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Compositional Variation of Archean Pelitic Rocks: A Case Study of the Kaapvaal Craton and Limpopo Belt, Southern Africa.

Toshiaki TSUNOGAE*

Abstract

Major and minor elements chemistry of Archean pelitic rocks was analyzed by X-ray fluorescence spectrometer. Samples were collected from three different terranes in southern Africa; Barberton and Sutherland greenstone belts in the Kaapvaal Craton, granulite terrane of the Southern Marginal Zone of the Limpopo Belt, and supracrustal sequences of the Central Zone of the Limpopo Belt. Although bulk chemical composition varies from sample to sample, pelitic rocks from the Kaapvaal Craton exhibit similar composition to those from the Southern Marginal Zone. In contrast, those from the Central Zone have wide compositional range probably because they were supplied from many different sources.

An enrichment in Ni and Cr in pelitic rocks from the Kaapvaal Craton and Southern Marginal Zone was well observed. The Ni and Cr contents increase from 30 to 260 ppm and 10 to 580 ppm (Central Zone) to 280 to 550 ppm and 710 to 1410 ppm (Southern Marginal Zone and Kaapvaal Craton), respectively. The enrichment in Ni and Cr in particular pelitic rocks can be inferred from the presence of high Ni- and Cr-bearing rocks (komatiite?) on the earth surface during sedimentation.

Key words: pelitic rock, XRF, Archean, Limpopo Belt, Kaapvaal Craton, southern Africa

Introduction

Archean metamorphic rocks crop out over wide areas in Precambrian shield, and are considered to record history of early earth. Discovery of 3.96 Ga Acasta Gneiss from Canada by Bowring *et al.* (1989) revealed that at least some parts of >4.0 Ga crust were composed of granitic rock, yet it is not obvious whether the granitic rock was a major constituent of Archean crust. Numerous geochemical works on Archean metamorphic rocks have been undertaken to identify characteristics of Precambrian crust. One principal approach to the problem is the chemical composition of Archean sedimentary (mainly pelitic) rocks because they are direct evidence of ancient earth surface. Unfortunately, most of the Archean pelitic rocks have already been recycled by subduction and subsequent melting, whereas some are still preserved together with volcanic rocks as a "greenstone belt". Geochemical study of these crustal materials is helpful to understanding of Archean crustal evolution. This study shows an example of major and minor elements chemistry of metamorphosed pelitic rocks from several southern African greenstone belts, and makes comments concerning composition of Archean crust.

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* Department of Earth Science, Faculty of Education, Shimane University, Matsue 690.
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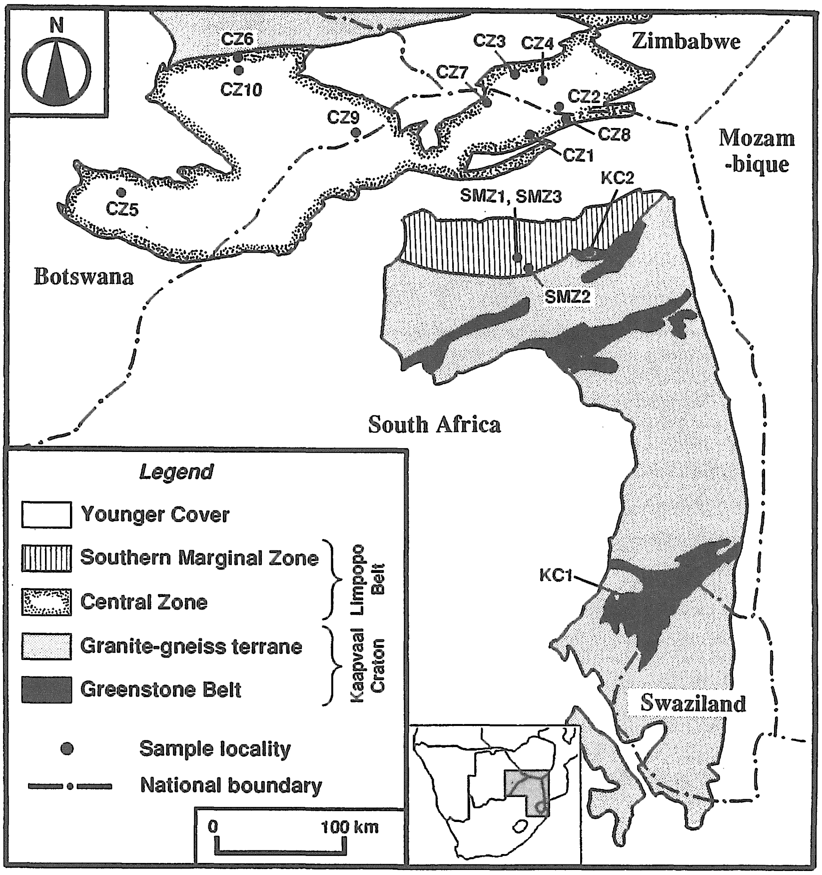

