韩国 Hadong_Sanchung 地区斜长岩 Sr_Nd 同位素初步研究——成因和前寒武纪构造意义

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摘 要: 斜长岩呈长条带出露于朝鲜半岛南部, 侵入到年代约为 2.0 Ga 的 Yeongnam 前寒武纪基底岩石中, 虽然岩石类型简单(斜长岩和辉长岩质斜长岩), 但可以同世界已知块状类型斜长岩相对比。这些斜长岩具有几个重要的差别, 例如呈层状构造, 镁铁相成分是角闪石而不是辉石, 并且不具斜方辉石巨晶。应用 Rb_Sr 和 Sm_Nd 同位素系统研究这些岩石的年龄和成因, 测定出一种页理化辉长岩质斜长岩矿物的 Sm_Nd 等时线年龄为 1 678 ±90 Ma, 推断其为侵位年龄, 因为中生代绿岩相变质期间这些岩石的 Sm_Nd 同位素体系呈封闭状态。这一年龄和过去曾报道的元古宙块状斜长岩的年龄范围(1.1~ 1.7 Ga) 相吻合。认为斜长岩成因可以用所谓元古宙斜长岩事件来解释。斜长岩的岩浆活动对朝鲜半岛南部前寒武纪基底岩石的构造历史有重要意义。全岩 $\varepsilon_{Nd}(t)$ 值范围 - 1.6~ - 5.2, 而 $^{87}Sr/^{86}Sr$ 初始值变化于 0.704~ 0.706 之间, 据此可解释地幔成因的斜长岩岩浆是在其结晶作用期间吸收了地壳物质的结果。然而不能排除是下地壳源的可能性。

关键词: Sr_Nd 同位素; 成因; 构造意义; 斜长岩; Hadong_Sanchung 地区; 韩国
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Preliminary Sr_Nd isotope study of the Hadong_Sanchung anorthositic rocks in Korea: Implication for their origin and for the Precambrian tectonics

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Abstract: The anorthositic rocks in southern part of Korean peninsula occur as a long belt, intruding the *ca*. 2.0 Ga old Precambrian basement rocks of the Yeongnam massif. Although they have simple rock types (anorthosite and gabbroic anorthosite) comparable to well known massif_type anorthosites worldwide, they possess several important differences such as layered structure, amphibole rather than pyroxene as a mafic phase, and no orthopyroxene megacrysts. The age of intrusion was not available previously. We have applied Rb_Sr and Sm_Nd isotope systematics to investigate the age and origin of these rocks. One foliated gabbroic anorthosite defines a Sm_Nd mineral isochron age of 1678 ±90 Ma. This age is tentatively interpreted as the emplacement age because of apparently closed_system behavior of Sm_Nd system in these rocks during greenschist_facies metamorphism of presumably Mesozoic age. This age agrees with the age range (1.1 to 1.7 Ga) reported for the occurrence of Proterozoic massif_type anorthosites, suggesting that origin of the anorthositic rocks might be explained in the context of so_called Proterozoic anorthosite event. Significance of the anorthositic magmatism to the tectonic history of the Precambrian basement rocks in southern Korea Peninsula is discussed. $\varepsilon_{Nd}(t)$ values of whole rocks range - 1.6 to - 5.2, while initial $^{87}Sr/^{86}Sr$ ratios vary from 0.704 to 0.706. These data are interpreted as the result of assimilation of crustal material during crystallization of presumed anorthositic magma of mantle origin, although possible lower crustal source can not be excluded.

Key words: Sr_Nd isotope; origin; tectonics; anorthositic rocks; Hadong_Sanchung area; Korea

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1 Introduction

The occurrence of massif_type anorthosites has been a long_standing controversy in the geologic history of the earth particurlarly due to their distinct chemistry and to limited emplacement ages during the mid_Proterozoic (Herz, 1969). The Hadong-Sanchung anorthositic rocks (HSARs), cropping out in southern part of the Korean Peninsula, appear to belong to such massif_type anorthosites by their simple lithology (anorthosites and gabbroic anorthosites). However, they seem to be distinct from well known massif_type anorthosites worldwide in the ubiquitous appearance of amphibole as a dominant mafic phase instead of pyroxene, in plagioclase composition(An_{60}, to An_{80}) which is more calcic than typical massif anorthosites, and in the emplacement into amphibolite facies metamorphic terrain rather than granulite facies terrain. No hypersthene_bearing granitic rocks, such as charnockite and mangerite, have been reported in associated with HSARs, which are characteristically observed with anorthosites intruding into granulite facies metamorphic rocks. Although the field occurrence, mineralogy and petrology have been studied previously, the age HSARs has been practically unknown.

