc-alkaline field. The CIPW norm gives normative corun-

Table 6 Major element analyses and CIPW Norms of the Jurassic Daejeon and Nonsan granitic rocks. L.I: Larsen Index. D.I: Differentiation Index.

	JN. 1	JN. 2	JN. 3	JN. 4	JN. 5	JN. 6	JN. 7	JN. 8	JN. 9
SiO_2	69.08	70.04	68.35	66.26	66.60	68.94	67.50	66.87	63.07
TiO_2	0.49	0.46	0.54	0.66	0.65	0.51	0.62	0.64	0.68
Al_2O_3	15.76	15.17	15.90	16.51	16.25	15.85	15.45	16.25	18.19
Fe_2O_3	1.09	1.05	1.21	1.43	1.44	1.13	1.58	1.67	1.36
FeO	2.27	1.81	2.78	2.89	2.95	2.34	2.72	2.78	3.89
MnO	0.04	0.04	0.04	0.05	0.06	0.04	0.05	0.06	0.08
MgO	0.70	0.54	0.93	1.31	1.33	0.86	1.12	1.26	1.78
CaO	2.55	2.12	2.84	3.44	3.42	2.78	2.80	3.31	4.42
Na_2O	4.28	4.02	4.15	4.01	3.96	3.83	3.84	3.90	3.85
K_2O	3.87	4.28	3.51	3.49	3.44	3.78	3.42	3.54	2.80
P_2O_5	0.17	0.12	0.19	0.20	0.19	0.15	0.18	0.19	0.19
Total	100.30	99.64	100.42	100.26	100.28	100.20	99.29	100.47	100.31
CIPW Norms									
Q	22.19	24.46	22.35	19.40	20.14	24.20	23.66	20.94	16.08
Or	22.87	25.29	20.74	20.62	20.33	22.34	20.21	20.92	16.15
Ab	36.22	34.02	35.12	33.93	33.51	32.41	32.49	33.00	32.58
An	11.54	9.73	12.85	15.76	15.73	12.81	12.72	15.18	20.69
Hy	4.28	3.12	5.60	6.39	6.58	4.74	5.55	5.92	9.48
Mt	1.58	1.52	1.75	2.07	2.09	1.64	2.29	2.42	1.97
Cr	0.03	0.36	0.57	0.36	0.25	0.76	0.77	0.44	1.25
Il	0.93	0.87	1.03	1.25	1.23	0.97	1.68	1.22	1.29
Ap	0.39	0.28	0.44	0.46	0.44	0.35	0.42	0.44	0.44
L.I	21.38	23.16	19.74	17.94	17.94	20.78	19.28	18.48	13.73
D.I	81.28	83.77	78.20	73.95	73.98	78.94	76.36	74.86	65.20

Table 6 Continued.

	JN. 10	JD. 11	JD. 12	JD. 13	JD. 14	JD. 15	JD. 16	JD. 17	JD. 18
SiO_2	63.78	71.16	70.68	71.03	71.05	70.61	70.51	72.05	70.86
TiO_2	0.74	0.24	0.24	0.38	0.31	0.23	0.23	0.20	0.26
Al_2O_3	17.21	15.37	16.01	15.53	15.58	16.04	15.71	15.25	15.64
Fe_2O_3	1.68	1.14	1.18	1.07	1.01	1.20	1.42	1.39	1.19
FeO	3.93	1.57	1.47	1.23	1.14	1.41	1.03	1.18	1.39
MnO	0.08	0.08	0.07	0.02	0.03	0.05	0.05	0.08	0.04
MgO	1.86	0.59	0.54	0.45	0.44	0.53	0.51	0.46	0.66
CaO	3.61	3.03	3.04	1.84	2.14	2.63	2.64	2.41	3.08
Na_2O	3.69	3.36	3.36	4.02	3.75	3.44	3.71	3.16	3.37
K_2O	2.70	3.17	3.57	4.13	4.14	3.59	3.67	3.79	3.32
P_2O_5	0.22	0.09	0.10	0.11	0.09	0.10	0.09	0.09	0.10
Total	99.51	99.79	100.26	99.81	99.69	99.83	99.56	100.06	99.91
CIPW Norms									
Q	19.93	31.60	29.77	27.18	28.04	30.12	28.53	33.19	30.70
Or	15.96	18.73	21.10	24.41	24.46	21.21	21.69	22.40	19.62
Ab	31.22	28.43	28.43	34.02	31.73	29.11	31.39	26.74	28.52
An	16.47	14.44	14.43	8.41	10.03	12.39	12.51	11.37	14.63
Hy	9.39	3.16	2.80	1.91	1.90	2.63	1.70	1.98	2.86
Mt	2.44	1.65	1.71	1.55	1.46	1.74	2.06	2.02	1.73
Cr	2.18	1.12	1.33	1.37	1.26	1.95	1.05	1.78	1.14
Il	1.41	0.46	0.46	0.72	0.59	0.44	0.44	0.38	0.49
Ap	0.51	0.21	0.23	0.25	0.21	0.23	0.21	0.21	0.23
L.I	14.56	21.70	22.08	24.29	24.10	22.56	22.99	23.76	21.81
D.I	67.11	78.76	79.30	85.60	84.24	80.44	81.61	82.32	78.83