Fig. 1. Simplified geological map of the Kaapvaal Craton and Limpopo Belt, southern Africa, after Watkeys (1983). Sample localities of pelitic rock are also shown.

General geological setting

Pelitic rocks were collected from the Kaapvaal Craton and also from the Southern Marginal Zone and Central Zone of the Limpopo Belt situated over countries of South Africa, Zimbabwe, and Botswana (Fig. 1). All the samples were collected during field trip in southern Africa in 1988 and 1990. The Kaapvaal Craton is composed predominantly of Archean tonalitic, trondhjemitic, and granitic gneisses and greenstone belts (granite-greenstone terrane). The Barberton and Sutherland greenstone belts which are located at southern and northern margin of the craton, respectively, contain many sedimentary sequences. Metamorphic grade of the belts varies from greenschist (Barberton belt) to amphibolite facies (Sutherland belt). According to previous geochronologic data, the pelitic rocks are considered to have been deposited before 3.5 Ga (Hamilton *et al.*, 1979) and before 2.7 Ga (Barton and van Reenen, 1992), respectively.

The Limpopo Belt, located north of the Kaapvaal Craton, is subdivided into three zones on the basis of lithological and structural characters; Southern Marginal Zone, Central Zone, and Northern Marginal Zone (Mason, 1973). The Southern Marginal Zone is composed of metasedimentary and metavolcanic rocks similar to the Kaapvaal Craton (Du Toit *et al.*, 1983), although metamorphic grade of the zone is granulite facies (temperature up to 800°C; van Reenen, 1983; Tsunogae and Miyano, 1989; Stevens and van Reenen, 1992). In contrast, the lithology of the Central Zone is different from that of the Southern Marginal Zone and is composed of supracrustal quartzite-pelite-carbonate association with minor quartzofeldspathic (leucocratic) gneiss (e.g. Watkeys *et al.*, 1983; Brandl, 1983). Metamorphic P-T conditions are highest in the Central Zone at about 850°C and $>$10 kbar (e.g. Watkeys *et al.*, 1983; Windley *et al.*, 1984; Tsunogae *et al.*, 1992). Although metamorphic age of the Central and Southern Marginal Zones varies from 3.2 to 2.7 Ga (Harris *et al.*, 1987; Barton and van Reenen, 1992), timing of sedimentation should be older than 2.7 Ga.

Analytical technique

Quantitative analyses of major (Si, Al, Ti, Fe, Mn, Mg, Ca, Na, K, and P) and minor (Cr, Ni, Sr, Y, Zr, and Ba) elements were performed by X-ray fluorescence spectrometer (XRF). The XRF at the University of Tsukuba (Philips PW1404) was employed for the present analysis. Homogeneous glass of rock sample was used for the analysis following the method of Tsunogae and Miyano (1992). Approximately 10 to 50g fresh and homogeneous rock specimen was crushed using automated HERZOG HSM-F36 pulverizer. The powdered sample (about 1g) was mixed with flux of anhydrous lithium tetraborate (5g $Li_2B_4O_7$) and melted at about 1130°C to make homogeneous glass. Twelve standard samples of igneous rocks provided by the Geological Survey of Japan were adopted for the quantitative analysis.