It has been well recognized that the age determination of anorthosites is not easy with conventional radiometric dating methods (e.g., Rb_Sr or U_Pb). Extremely low value and narrow range of Rb/Sr ratios of anorthositic rocks limit the application of Rb_Sr system, while scarcity of zircon or other high U minerals in general does not allow the application of U_Pb dating either. Therefore, the age of the anorthositic rocks has often been inferred from those of associated rocks (e.g., Pasteels *et al.*, 1979). However, recent application of Sm_Nd system, in favorable cases, appears to overcome the above problems and permit direct dating of anorthosites (Ashwal and Wooden, 1983a; Pettingill *et al.*, 1984).

In this paper, we present some preliminary Rb_Sr and Sm_Nd isotopic data 1) to obtain the emplacement age of the HSARs and 2) to evaluate to origin amphibole_bearing HSARs based on the isotopic data, and 3) to discuss tectonic implication of HSARs for the history of the Korean Precambrian basement.

2 Geologic setting

The geology of the HSARs and its vicinity has been studied in some detail by Son and Jeong(1972) and Jeong(1980, 1982). Only a brief summary will be stated in the following.

Fig. 1 shows the general geologic aspects of the study area. The HSARs occur as an elongated form in the north_south direction which were divided into two bodies by a later intrusion of the syenitic pluton in the middle, the northern Sanchung and the southern Hadong body. The HSARs have mainly two rock types i.e., anorthosite (> 90% plagioclase) and gabbroic anorthosites (plagioclase+ amphibole ± clinopyroxene ±orthopyroxene). Although the syenitic and gabbroic plutons intruding the Sanchung body were considered to be genetically related to the HSARs, initial radiogenic isotope data suggest that they are probably of Mesozoic age.

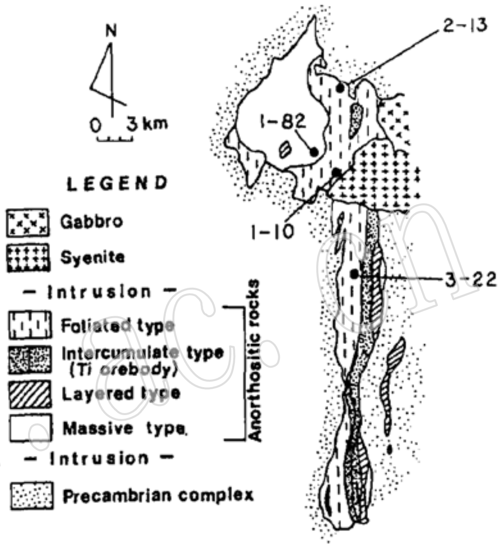

Fig. 1 Geologic map of the study area with sample locations, after Jeong *et al.* (1989)

Recently, Jeong *et al.*, (1989) subdivided the elongated Hadong body into four types: massive, layered, intercumulate and foliated types from east to west, based on texture and mafic mineral content. The intercumulate and foliated types have abundant mafic mineral, chiefly amphibole. Such a sequence was regarded as the differentiation trend of the anorthositic magma. This zoning suggests that the Hadong body might be better described as a layered intrusion rather a massif. On the other hand, circular Sanchung body can be divided into an inner massive and other foliated types, resembling , a massif. Magmatic nature of HSARs has been established through field and petrologic studies (Jeong, 1980; Jeong and Lee, 1986).