dum (Table 6) and shows this calculated mineral increasing with normative quartz which is possibly due to post-consolidation upset by percolating groundwater in the elemental proportions or contamination of pelitic country rock.

Trace and rare-earth element analytical results are listed in Table 7 and Table 8, respectively. The conventional Harker variations for the trace element are plotted in Fig. 4. The Daejeon two-mica granite shows wide range (120~183ppm) in Rb concetrations relative to the Nonsan granodiorite (110~142ppm). The plot between Rb and Sr shows a negative relationship. Rb/Sr ratios are higher in the Daejeon two-mica granite (0.19~0.35) than in the Nonsan granodiorite (0.16~0.24) and show positive trend with Rb. K/Rb ratios range from 176 to 267 in the Nonsan granodiorite with mean value of 230 and are plotted against the differentiation index showing a positive correlation. K/Rb ratios in the Daejeon two-mica granite illustrate a small variation (181~233) with average ratio of 210.

On a plot of K/Rb versus Rb/Sr (Fig. 5), the Jurassic Daejeon and Nonson granitoids cluster in two separate groups. This can be explained by differing parental materials and those granitoids are certainly not the final products of different degree of fractional crystallisation from same parental magma. Variation of less mobile elements such as Zr, Ti, Nb, Cr, Ni and V in the granitoids also reflect differences in source compositions of parental magmas.

The REE abundance data for the Daejeon

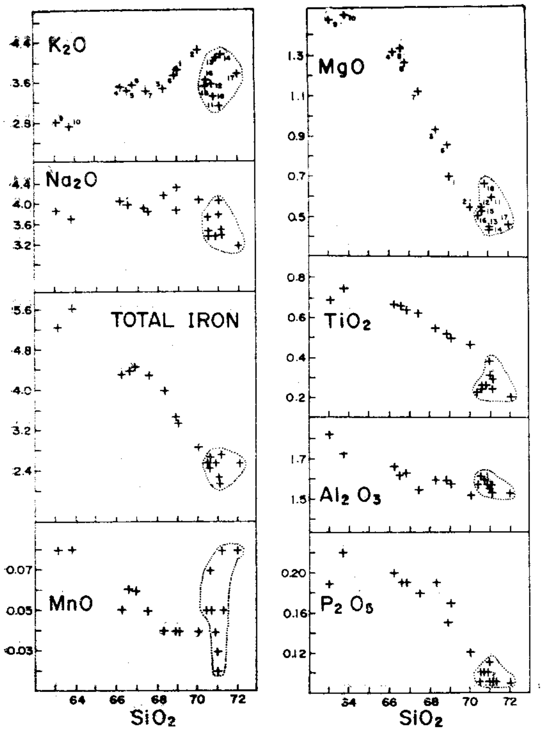

Fig. 3 Harker (major elements in wt. %) variation diagrams of the Daejeon two-mica granite (dotted line) and the Nonsan granodiorite. The numbers are as sample location in Fig. 1.