Results

Representative XRF analyses of pelitic rocks are shown in Figs. 2, 3, and Table 1. As the figures and table demonstrate, pelitic rocks from the Kaapvaal Craton have similar major element chemistry to those from the Southern Marginal Zone except MnO and MgO. This is consistent with field and petrological evidence that the Southern Marginal Zone of the Limpopo Belt is a high-grade equivalent of the Kaapvaal Craton. SiO_2 content, for example, of samples KC1 to KC2 (Kaapvaal Craton) and SMZ1 to SMZ3 (Southern Marginal Zone) is about 60 to 65 wt.%, whereas that of pelitic rocks from the Central Zone varies from 48 wt.% (sample CZ6) to 69 wt.% (sample CZ4). It can be deduced that the compositional variation within the Central Zone may come from a significant effect of migmatization with SiO_2 extraction as well as original compositional differences of pelitic rocks. The possible effect of migmatization on bulk chemistry is, however, little, because no depletion of K_2O was identified from low-SiO_2 pelitic rocks (e.g. samples CZ1 and CZ10). If the pelitic rocks suffered migmatization, K_2O, which is one of the most movable element, should have been removed from the rocks together with felsic melt. The present data should therefore reflect compositional variation of protolith.

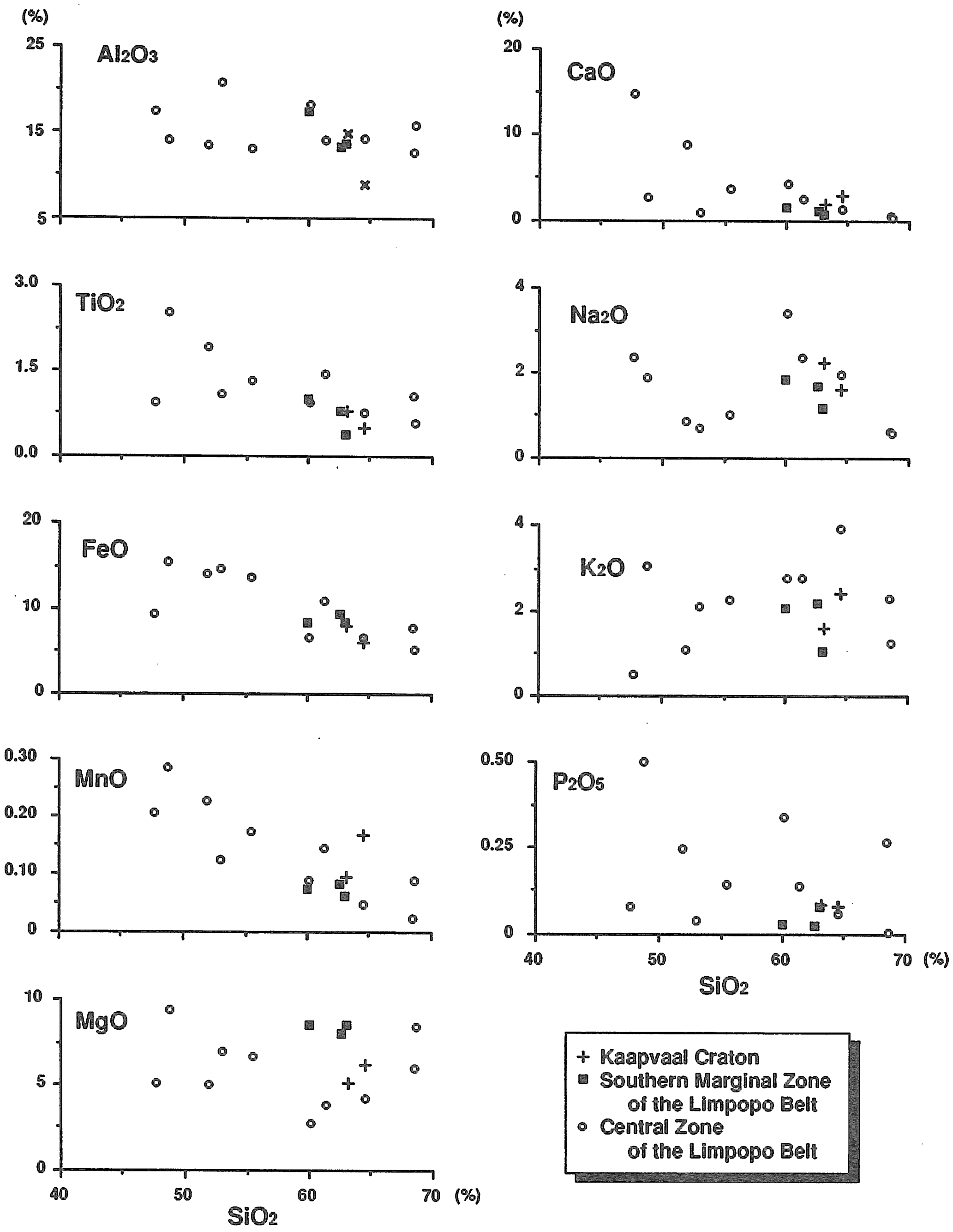

Fig. 2. Variation diagrams showing compositions of major elements in pelitic rocks.

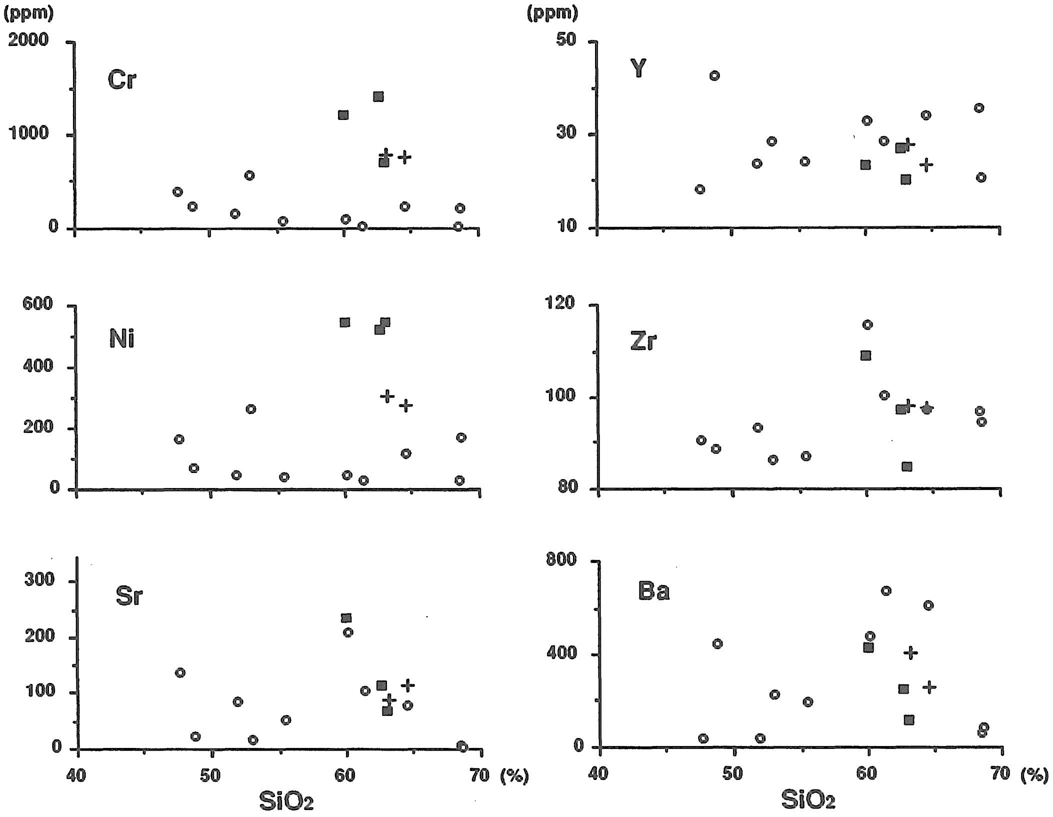

Fig. 3. Variation diagrams showing compositions of minor elements in pelitic rocks. Symbols are the same as Fig. 2.