The HSARs intruded the Precambrian basement rocks of the Yeongnam massif. These basement rocks were subjected to three episodes of regional retrogressive metamorphism from the earliest upper amphibolite facies through epidote amphibolite facies to the last greenschist facies (Lee *et al.*, 1981; Song, 1981; Lee and Kim, 1984). Jeong and Lee (1986) have shown that HSARs itself suffered only to the last phase of greenschist facies metamorphism, evidenced by memtamorphic mineral assemblages consisting of chlorite, muscovite, biotite, and actinolite. Their study suggested that the hornblende in HSARs is probably of igneous origin. However, it should be noted that primary amphiboles are rare in anorthosites and most amphiboles in anorthosites are considered to be metamorphic (e.g., Simmons and Hanson, 1978). Field evidence suggested that the basement rocks consist of banded and migmatitic paragneisses, and dioritic and granitic orthogneisses (Kim and Kang, 1965). Rb_Sr whole rock age determinations indicated that the metamorphic rocks of both igneous and sedimentary origin in the Yeongnam massif are about 2.0 Ga old (Choo and Kim. 1985 and 1986; Choo, 1986 and 1987). Specifically, Choo and Kim (1986) reported Rb_Sr whole rock ages for banded gneisses (1.95 ±0.04 Ga) and porphyroblastic gneisses (2.07 ±0.04 Ga) occurring to the west of HSARs. The HSARs were, in turn, intruded by later plutonic rocks of diorite to the south, of schistose granite to the northwest, and of gabbro and syenite to the northeast and in the middle as described above. Although the emplacement ages of these later plutons are not well known, they are generally considered to be of Mesozoic age from field relationships. A biotite K_Ar age of 178 Ma was reported for a schistose granite to the north of the HSARs (Kim, 1971). Since similar granites intruded the HSARs, this age provides a lower limit for the emplacement of the latter. Although no estimates for the emplacement depth are available, regional metamorphic mineral assemblages of the basement rocks provide an indication that the depth of intrusion was not deeper than about 20 km (Lee *et al*., 1981).

3　Analytical procedures

Two anorthosites (2_13 and 1_82) and two gabbroic anorthosites (1_10 and 3_22) were analyzed for Sr and Nd isotopes. Samples locations are shown in Fig. 1.

Sample preparation, chemistry and mass spectrometry were done at the University California at Santa Barbara, U.S.A. by the senior author.

Plagioclase and mafic (mostly amphibole) separates were leached with warm 7 N HNO_3 for an hour before dissolution to remove any surface contaminations. Both whole rock samples and mineral separates were spiked with mixed ^{85}Rb_^{84}Sr and ^{149}Sm_^{150}Nd spikes before digestion in conc. HF and $HClO_4$ to ensure complete mixing of spike and sample. Rb, Sr and REE were separated using cation exchange column chemistry using 2.5 N HCl as an elution medium. Sm and Nd were separated with teflon powder method described in Bell *et al*. (1987). A more detailed description of chemical procedures appears in Kwon (1986).

Isotopic analyses were carried out on a Finnigan MAT 261 multicollector mass spectrometer equipped with 5 adjustable Faraday cups and one fixed cup. Sr was loaded with a Ta_2O_5_H_3PO_4 mixture on a single Re filament. Sr isotope ratios were measured with Faraday cups in a static mode and were normalized to $^{86}Sr/^{88}Sr = 0.1194$. Measured $^{87}Sr/^{86}Sr$ isotope ratios of samples are reported relative to a value of 0.71025 ±0.00002 (2σ) for repeated runs of NBS987 standard. Rb was loaded with 1 N HCl on a single Re filament and measured with Faraday cups. No instrumental fractionation correction was applied for measured $^{85}Rb/^{87}Rb$ ratios. $^{87}Rb/^{86}Sr$ ratios are estimated to be better than 5% (1σ), mostly due to errors on ^{87}Rb contents.

Nd was loaded with a dilute HCl_H_3PO_4 mixture on a Re filament and ionized with a double filament technique. Nd isotopic ratios were measured with Faraday cups in a static mode and normalized to $^{146}Nd/^{144}Nd = 0.72190$. Repeated runs of La Jolla Nd standard give $^{143}Nd/^{144}Nd$ ratio of 0.511 86 ±0.000 01 (2σ). Sm was measured with an identical technique as for Nd. Instrumental fractionation of Sm isotope ratios corrected with $^{147}Sm/^{152}Sm = 0.56028$. Estimated $^{147}Sm/^{144}Nd$ ratios are better than ±0.25% (1σ). Reported errors on measured $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios are two standard errors of mean (2σm).