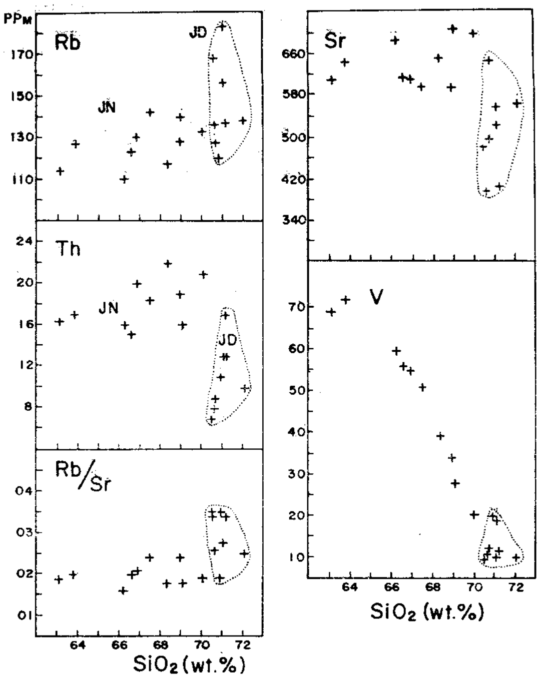

Fig. 4 Harker (trace elements) for the Daejeon and Nonsan granitic rocks.

and Nonsan granitoids have been normalised to the average chondritic abundances (Frey et al 1968), and presented in Table 8. The chondrite-normalised REE patterns for the granitoids yield very similar patterns (Fig. 6) with steep negative slopes which show light REE enrichment and few or no Eu anomalies. Both the Daejeon and Nonsan granitic rocks are characterised by high total REE (about 215ppm). The occurrence of Eu anomalies, which would be expected from feldspar fractionation, are absent in the Daejeon and Nonsan granitic rocks. The studied granitic rocks show heavy REE depletion with (Ce/Yb) N ratios of 20~120. The highly fractionated REE distribution patterns with few or no Eu anomalies in the Jurassic granitic rocks militate against a direct mantle origin. The REE results

Table 7 Trace elements analyses (in ppm) of the Jurassic Daejeon and Nonsan granitic rocks.

	JN. 1	JN. 2	JN. 3	JN. 4	JN. 5	JN. 6	JN. 7	JN. 8	JN. 9
Ni	3	4	3	5	5	4	5	4	5
Cr	12	19	17	23	22	20	22	21	22
Y	7	2	4	13	11	9	9	13	14
V	28	20	39	59	56	34	51	55	69
Zr	205	250	206	183	177	167	191	186	175
Nb	9	7	7	12	12	9	13	13	11
Rb	128	133	117	110	123	140	142	130	114
Sr	711	699	651	684	616	597	598	615	612
Th	16	21	22	16	15	19	18	20	16

Table 7 Continued

	JN. 10	JD. 11	JD. 12	JD. 13	JD. 14	JD. 15	JD. 16	JD. 17	JD. 18
Ni	5	3	3	2	3	2	2	2	2
Cr	20	13	15	9	13	11	19	12	14
Y	12	31	26	7	15	22	11	13	19
V	72	12	12	19	10	11	10	10	20
Zr	197	185	142	192	159	147	133	109	167
Nb	12	43	25	8	13	36	15	16	20
Rb	127	137	127	156	183	136	168	138	120
Sr	643	403	499	560	522	398	480	564	648
Th	17	17	9	13	13	8	7	10	11

Table 8 Rare-Earth Elements analyses (in ppm) of the Jurassic Daejeon and Nonsan granitic rocks.

	JN. 2	JN. 3	JN. 7	JN. 9	JD. 15	JD. 17
La	71.13	69.17	41.33	48.54	67.82	59.04
Ce	137.23	121.01	87.72	93.39	114.56	96.27
Nd	47.48	39.35	35.01	31.82	34.22	29.02
Sm	5.98	4.88	5.34	4.67	5.27	4.22
Eu	1.44	1.10	1.27	1.43	1.08	1.02
Gd	3.37	2.65	3.45	3.92	3.25	2.82
Tb	0.41	0.31	0.51	0.58	0.46	0.41
Tm	0.06	0.06	0.13	0.22	0.20	0.16
Yb	0.29	0.26	0.64	1.20	1.15	0.94
Lu	ND	ND	0.08	0.11	0.18	0.12
Hf	6.23	5.34	5.18	5.42	3.42	3.12
Ta	0.12	0.21	1.03	ND	1.37	1.80
ΣREE	267.39	238.79	175.48	185.88	228.19	194.02
La/Yb	245.28	266.04	64.46	40.45	58.97	62.81
Ce/Yb	473.21	465.42	137.06	77.83	99.62	102.41
Eu/Eu*	1.00	0.97	0.92	1.00	0.82	0.87
(La/Sm)N	7.36	8.61	4.81	6.26	8.33	8.68
(Ce/Yb)N	120.04	118.40	34.80	19.80	24.81	26.06
(La/Yb)N	167.69	175.00	54.35	46.03	37.04	50.86
Zr/Hf	40.13	38.58	36.87	32.29	42.98	34.94
ΣCe	263.26	235.51	170.67	179.85	222.95	189.57
ΣY	4.13	3.28	4.81	6.03	5.24	4.45

