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SYSTEMATIC COVARIATION OF SR, BA, CA ELEMENTS IN CENOZOIC VOLCANIC ROCKS ON THE FILDES PENINSULA, WEST ANTARCTICA, AND ITS RELATION TO PETROGENESIS

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Abstract Cenozoic volcanic rocks in the Fildes Peninsula are composed of High-Al basalt, basaltic andesite, andesite, and dacite belonging to a calc-alkaline volcanic series with low-K and high-Al characteristics. Using a new indicator, the Sr / Ca-Ba / Ca, systematics proposed by Onuma (1980, 1981) and Sr, Ba, Ca concentrations in volcanic lavas and subvolcanic rocks, the authors find that the high-Al basaltic volcanic rocks either in volcanic strata or in subvolcanic intrusives were formed from a primary magma, in different stages through the fractional crystallization of clinopyro-xene(Cpx)and plagioclase (Pl) in the process of magmatic evolution, resulting in the formation of basaltic-andesitic, andesitic and dacitic rocks.

Key words Fildes Peninsula, Cenozoic volcanic rocks, Sr / Ca-Ba / Ca systematics

Fildes Peninsula is located at the southwestern tip of King George Island, which is the largest island of South Shetland Islands, West Antarctica; it is covered with the early Tertiary volcanic rocks. Since the Chinese Great Wall Station has been built up in 1985, a series of works, such as stratigraphical division, petrological, mineralogical and petrochemical studies of the volcanic rocks has been carried out(Li & Liu, 1987; Li *et sl.* ,1989; Liu and Zheng, 1988; Zheng & Liu, 1989a, 1989b; Zheng, *et al.*, 1989)This paper deals mainly with the systematic covariation of Sr, Ba, and Ca elements and its relation to the petrogenesis of the volcanic rocks on the peninsula.

1. Geological Background

The volcanic strata in the studied area dip generally uniclinally to NNE or NE at an angle less than 25 degree. Based on the geologic contact relation and the rock association, the authors subdivide the volcanic rocks into two litho–stratigraphic formations, each of which has two members respectively . These members, in ascending order are: 1) Jasper Hill Member (JHM), a sequence of basalt and basaltic andesite lavas with basaltic volcanic breccias and agglomerates in the lower part of the sequence, outcropping on the southwestern end of the Filde Peninsula only; 2) Agate Beach Member (ABM), found throughout the peninsula and overlying disconformably on the JHM, which is composed of amygdaloidal basalt and basaltic andesite lavas, with basal volcanic breccias and agglomerates. The top part of the ABM is a layer of andesite–dacite, outcroping on the northeastern part of the Peninsula; 3) Fossil Hill Member (FHM), volcanic–clastic sedimentary rocks with a few fossiliferous intercalations, within which some ripplemarks, mud cracks and bird tracks were found overlying disconformably on different positions of ABM on the eastern side of the peninsula; 4) Block Hill Member (BHM), occurring on the eastern coast of the peninsula and composed of basaltic andesite and andesitic lavas, agglomeratic and brecciated lavas with various clast size. The first two members belong to the Great Wall Formation (GWF) and the rest to the Fossil Formation. It can be seen that there is an erosion gap between the ABM and the FHM: the layers of the ABM has been disintegrated and ovelain by the volcanic–clastic sedimentary rocks of the FHM. The isotope chronological data (Davies, 1982; Li *et al.*, 1989; Pankhurst *et al.*, 1980; Smellie, et al., 1984; Watts, 1982) show that the GWF was probably formed mainly in Paleocene and the Fossil Formation (FF) from Eocene to Oligocene or the begining of Miocene.

The subvolcanic bodies, are developed widely on the peninsula including stocks and veins, which are distributed along or near the fracture zones, and dykes concentrated around the volcanic centres.