Blank levels for Rb, Sr, Sm, and Nd were in average 40 pg, 100 pg, 40 pg, and 30 pg respectively. These blanks were insignificant to the results of the analyses.

The parameter $\varepsilon_{Nd}(t)$ used in this paper is defined as follows (DePaolo and Wasserburg, 1976): $\varepsilon_{Nd}(t) = (R_S(t)/R_E(t) - 1) \times 10^4$, where $R_S(t)$ is the $^{143}Nd/^{144}Nd$ ratio in the sample at time t and $R_E(t)$ is the ratio for the bulk earth at time t, estimated from the value of average chondrites (Jacobsen and Wasserburg, 1980 and 1984). Present_day bulk earth parameters are shown in Table 1.

Isochron parameters were estimated after the method of York (1969). Calculated ages and initial ratios were multiplied by square root of mean squared weighted deviation (MSWD) to account for presumed geological errors, when MSWD is greater than 1 Decay constants used area: 1.42×10^{-11}/y for ^{87}Rb (Steiger and Jager, 1977) and 6.54×10^{-12}/y for ^{147}Sm (Lugmair and Marti, 1978).

4　Results

The Sr and Nd isotope data are shown in Table 1. The anorthositic rocks have 5 to 10 ppm Rb, 300 to 400 ppm Sr, 0.3 to 1.6 ppm Sm, and 1.5 to 7.6 ppm Nd. Note that gabbroic anorthosites (1_10 and 3_22) have higher abundance of Sm and Nd than anorthosites proper (2_13 and 1_82), which can be attributed to the larger amount of mafic phases in the former. Also note that Sr concentration in plagioclase is much lower than that (600 to 1200 ppm) of most massif anorthosites, indicating that HSARs are chemically similar to mafic layered intrusion rather than to massif anorthosite (see Fig. 4 of Emslie, 1985). Low $^{87}Rb/^{86}Sr$ ratios (< 0.1) of the analyzed samples does not allow any isochron relationship in a $^{87}Rb/^{86}Sr$_$^{87}Sr/^{86}Sr$ diagram (not shown). Neither the whole rocks define an isochron in a $^{147}Sm/^{144}Nd$_$^{143}Nd/^{144}Nd$ diagram (Fig. 2) due to the limited range in Sm/Nd, as expected from most felsic rocks.

Table 1 Sr and Nd isotopic data of the Hadong– Sanchung anorthositic rocks in Korea

Sample	ppm		Measured		Initial	ppm		Measured		$\varepsilon_{Nd}(T)^{\#}$
	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sm	Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	
2_13WR	4.84	354	0.0396	0.705746 (40)	0.70479	0.3098	1.483	0.1263	0.511688 (25)	−3.4
1_85WR	9.98	411	0.0703	0.705745 (28)	0.70405	0.3373	1.878	0.1086	0.511517 (10)	−2.9
1_10WR	7.85	284	0.0800	0.704683 (35)	0.70455	0.5763	2.612	0.1334	0.511859 (23)	−1.6
Pl	8.87	347	0.0739	0.706323 (30)	0.70454	0.3589	2.348	0.0924	0.511429 (21)	
Mf	–	–	–	–	–	0.7598	3.609	0.1274	0.511854 (10)	
3_22WR	–	351	–	0.706810 (33)	–	1.601	7.555	0.1281	0.511617 (17)	−5.2
Pl	2.86	414	0.0200	0.706531 (36)	0.70605	0.5751	4.207	0.0827	0.511170 (11)	
Mf	2.67	83.7	0.0923	0.707084 (32)	0.70486	2.553	8.293	0.1864	0.512311 (16)	