ΣREE: total concentration of REE
Eu* : Eu value derived by interpolation between Sm and Gd
N : chondrite normalised value
ΣCe : sum of light REE (La to Eu)
ΣY : sum of heavy REE (Gd to Lu)

of the Jurassic granitoids agree with the average REE pattern for Precambrian metasedimentary rocks (Shaw et al 1976); heavy REE depletion is thought to have occurred by hornblende and/or garnet fractionation during differentiation (Hanson 1978), or those minerals are not involved in the process of partial melting. For example, the REE content of the average

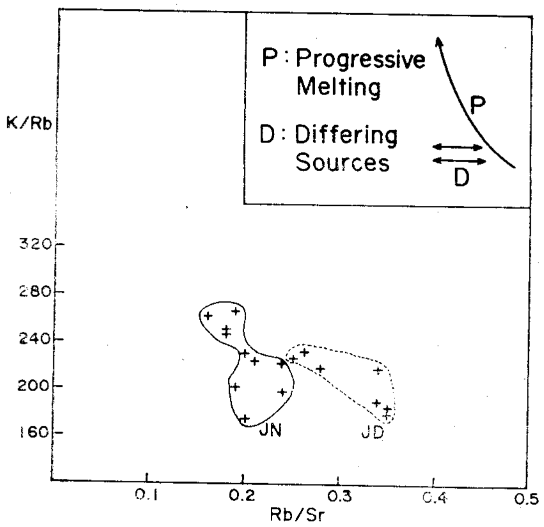

Fig. 5 Variation in ratios K/Rb versus Rb/Sr in the Daejeon and Nonsan granitoids. The insert shows trend that might result either from differing degrees of partial melting of a fixed source composition or from differing source compositions (after Strong & Hanmer, 1981).

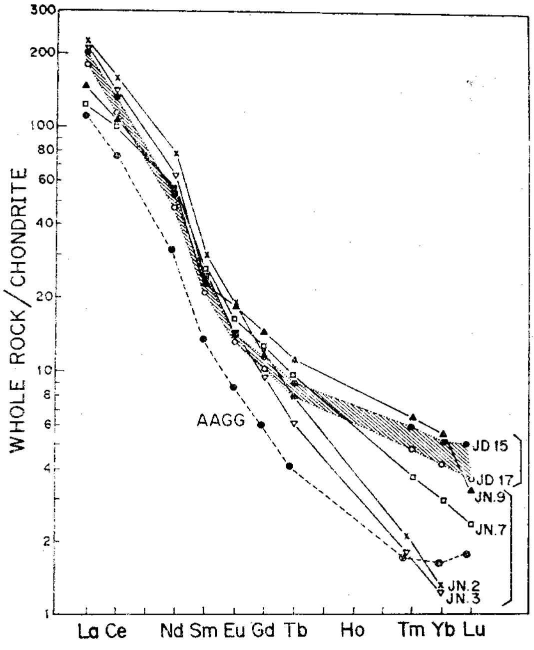

Fig. 6 Chondrite-normalised REE patterns for the Daejeon and Nonsan granitic rocks. AAGG: Average Achaean Grey Gneisses(after Martin, H. et al. 1983).

Archaean grey gneiss in the Finland shows quite similar pattern with the Jurassic granitoids (Fig. 6 and Table 9). The high total amount of REE in the granitoids (175∼267ppm) is possibly due to either the abundant presence of the accessary iminerals (Sawka, et al. 1984) or the dervation of the granitoids from LIL elements, including REE, enriched source materials.