2. Petrological Characteristics of the Volcanic Rocks

The volcanic lavas from the studied area include high–Al basalt, basaltic andesite, andesite and dacite. The intrusive rocks are generally basaltic or basalt–andesitic. The massive and compact high–Al basaltic and basaltic andestic rocks exhibit usually amygdaloidal structure. Although the most of rocks are porphyritic, but microporphyritic or macromertic textures can be also found in some of lavas and subvolcanic rocks. The phenocrystals in rocks are mainly euhedral plagioclase, clinopyroxene and few orthopyroxene, as well as olivine which was replased by iddingsites. The ground mass in the basalts and basaltic andesites exhibits intergranular or pilotaxitic texture . The porphyritic andesite is massive with amygdaloidal structure, containing plagioclase and some clinopyroxene and rothopyroxene phenocrystals. The matrix exhibits hyalopilitic or pilotaxitic textures. The texture of the whole dacitic rock is oligophyric or microphyric, and the texture of the ground mass is intergranular–intersertal and pilotaxitic.

Results of electric microprobe and X–ray diffraction (XRO) show that the plagioclase phenocrystals in high–Al basalt and basaltic andesite have a rather basic component, i.e. the An content ranges from 93.69% to 57.49%, with a high temperature disorder structure. The positive and cyclothemic zonal structure is well developed, and the An content in the central part of plagioclase phenocrystals is almost over 80% and decreases towards the matrix (An = 74.05%–49.25%). The porphyritic crystals in andesite and dacite are mainly labrador and andesine. It means that (a) these phenocrystals are in balance with the composition of magma during whole crystallization, and (b) the primary magma was more basic.

The microprobe determination of clinopyroxene shows that they are mainly augite, only a few diposide and Mg–diopside. The composition of orthopyroxene in the rocks varies from bronzite in basalt and basaltic andesite to augite bronzite in subvolcanic rocks. The olivine is almost iddingsite, which has a $Mg / Mg + Fe$ ratio ranging between 77.8% and 87% and is classified to Mg–rich chrysolite.

3. Petrochemical characteristics and contents of Sr, Ba, Ca

The contents of major oxides in more than 100 volcanic rock samples were determined with XRFS. Generaly speaking, the rock association, basalt–basaltic andesite– andesite– dacite, on the Fildes Peninsula is chemically lower in potassium but richer in Al_2O_3 with a relatively high Na_2/K_2O ratio. In high–Al basalt of JHM and in lower and middle parts of ABM, the SiO_2 content is lower than 53wt%; $K_2O<0.6$wt%; total iron concentration and MgO content range from 7.52wt%to 11.23wt%and 3.65 wt% to 7.68wt%, respectively; CaO is usually higher than 7wt% . The MgO, Al_2O_3, CaO and total iron contents decrease and the K_2O, Na_2O increase with increasing SiO_2 content in lavas of the middle and top parts of ABM which can be distinguished as basaltic andesite, andesite and dacite. The compositions of BHM lavas are basalt andesitic and andesitic. The plots of SiO_2–K_2O (Fig. 1, after Peccerills and Taylor, 1976) and AFM (after Kuno, 1965) suggest that the volcanic rocks on the Fildes Peninsula belong to the calc–alkaline series, which is also been confirmed with the F_1–F_2–F_3 diagrams for determining the relationship between volcanic rock and tectonic background designed by Pearce (1976).