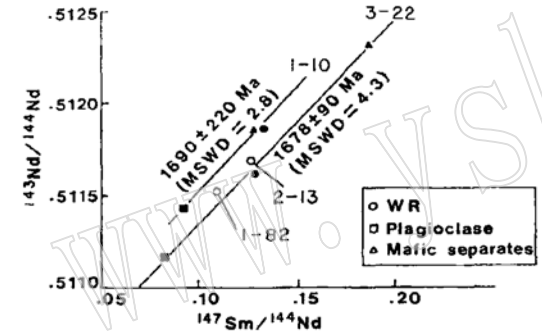

Fig. 2 Sm_Nd isochron diagram for the Hadong_Sanchung anorthositic rocks

However, a gabbroic anorthosite (3_22) gives a reasonably well defined internal isochron age of 1.68 ±0.09 Ga (MSWD= 4.3), chiefly controlled by mafic separate with relatively high Sm/Nd ratio and plagioclase with low Sm/Nd. An ill_defined isochron age of 1.69 ±0.22 Ga (MSWD= 2.8) can be obtained from sample 1_10. It is not clear why the mafic separate in this sample has lower Sm/Nd ratio than the other one. Although regional low grade metamorphism after the emplacement of the anorthositic magma, probably of Mesozoic age, has been noted for HSARs (Jeong and Lee, 1986), it appears that Sm_Nd system of the analyzed samples has not been disturbed significantly. It has been well documented that Sm_Nd systems are resistant during low_grade metamorphism and/or chemical weathering, due to more or less coherent geochemical behavior of the two elements. Thus, we tentatively interpret the internal isochron age as that of emplacement. This age effectively constrains those of amphibolite facies metamorphism in the basement to be before 1.7 Ga ago the amphibolite facies metamorphism did occur before the emplacement of HSARs, as suggested by Jeong and Lee (1986).

Calculated initial Sr ratios range from 0.7041 to 0.7061 and $\varepsilon_{Nd}(T)$ values range from −5.2 to −1.6, indicating a significant involvement of crustal component in the anorthositic rocks.

5 Discussion

5.1 Origin of the anorthosites

The origin of the massif_type anorthosites has been controversial because of their peculiar chemical compositions and limited occurrences during mid_Proterozoic time (see Hyndman, 1985 for a brief summary of suggested origins). Major problems about the origins of the anorthositic rocks include 1) whether anorthositic rocks represent cumulate during crystallization of basaltic magma, or crystallization of anorthositic magma, and 2) whether they came from mantle or crustal source region. Since the isotopic data have no bearing to the first question, discussions are confined to the second one in the following.

To assess the origin of HSARs, we need to examine the isotopic signatures of mantle and crust at the time of intrusion. Fig. 3 compares initial Sr isotopic ratios of HSARs with a model Sr isotopic evolution of the mantle. The calculated initial Sr ratios of 0.704– 0.706 are significantly higher than inferred mantle values of 0.702 – 0.703 at about 1.7 Ga ago, suggesting that HSARs was not purely of mantle origin. As an estimation of crustal Sr isotope signatures at the time, the Rb_Sr data of the metamorphic rocks of Jirisan gneiss complex in the vicinity of HSARs (Choo and Kim, 1985) were calculated back to 1.68 Ga ago assuming a closed system evolution of analyzed rocks. The calculated $^{87}Sr/^{86}Sr$ ratios of crustal rocks at the time of HSARs intrusion are in the range of 0.714 to 0.732 These values are much higher than those of HSARs, suggesting that these crustal rocks could not be the sole source of HSARs. Above consideration suggests that the parental magma of HSARs probably came from the mantle and was subsequently subjected to contamination of crustal rocks. However, we do not disregard a possible lower crustal source with Sr isotopic ratios comparable to those of HSARs. It has been recognized that the lower crustal rocks tend to have low $^{87}Sr/^{86}Sr$ ratios presumably due to preferential loss of Rb relative to Sr during granulite facies metamorphism (Hamilton *et al.*, 1979; DePalo, 1981a), although it still depends on the time scale of such metamorphism. No outcrops representing lower crustal meterial, such as granulite facies metamorphic rocks, were reported in the Yeongnam massif (Lee *et al.*, 1981; Lee and Kim, 1984). We defer further discussion of possible role of such source without the knowledge on the nature and age of the lower crust.