DISCUSSION

The Jurassic Daejeon and Nonsan granitic rocks are subsolvus granitic rocks, mainly consisting of two-feldspars, quartz and biotite. These granitic rocks show considerable variation in texture and mineral components; (1) the Nonsan granodiorite is a medium to coarse grained and slightly foliated porphyritic granodiorite with megacrysts of K-feldspar; and (2) the Daejeon granite is strongly foliated and medium grained two-mica granite.

The widespread distribution of schlieren in the Nonsan granodiorite suggests possible preservation of "restite" which left behind by voluminous partial melting of the source terrane. These facts illustrate the deformation took place while the complexes were still hot (syntectonic intrusion) during the Daebo orogeny. The mineralogical and chemical homogeneity of the Daejeon two-mica granite and its generally felsic nature suggests that it might be derived from by partial melting of the continental crust and undergone little differentiation. In terms of nomenclature of Chappell & White (1974), there is a distinction between the Daejeon two-mica granite and the Nonsan granodiorite; (1) the former exhibits most of the diagnostic features of "S-type" by restricted range of major element and two-mica. (2) the latter shows a broad compositional spectrum in major and trace elements, high Ca and Na/K, and contains sphene. The characteristic between the granitic

Table 9 The average modal composition and major, trace elements in the studied granitic rocks and the Average Archaean Grey Gneisses (AAGG) from the Eastern Finland (after Martin, H. et al. 1983)

	JN	JD	AAGG
Qz(%)	33.3	36.1	13.5
Or	14.5	25.0	16.3
Pl	38.2	30.0	53.3
Hb	—	—	17
Bt	11.2	5.6	—
SiO_2	67.05	71.00	60.54
TiO_2	0.60	0.27	0.42
Al_2O_3	16.25	15.6	15.47
FeO*	4.20	2.60	3.03
MnO	0.05	0.05	0.05
MgO	1.17	0.53	1.28
CaO	3.13	2.60	2.85
Na_2O	3.95	3.53	4.50
K_2O	3.48	3.67	2.26
P_2O_5	0.18	0.10	0.14
An(%)	14.35	12.27	20.36
Ab	33.45	29.80	58.95
Or	20.58	21.71	20.69
Rb(ppm)	126	146	96
Sr	643	509	460
La	57.5	63.4	34.7
Ce	110	105	61
Nd	38.4	31.6	19.8
Sm	5.22	4.75	2.76
Eu	1.31	1.05	0.65
Gd	3.35	3.04	1.64
Yb	0.60	1.05	0.35
Lu	0.05	0.15	0.06
(La/Yb)N	110.7	43.9	65.4

rocks may reflect chemical differences in the parental magmas (see Fig. 5) which is mainly due to differences in the source regions or degree of partial melting.

The Daejeon and Nonsan granitic rocks show very similar patterns in REE, although considerable differences in major and trace elements: (a) they show enrichment in LREE (light REE) relative to HREE (Heavy REE) with steep slope with average (Ce/Yb)N ratio being 57.32; (b) they present no significant Eu anomalies (Eu/Eu*=0.93); and (c) they show high total REE (about 215ppm). These REE and trace element features can be discussed in relation to hypotheses about the origin of the Daejeon and Nonsan granitic rocks. Strongly fractionated REE patterns and the absence of Eu anomaly in the Jurassic granitoids are chemically similar to the Precambrian metasedimentary rocks (Shaw et al., 1976). Hornblende fractionation could account for the pattern of REE distributions in the studied granitic rocks, the important feature of hornblende being the high partition coefficient for HREE and the fact that hornblende develops a negative Eu anomaly in equilibrium with silicic liquids (Arth & Barker 1976). Thus, extensive hornblend fractionation should yield residual liquids with HREE depletion and positive Eu anomalies. Garnet, also, is potentially capable of reproducing the same REE features (Hanson 1978). Depletion of HREE in the studied granitoid is possibly due to either hornblende and garnet fractionation or those minerals are not involved in the process of partial melting.

The role of feldspar minerals is clearly of great importance in any of the evolutionary models involving Sr, Rb and Eu. Thus, it could be argued that plagioclase fractionation (either by fractional crystallisation of plagioclase or by the separation of a magma from a plagioclase-rich residue) must have played a significant part in the development of the Daejeon and Nonsan granitic rocks. But they are markedly enriched in Sr (583ppm) and Eu (1.22ppm) relative to K and Rb which indicates that no feldspar can have played such a part in the evolution of these granitic rocks. The absence of Eu anomalies is caused by high concentrations of divalent Sr, which prevent fractionation of divalent Eu. Both Sr and Eu would be strongly partitioned into crystallising alkali-feldspar and plagioclase, respectively.