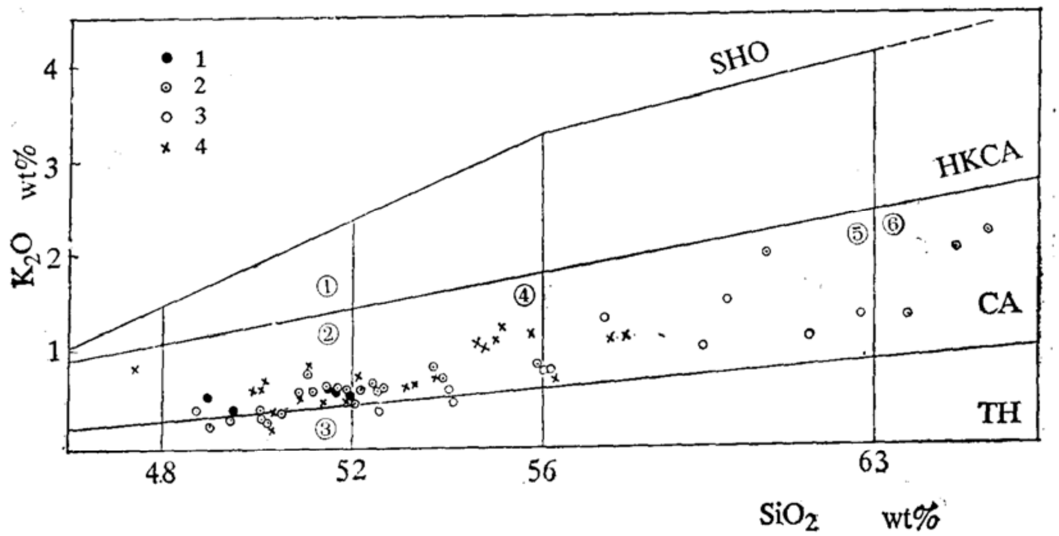

Fig. 1. Si_2O–K_2O, diagram showing the volcanic rock series (after Peccerills and Taylor, 1976). 1. rocks of Jasper Hill Member; 2. Agate Beach Member; 3. Block Hill Member; 4. Fossil Hill Member; 5. subvolcanic (1) high-k, high-Al basalt; (2) high-Al basalt; (3) low-K, high-Al basalt: (4) basaltic andesite; (5) andesite; (6) dacite; CA: calc-alkaline series; TH: tholeiitic series; SHO: shoshonite; HKCA: high-K calc-alkaline series.

Sr,Ba,Ca and SiO_2, K_2O, CaO contents in 58 samples of volcanic and subvolcanic rocks (basalts, basaltic andesites, andesites and dacites) from the Fildes Peninsula are presented in Table 1. The Sr and Ba concentrations were determined by INAA and the others by XRFS methords.

Table 1. Concentrations of Sr, Ba, Ca in ppm and SiO_2, K_2O, CaO in wt%

No.	Sam. No.	SiO_2	K_2O	CaO	Ca	Sr	Ba
1	XN71	48.90	0.55	13.59	97127	848	171
2	XN10	49.45	0.41	12.43	88836	584	198
3	XN13	49.54	0.29	12.51	89408	485	223

4	XN12	51.73	0.62	9.66	69039	480	200
5	ZF8	51.92	0.57	10.19	72827	527	154
6	2601	48.51	0.23	10.32	73756	556	135
7	ZF65	49.05	0.25	11.07	83405	416	107
8	305	49.36	0.23	11.59	82833	549	98
9	2603	49.45	0.35	10.24	73185	459	147
10	1816	50.08	0.39	10.86	77616	546	120
11	1803	50.33	0.21	10.03	71684	488	161
12	ZF31	50.45	0.25	11.17	79831	576	115
13	C115	50.46	0.23	10.47	74828	425	141
14	ZF18	50.51	0.37	11.82	84477	547	82
15	TN6	50.52	0.29	11.43	81689	380	100
16	ZF53	50.81	0.60	11.46	81905	640	200
17	C120	51.86	0.62	9.93	70969	498	177
18	C111	52.05	0.46	10.16	72613	415	195
19	1807	52.13	0.54	9.83	70254	553	134
20	311	52.53	0.61	9.34	66752	527	165
21	ZF72	53.75	0.86	9.42	67324	511	261
22	Ad1	54.08	0.61	8.33	59534	480	290
23	ZF57	60.73	1.96	4.79	34234	342	438
24	ZF13	63.76	1.34	4.21	30089	406	316
25	ZF80	64.35	1.96	4.20	30017	363	425
26	ZF58	65.16	2.17	3.37	24085	333	455
27	ZF59	66.03	2.44	2.95	21083	270	469
28	ZF81	52.60	0.37	9.98	71326	471	200
29	ZF84	54.05	0.46	9.72	69468	563	228
30	Ad12	54.05	0.49	9.04	64608	760	248
31	ZF781	56.05	0.78	8.49	60677	550	250
32	ZF78	56.17	0.77	8.56	61178	500	205
33	Gu1	57.79	0.71	6.99	49957	523	249
34	Ad11	59.42	1.54	5.12	36592	539	200
35	HT13	59.46	1.06	5.78	41309	488	267
36	HT14	61.62	1.12	5.18	37021	465	281
37	ZF77	62.76	1.37	5.18	37021	428	426
38	FTP	47.36	0.78	13.49	96412	545	241
39	2505	49.07	0.21	11.96	85477	533	134