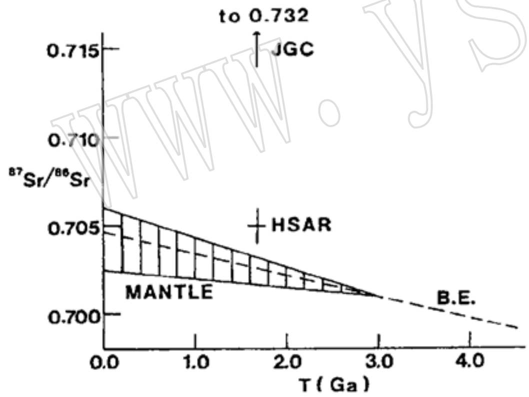

Fig. 3　$^{87}Sr/^{86}Sr$_age diagram showing differences between mantle, crust, and HSARs at about 1.7 Ga ago. A simple model mantle evolution assumes that present - day isotopic heterogeneities in the mantle (Staudigal *et al.*, 1984) originated from a differentiation event during late Archean time (Taylor and McLennen, 1985) from primitive mantle. JGC: Jirisan Gneiss Complex, estimated form the data of Choo and Kim (1986)

Since the application of Sm_Nd isotope system to terrestrial rocks, it has been shown that the mantle derived rocks tend to have positive ε_{Nd} values, while crustally derived rocks have negative values, reflecting fractionation between Sm and Nd during partical melting in the mantle to form crust (e.g., DePaolo, 1981b). Thus, the negative ε_{Nd} values for the HSARs already suggest influence of crustal material, consistent with Sr arguments. The data are plotted in a age vs. ε_{Nd} diagram (Fig. 4), and are compared with model Nd isotopic evolution of the large_ion_lithophile_elements depleted mantle (DePaolo, 1981a) and with 1.0 to 1.7 Ga old massif_type anorthosites occurring in North America (Ashwal and Wooden. 1983a). Note that the age and Nd isotopidc ratios of HSARs are very similar to those of Harp Lake complex, Labrador. As in the case of Sr, we need to know crustal Nd isotopic signature at the time of anorthosite intrusion to evaluate relative importance of mantle and crustal sources. At present, no Nd data are available for the basement gneisses in the vicinity of HSARs. We circumvent this problem with Sm_Nd data from granite gneisses (Buncheon and Hongjesa) in northeastern part of the Yeongnam massif (Kwon, unpublished data), assuming a similar crustal component in the southwestern Yeongnam massif. The evolution of these samples are also plotted in Fig. 4. Note that these samples indicate late Archean crust formation ages, although their emplacement ages are about 2 Ga old. In contrast to Sr isotope relationships, Nd isotope ratios of the HSARs show significant departure from the mantle value at about. 1.7 Ga ago, closer to the crustal values. This relationship is not unexpected because crustal rocks in general has more abundant Nd (about 30 ppm) than supposed anorthosite magma (about 3 ppm). It means that a small amount of crustal contamination can cause a very significant change of mantle Nd isotope values. Note that the sample (3_22) with the highest Nd contents has the lowest ε_{Nd} value. Although we definitely need more Nd data, the Nd isotope relationships of mantle, crust and anorthosites suggest that we may exclude the possibility of lower crustal source for the HSARs, if

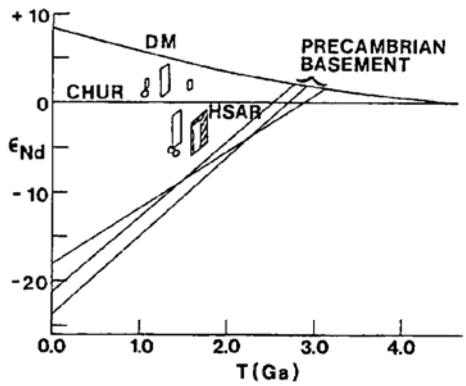

Fig. 4　ε_{Nd}_age diagram showing differences between mantle, crust and HSARs. The depleted mantle evolution curve (DM) id from DePaolo (1981a). Data for the Massif_type anorthosites occurring in North America are from Ashwal and Wooden (1983b) the crust formation ages of the lower crustal source for the HSARs are similar to those of the analyzed crustal rocks.