The relatively high concentrations of Sr in Lewisian granulites when compared with recent volanic rocks of a similar range of compositions, proposed that deep-crustal fractionation of hornblende under conditions of high P_{H_2O} gave rise to predominantly tonalitic rocks with a distinctive chemical signature involving high Sr (Tarney & Windly 1977). Subsequent granulite-facies metamorphism would trend to strengthen their Sr-rich character as the fugitive elements, K, Rb, Th and U were depleted (Moorbath et al. 1969; Heier 1973). This depletion is thought by many workers (Tarney & Windley 1977, 1979; Hamilton et al. 1980) to be the result of partitioning of these elements into a metamorphic fluid phase removed during granulite facies dehydration. In relation to the present discussion, the possibly unique chemical nature of the granulite facies gneisses offers an opportunity to test models of crustal origin for the Jurassic granitoids with high Sr and low Rb, possibly inherited from the granulites. Large depletion of HREE and Y, and high CaO and Al_2O_3 in the Jurassic granitoids is smilar to an Archaean basement rock such as grey gneisses (Table 9). The chemica characteristics of such a crustal component would include low Na_2O, HREE, Y, Zr and high Sr. Most Archaean gneisses clearly have high Ce/Y ratios (Tarney & Windley 1977). It is also evident that many of the silicic gneisses have very low Y contents, indicating significant HREE depletion as is common in many tonalites, trondhjemites and quartz monzonites from Archaean greenstone belt terrains. Rb, which should partition into liquids very efficiently during melting (relative to Sr), seems unexpectedly low in the granitic rocks, with Rb/Sr ratio (0.24) as low as those of the Precambrian granulites. This feature suggests the availability of only small amounts of Rb during the melting process itself. High initial $^{87}Sr/^{86}Sr$ ratios (0.710~0.718) of both Daejeon and Nonsan granitoids also suggest their origin by remobilization of old sialic crust.

The differences between the Daejeon two-mica granite and the Nonsan granodiorite in mineralogy, major and some trace elements although they are derived from the crustal source, can be explained by: (a) the former could be derived from low degree of partial melting of the Precambrian granulite; (b) the latter might be inherited from a parental magma which generated from high degree of partial melting of the Precambrian granulite.

The primary magmas for the Daejeon and Nonsan granitoids are derived from partial melting of the Precambrian granulite, but they crystallised from different parental magmas with different chemical characteristics. The heat source to melt those Precambrian granulite was possibly available from basement reactivation during continental collision and crustal thickening in the Ogcheon basin.

The calculated temperatures for cessation of perthite exsolution in the studied granitoids remain within a generally narrow range of about 350~450°C at assumed pressure of 0.5~3Kbar for the Daejeon two-mica granite and 400~480°C at assumed pressure of 5Kbar for the Nonsan granodiorite. These low temperatures could have been the results of slow cooling of the parental magmas, high water content and high heat flow in the country rocks (by regional metamorphism). In the Ogcheon Fold Belt, water could have been made available by the dehydration of the micas during regional metamorphism and by the geosynclinal environment, which made it possible to melt the large amount of the Precambrian basement for producing granitic batholiths. The parental magmas, saturated in water or nearly so, could not rise appreciably above their source environment before crystallisation, not far below the present levels of exposure. The Jurassic granitic rocks are dominant at the Ogcheon Fold Belt may be resulted by closing-collision situation and belong to the Hercynotype (Pitcher 1979) such as compressive ductile regime of an intracontinental orogen. Shortening of the crust leads to tectonic thickening when, particularly as a consequence of uplift, magmas are generated within the regionally heated root. The crustal-derived "S-type" granitic magmas are most likely to occur, and be emplaced by diapiric intrusion into a ductile crust. The Jurassic granitoids in the Ogcheon Fold (Mobile) Belt may reflect a relaxation process after extreme thickening of continental crust following continental collision (with basement block movement). According to currently accepted plate tectonic theroy, such collision can occur if an ocean or a marginal basin closes, and such closures can occur by the process of subduction of oceanic lithosphere. Thus, "S-type" Jurassic granitoids would be expected to occur extensively on at least one side of the suture zone (NW side of the Ogcheon Fold Belt) representing the former ocean basin with evidences of marine sediments and fossils.