40	ZF33	49.73	0.93	10.49	74971	450	213
41	ZF37	49.94	0.67	11.68	83476	626	144
42	ZF46	50.02	0.66	11.53	82404	649	118
43	BH32	50.29	0.18	12.36	88336	701	116
44	BH15	50.85	0.34	9.88	70612	513	174
45	BH39	51.36	0.46	11.30	80760	606	165
46	HS4	52.43	0.66	8.74	62464	360	214
47	309	52.55	0.23	7.52	53745	494	160
48	TN 7	53.21	0.62	8.57	61249	609	140
49	Ju2	53.35	0.65	9.56	68325	635	282
50	ZF68	54.57	1.09	8.56	61178	365	245
51	ZF55	55.06	1.14	7.29	52101	452	255
52	ZF38	55.13	1.24	8.86	63322	442	177
53	BH25	55.65	0.21	6.47	46241	440	169
54	ZF67	55.77	1.18	8.03	57390	389	195
55	Ad2	56.22	0.65	7.50	53602	425	257
56	701	57.42	1.10	6.62	47313	353	173
57	HS3	57.68	1.77	7.87	56246	320	340
58	ZF56	57.71	1.14	7.81	55818	455	283

notes: N. 1–5 from JHM, 6–27 from ABM, 28–37 from BHM; N. 38–58 from intrusives; Ca content is recalculated with CaO.

4. Result and Discussions

Firstly, we briefly introduce the Sr / Ca–Ba / Ca covariation systematics and elucidate generation of the magma . The Ca, Sr, Ba elements controlled by crystal structure exhibit different behaviors in the process of magma genesis and evolution. The ionic radius of Ca^{2+} is 100pm, smaller than that of Sr^{2+} (117pm) and Ba^{2+}(136pm). In a mantle periodtite Sr^{2+} and $Ba^{2+}$with larger ionic radii should be accomodated in accessory mineral phases, such as in apatite and phlogopite, while Ca^{2+} major mineral phases, such as in garnet and pyroxenes as well as in the accessory phases. The major phases, olivine, does not accept Ca^{2+}, $Sr^{2+}$and Ba^{2+} such a large triad. A primary magma generated by partial melting to smaller degree should have larger Sr / Ca and Ba / Ca ratios, since the accessory mineral phases (apatite and phlogopite) are the first components to melt and more Sr^{2+}, and Ba^{2+}ions enter into the melt, resulting in higher concentration of $Sr^{2+}$and Ba^{2+}. The primary magma melting to larger degree, however, Should have lower Sr /Ca and Ba / Ca ratios and relatively stable Sr/ Ba. This is because the clinopyroxene, orthopyroxene and garnet melted and Ca^{2+} added to the melted material. Melting and crystallization of olivine does not change the Sr / Ca and Ba /Ca ratios in the generated magma. Based on above element behaviors, Prof. Onuma (1980, 1981, 1983) suggested a principle of the Sr / Ca–Ba / Ca covariation systematics as an indicator for elucidation of magma genesis (Fig 2).