In summary, the Sr and Nd isotope data suggest that the anorthositic magma which resulted in HSARs probably came from the mantle, but was contaminated with variable amounts of crustal material. The results are in general agreement with conclusions reached from isotopic studies of other massif type anorthosites (e. g., Ashwal *et al*., 1986; Menuge, 1988).

5.2 Precambrian igneous activities in South Korea

Inferences about the tectonic environment for the massif type anorthosites suggested that they were probably related to incipient or failed continental rifting and represent nonorogenic magmatism instabilized craton (e. g., Emslie, 1978). Thus, the occurrence of anorthositic rocks has a particular meaning about the tectonic environment to which Precambrian basement was subjected. Majority of Precambrian igneous plutonic rocks in Korea are granitic in composition, which can be probably related to orogenic activities in the past. In discussing the Precambrian igneous activities in Korea, only Rb_Sr whole rock and U_Pb zircon ages will be considered here, since the meaning of K_Ar ages appears to be ambiguous due to later thermal events. For example, the Hongjesa granite has a Rb_Sr whole rock age of 1.71 Ga (Kim *et al*., 1978), but a K_Ar biotite age of 0.73 Ga (Yun an Silberman, 1979).

Early measurements of the basement gneisses in South Korea showed Rb_Sr whole rock model ages of 2000±500 Ma for Yeongnam and Kyonggi massifs (Hurley *et al*., 1973) and U_Pb zircon upper intercept ages 2150±20 Ma for a Precambrian granite (Gaudette and Hurley, 1973). Subsequent Rb_Sr whole rock age determinations refined the age structure of the Precambrian basement rocks. These later studies of the Yeongnam massif, though of reconnaissance character, showed that the ages of the Precambrian granitoids cluster around two groups, 2.0– 2.1 Ga and 1.7– 1.8 Ga with the former predominant (Choo and Kim, 1985 and 1986; Choo, 1986 and 1987). The younger group includes granite gneisses. such as Hongjesa (1.71 Ga), and Jungbongsan (1.77 Ga from Cho, 1984). The age of 1.68 ±0.9 Ga for the emplacement of HSARs suggests that HSARs is probably related to igneous activities of the younger group, although more precise measurements are required to firmly establish such a relation. If HSARs shared the same tectonic environment as other massif_type anorthosites, we can infer that the Precambrian basement in South Korea was subjected to an orogenic environment about 2 Ga ago and existed as a stable craton at least by about 1.7 Ga ago. Few igneous activities since 1.7 Ga ago have been identified until the Phanerozoic, suggesting that the basement rocks of South Korea remained in a stable region of the craton from mid_Proterozoic until Phanerozoic.

6 Conclusion

The measured Sm_Nd internal isochron age of 1.68±0.09 Ga is interpreted as that of emplacement since Sm_Nd system in the analyzed samples does not appear to have been disturbed by later (presumably Mesozoic) metamorphism in the anorthositic rocks. This age agrees with those of well known Proterozoic massif_type anorthosites worldwide, suggesting that the origin of HSARs may be considered in the context of so- called Proterozoic anorthositic event. However, we note that there are several differences between HSARs and typical massif anorthosites, such as 1) layered structure, 2) predominance of amphibole over pyroxene as a mafic phase, 3) low Sr concentration of plagioclase with anorthite_rich composition, 4) no orthopyroxene megacrysts, and 5) apparent intrusion into amphibolite facies metamorphic terrain rather than granulite facies.

Both Sr and Nd initial isotopic ratios indicate that presumably mantle_derived magma which was parental to HSARs assimilated a significant amount of crustal material during emplacement in the crust.

Presumed tectonic environment of anorthosite massifs and published age data for the Precambrian basement rocks suggest that at least southern part of the Korean peninsula existed as a stable craton by about 1.7 Ga ago and probably remained in a stable part of a craton until Phanerozoic.

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