Fig. 3 also suggests compositional variation of original pelitic rocks rather than the effect of migmatization. Sr, Ba, Y, and Zr are relatively movable elements compared to Ni and Cr. As shown in Fig. 3, Sr, Ba, Y, and Zr contents in pelitic rocks with mafic composition are similar to those with felsic composition (e.g. up to 137 ppm Sr in sample CZ6, 43 ppm Y in sample CZ10, 93 ppm Zr in sample CZ7, and 445 ppm Ba in sample CZ10), although their SiO_2 content is less than 55 wt.%. The results therefore suggest that original composition of pelitic rocks was not eliminated during metamorphism.

In contrast, Ni and Cr contents show obvious differences between each terrane. As Fig. 4 clearly demonstrates, the Ni and Cr contents increase in unison. The Ni and Cr contents increase from 30 to 260 ppm and 10 to 580 ppm (Central Zone) to 280 to 550 ppm and 710 to 1410 ppm (Southern Marginal Zone and Kaapvaal Craton), respectively.

Petrographical observations suggest that the difference in bulk chemistry results in different mineral assemblage, even if metamorphic conditions are similar. Sample CZ1 shows high modal abundance of cordierite and garnet because of enriched Al_2O_3. Abundant plagioclase in sample CZ6 can be ascribed to high CaO and Na_2O contents in the rock. Sample SMZ3 which has high bulk MgO/FeO ratio contains Mg-rich biotite compared with the other samples.

Table 1. Representative major (%) and minor (ppm) element analyses of pelitic rocks from the Kaapvaal Craton and Limpopo Belt.

Sample	CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8
SiO_2	53.07	61.33	68.50	68.64	60.16	47.69	51.87	55.48
Al_2O_3	20.78	13.94	12.72	15.73	18.09	17.35	13.39	13.01
TiO_2	1.09	1.44	1.06	0.59	0.96	0.94	1.93	1.33
FeO*	14.76	10.97	7.84	5.38	6.70	9.43	14.12	13.76
MnO	0.12	0.14	0.03	0.09	0.09	0.21	0.23	0.17
MgO	6.94	3.82	5.95	8.46	2.76	5.08	4.99	6.70
CaO	1.05	2.46	0.66	0.38	4.33	14.61	8.90	3.82
Na_2O	0.70	2.36	0.64	0.58	3.42	2.33	0.85	1.01
K_2O	2.11	2.79	2.30	1.26	2.79	0.51	1.09	2.26
P_2O_5	0.04	0.14	0.27	0.01	0.34	0.08	0.24	0.14
Total	100.65	99.38	99.97	101.13	99.62	98.23	97.61	97.68
Cr	578	15	14	211	101	392	159	79
Ni	264	28	27	172	48	163	49	41
Sr	17	104	7	3	209	137	85	52
Y	29	29	36	21	33	18	24	24
Zr	86	100	97	95	116	91	93	87
Ba	231	673	59	88	476	41	42	193

Sample	CZ9	CZ10	SMZ1	SMZ2	SMZ3	KC1	KC2
SiO_2	64.46	48.79	60.01	62.66	63.01	64.53	63.09
Al_2O_3	14.19	13.98	17.37	13.19	13.65	8.91	14.78
TiO_2	0.76	2.53	0.99	0.81	0.38	0.51	0.80
FeO*	6.62	15.53	8.38	9.42	8.35	6.06	7.96
MnO	0.05	0.29	0.07	0.08	0.06	0.17	0.09
MgO	4.19	9.44	8.56	8.00	8.52	6.16	5.11
CaO	1.31	2.69	1.51	1.15	0.79	2.91	1.96
Na_2O	1.98	1.87	1.86	1.68	1.16	1.62	2.24
K_2O	3.93	3.05	2.07	2.19	1.06	2.43	1.62
P_2O_5	0.06	0.50	0.03	0.03	0.08	0.08	0.08
Total	97.54	98.66	100.84	99.19	97.05	93.36	97.73
Cr	233	229	1214	1411	707	768	784
Ni	117	68	549	522	549	275	305
Sr	80	24	235	114	69	116	89
Y	34	43	23	27	20	23	28
Zr	97	89	109	97	85	98	98
Ba	609	445	433	250	117	256	410