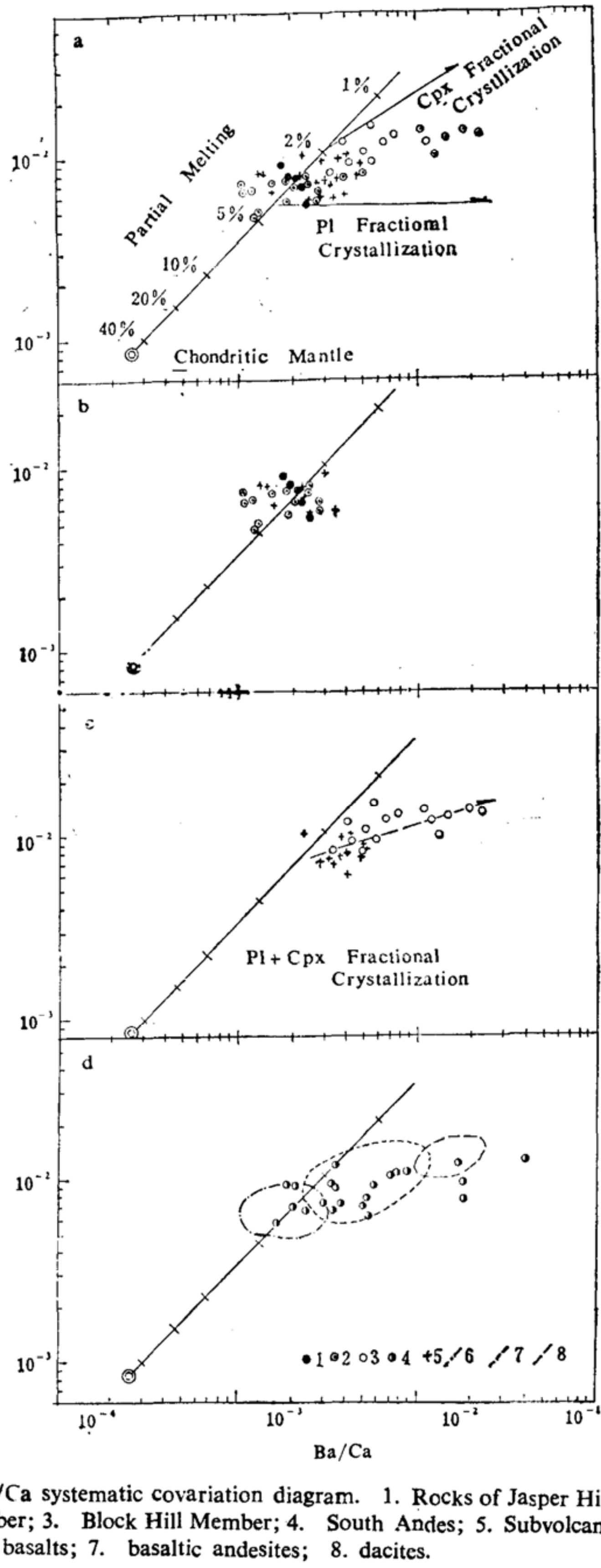

Fig. 2. Sr / Ca - Ba/Ca systematic covariation diagram. 1. Rocks of Jasper Hill Member; 2. Agate Beach Member; 3. Block Hill Member; 4. South Andes; 5. Subvolcanics; 6. the range of High-Al basalts; 7. basaltic andesites; 8. dacites.

A series of magmas could be generated by different degrees of partial melting from a primary mantle with chondritic Sr / Ca (8.4×10^{-4}), and Ba / Ca (2.6×10^{-4}) ratios (data from Tera *et al.*, 1970). If a series of magmas is available, we can expect to get a partial melting line with a slope of about 45°, which passes through mantle peridotite in the Sr / Ca–Ba /Ca diagram (Fig, 2a, A) and corresponds to nearly constant Sr / Ba ratio with variable Ca content in the series of magmas. The degree of partial melting of the mantle peridotite marked by the line (Fig. 2) is estimated by Onuma (1981) on the basis of melting experiments of a garnet peridotite by Mysen and Kushiro (1977).