CONCLUSIONS

1) The Daejeon and Nonsan granitic rocks are "S-type" syntectonic calc-alkaline subsolvus two-mica monzogranite and granodiorite, respectively. These syntectonic granitoids are foliated with N20°～30°E direction which is parallel to the Ogcheon Fold Belt.

2) Highly fractionated REE distributions with no appreciable Eu anomalies and high initial $^{87}Sr/^{86}Sr$ ratios (0.7104～0.7176) rule out a possibility of direct mantle origin. Large depletion of HREE and Y, and high CaO and Al_2O_3 is similar to chemical characteristics of the Precambrian granulite. The facts that the Daejeon and Nonsan granitic rocks show very similar patterns in REE, although considerable differences in mineralogy and major element are considered to be mainly due to different proportion of partial melting. The primary magmas for the studied granitoids appear to be derived from partial melting of the Precambrian granulite, but those granitoids crystallised from different chemical characteristics of parental magmas.

3) The Daejeon and Nonsan granitoids show enrichment of LREE and depletion in HREE (chondrite normalised Ce/Yb=57.32) with few or no Eu anomalies, which suggest a probable separation of hornblende and/or garnet from the parental magmas by partial melting in which these minerals are left in the residues.

4) The Daejeon two-mica granite could be derived from low-degree of partial melting of the Precambrian granulite with its felsic nature. The Nonsan granodiorite might be inherited from high degree of partial melting of the Precambrian granulite.

5) The heat source to melt the large extent of the Precambrian granulite was easily available from the closing the Ogcheon basin together with basement reactivation during microcontinental collision from which sufficient water provided by the dehydration of the hydrous minerals, particulary during regional metamorphism (Daebo orogeny).

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沃川 變成帶에 分布하는 쥬라紀 大田 및 論山 花崗岩類의 岩石地化學的 研究

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요약 : 쥬라紀 大田複雲母花崗岩과 論山花崗閃綠岩은 Syntectonic 칼크—알카라인 subsolvus 花崗岩類에 屬한다. 本 花崗岩類들은 CaO, Al_2O_3, LIL/HFS 元素比, 全 REE 含量과 ($^{87}Sr/^{86}Sr$) 初生値가 높고, Eu 累常値가 거의 없으며 HREE〔(Ce/Yb)N=20～120〕와 Y含量이 낮은것은 先—캠브리아紀 Granulite(例 ; 灰色片麻岩)의 部分熔融에 依하여 形成된 것으로 思料된다("S-type"). 特히, 稀土類元素의 分析結果에 依하면 本 花崗岩類가 形成되는 過程에서 hornblende와 garnet가 根源岩(先—캠브리아紀 Granulite)으로 부터 分離 熔融되지 않고 residue로 남았으며, 또한 長石은 部分熔融에 依하여 形成된 magma內에서 分結(fractionation)되지 않고 incompatible behaviour를 取했음이 밝혀졌다. 이들 두 花崗岩類는 稀土類元素의 分布相에 있어서 거의 同一하지만, 그들의 鑛物組成 및 主元素등의 差異는 根源岩의 部分熔融 過程中 熔融比率上의 差異때문이다. 即, 大田複雲母花崗岩은 論山花崗閃綠岩에 比하여 "낮은 比率"로 部分熔融되어 形成된 것으로 生覺된다. 根源岩이 部分熔融될 수 있는 熱源은 microcontinental collision과 basement 再活性化에 따라 沃川地向斜가 closing 되는 地殼變動에 依하여 供給可能할 것이다. 特히, 大寶造山運動에 수반된 廣域變成作用時 雲母와 같은 含水鑛物들의 脫水作用에 依하여 生成된 水分은 部分熔融을 더욱 容易하게 했다. 各 花崗岩體內에 含有된 퍼시틱 알카리—長石들의 Exsolution 溫度가 大體로 작은 變化幅을 가지는 것은 花崗岩類 貫入時期에 주위母岩들도 熱流量이 높은 地域에 位置해 있었으며, 그後 花崗岩類와 함께 천천히 冷却되었기 때문인 것으로 思料된다.

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