*: Total Fe as FeO

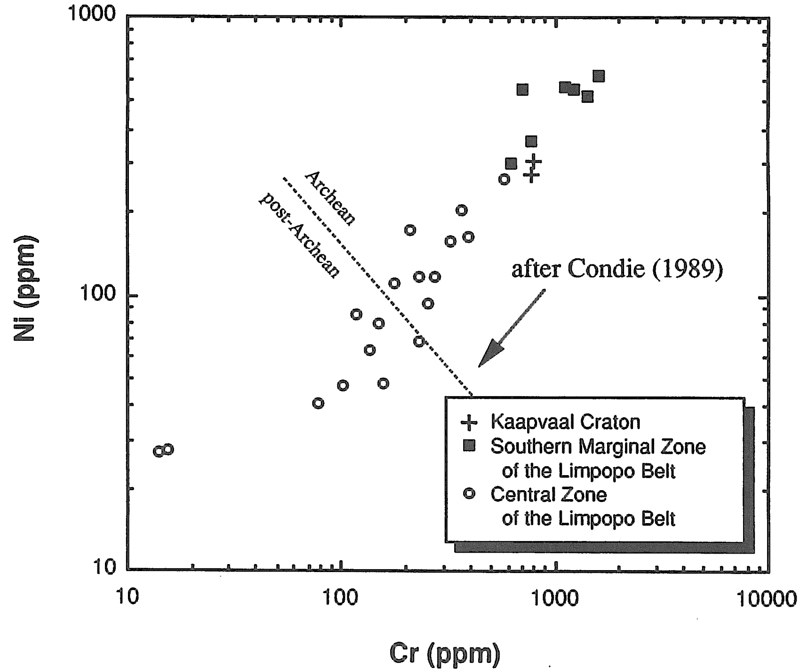

Fig. 4. Ni-Cr distributions in pelitic rocks from the Kaapvaal Craton and Limpopo Belt.

Discussion

This study tried to clarify compositional differences in pelitic rocks from individual terranes, but it failed to identify significant differences except Ni and Cr contents. Condie (1989) analyzed the Ni and Cr contents in pelitic rocks and pointed out a gap between Archean and post-Archean rocks; the Ni and Cr contents in Archean pelitic rocks (>90 ppm and >170 ppm, respectively) are higher than those of post-Archean rocks. According to his subdivision, pelitic rocks from the Kaapvaal Craton and Southern Marginal Zone are grouped into Archean, whereas those from the Central Zone exhibit geochemical signature of both Archean and post-Archean. Pelitic rocks from the Kaapvaal Craton and Southern Marginal Zone can be therefore regarded to have been deposited under similar environment. In contrast, the Central Zone contains various pelitic rocks which may have been supplied from many different sources. Although both the Central and Southern Marginal Zones of the Limpopo Belt have suffered Limpopo Orogeny at about 2.7 Ga (Barton and van Reenen, 1992), pelitic rocks from the two zones show different compositional characters. Previous geochronologic data show that the Central Zone has several older ages than the Southern Marginal Zone (e.g. Harris *et al.*, 1987; Retief *et al.*, 1990; Tsunogae and Yurimoto, 1994), whereas this paper suggests that the latter may have older protolith.

An enrichment in Ni and Cr in particular pelitic rocks can be inferred from the presence of high Ni- and Cr-bearing rocks on the earth surface during sedimentation. Komatiite, which is a unique ultramafic volcanic rock common in Archean greenstone belts, is a probable source of high-Ni and Cr pelitic rock. Archean crust should have been therefore abundant in ultramafic rocks, and weathering of those materials provided Ni and Cr into sediments. These data support the evidence of Archean active ultramafic magmatism. It has to be noted, however, that the Ni and Cr enrichment may be because of later accretion of Ni and Cr by hydrothermal fluid during diagenesis. Compositional data of deep sea sediments (e.g. chert) which has no effect of clastic sediments will be a key to solve the problem.

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