As aprimary magma generated, it may be evolved by fractional crystallization in the magma chamber. Unfortunately, olivine and magnetite crystals can not be visualized in the Sr / Ca–Ba / Ca diagram, since these minerals do not accept the triad and do not change the Sr / Ca and Ba / Ca ratios of the primary magma. Orthopyroxene crystallization may increase Sr/ Ca and Ba / Ca ratios to a negligibly small extent, because orthopyroxene accepts small amounts of Ca^{2+}, but excludes Sr^{2+} and Ba^{2+} by crystal structure control. On the other hand, the crystallization of clinopyroxene and plagioclase changes Sr / Ca and Ba / Ca ratios. The plagioclase phenocrystal crystallization gives a nearly horizontal evolution line in Fig.2, since the fractional crystallization of plagioclase containing larger amount of Ca^{2+} and Sr^{2+} could result in the increasing Ba / Ca greatly, but does not change the Sr / Ca ratio in the evolved magma. The clinopyroxene crystallization gives a line with a steep slope through the primary magma, because the Ca^{2+}, easily, Sr^{2+} hardly and Ba^{2+} scarcely enter the mineral by crystal structure control, While the magma evolution was controlled by both clinopyroxene and plagioclase crystallizations, the slope of evolution line in Fig. 2 may depend on the Cpx–Pl ratio.

To discuss the generation and evolution of the volcanic rocks on the Fildes Peninsula, we have considered the contents of the Sr. Ba and Ca elements in different rocks and their characteristics on Sr/Ca–Ba/Ca diagram, and found some important information. Firstly, all plots of high–Al basalts and basaltic subvolcanic rocks are concentrated near the partial melting line, showing that they are from same resource and could be of a primary magma in studied area (Fig. 2b). The plots of basaltic andesites, andesites and dacites on the diagram (Fig. 2c) are basically distributed along a fractional crystallization trend diverging from the partial melting line, suggesting an evolution the rocks from high–Al basalt throught basaltic andesite, andesite to dacite controled by the crystallization of plagioclase and clinopyroxene (Fig. 2c). The information of magma evolution provided by Sr/Ca–Bz/Ca covariation systematics is consistent with other research results. The researches on the rock-forming minerals. major components, trace and rare earth elements in the volcanic rocks have also suggested that the rock association on the Fildes Peninsula is resulted from a Mg–rich primary magma by plagioclase and pyroxene, as well as olivine crystallizations. To confirm this suggestion, the authors have calculated the evolution from high–Al basalt through andesite to dacite using a model for mixed magma with major oxides and the Rayleigh fractional function with trace elements (Zheng & Liu, 1989). The above data support the magma evolution process provided by Sr/Ca–Ba / Ca systematics.

Finally, we would like to compare the Cenozoic volcanic rocks on the Fildes Peninsula with those on South Andes in the southern part of Chile in the Sr/Ca–Ba/Ca diagram for discussing their genesis. The volcanic rocks on south Andes including high–Al basalt and andesite were formed when the Phoenix Plate were subducting eastwards. The crust thickness in this area is about 30km and as a young crust in the geotectonic sense. The South Shetland Islands, where the Fildes Peninsula is located. with a crust about 23km in thickness (Asheroft, 1972) have been constructed by the island-arc volcanism since Cretaceous. Before 60Ma, these two areas were both affected by the eastward subduction of Pheonix Plate (Barker, 1982). The process of Pheonix Plate subduction and consumption just became a process of the developed volcanism in these two areas. Therefore, the volcanic rocks on the Fildes Peninsula and in South Andes magmatic rock zone could be considered to be affined under the same tectonic control.

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