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Lead Isotope Study on Lead-Zinc Ore Deposits in the Eastern and Southern Parts of the Gyeongsang Basin

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ABSTRACT: Based upon the lead isotopic compositions of the galenas collected from Pb-Zn ore deposits distributed in the eastern and southern parts of the Gyeongsang basin, we investigated what kinds of source materials were involved in the formation of these ore deposits and compared the lead isotopic characteristics of these ore deposits with those of the ore deposits in the Taebaegsan area. The isotopic compositions of the common leads from Pb-Zn ore deposits in the Gyeongsang basin show the variation with the relatively limited range ($^{206}Pb/^{204}Pb$=18.156~18.377, $^{207}Pb/^{204}Pb$=15.482~15.638, and $^{208}Pb/^{204}Pb$=37.953~38.605),. They are plotted on or below ore lead growth curve(Cumming & Richards, 1975) and average crustal lead evolution curve (Stacey & Kramer, 1975). In the plumbotectonic model IV(Zartman & Haines, 1988), they are plotted between the evolution curves of mantle and orogene. But the lead isotopic compositions of the common leads in the Taebaegsan area are plotted on and above upper crust curve. Considering the above-mentioned lead isotopic characteristics, the linear trend shown in the isotopic compositions of the common leads in the Gyeongsang basin can be considered as the mixing isochron between high radiogenic crustal materials such as the Ryongnam massif and low radiogenic materials derived from depleted mantle or materials with relatively low U/Pb and Th/U ratios.

INTRODUCTION

Lead isotopic compositions of rocks and ore deposits keep chemical records on the evolution of geological environments, such as mantle, crust, and orogene. Each of these environments has distinct U/Pb and Th/Pb ratios on the isotopic evolution of lead. The ratios are changed by geological processes, such as magma generation, fractionation, crystallization, hydrothermal alteration, or metamorphism.

Common leads offer important informations on the origin of lead in rocks and ore deposits. Common leads occur in minerals, whose U/Pb and Th/Pb ratios are so low that their lead isotopic compositions do not change appreciably since the time of mineral formation. The principal mineral which bears common lead is galena(PbS). Other base metal sulfides and K-feldspars, in which Pb^{2+} replaces K^+, also contain common leads. Therefore, these minerals can give informations on lead isotopic systematics at the time of mineralization.

Domestic studies on ore deposits were mainly focused on physico-chemical conditions of ore formations, but lead isotopic studies on the origin of ore source materials were rarely carried out.

Based upon the lead isotopic compositions of the galenas collected from 14 Pb-Zn ore deposits in the eastern and southern parts of the Gyeongsang basin, we investigated that the leads in the ore deposits were derived from what kind of source materials. We also compared their lead isotopic compositions to those of the ore deposits in the Taebaegsan area.

GENERAL GEOLOGY

The Gyeongsang basin is located in the south-eastern part of the Korean Peninsula, where non-marine sediments and volcano-clastics and volcanic rocks were accumulated during Cretaceous to early Tertiary. This sedimentary sequence composes the Gyeongsang supergroup. The volcano-clastic and volcanic rocks in the upper part of the supergroup consist of acidic to intermediate extrusive rocks, such as lavas and tuffs. The stratigraphic units of the basin divide into three groups, namely, the Sindong group, the Hayang group, and the Yucheon group (Chang, 1977). The emplacement of Bulguksa granite followed in early Paleogene after the sedimentation of these sedimentary rocks. Tertiary Miocene volcanic rocks are distributed in Yeonghae, Pohang, Eoil and Ulsan areas, overlying unconformably the previous groups. Pre-Cretaceous Jangsadong granites are exposed in the north-eastern part of the basin. The localities of mines, from which galenas were collected, are shown in Fig. 1. Most of ore deposits in the Gyeongsang basin have temporal and spatial relationship to

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Table 1. Brief descriptions of studied Pb-Zn ore deposits in the Gyeongsang basin.

	Mines	National Grid	Type	Commodity	Ore minerals	Analyzed mineral	Igneous rocks
Cheongsong-Yeongdeok	Munmyung	2277/3247	hy	Au-Ag	cp, gn, sl, py	gn	?
	Dongcheok (Oksan)	1830/3160	hy	Pb-Zn	cp, gn, sl	gn	Quartz-Porphyry
	Cheongsong (Jiso)	2005/3150	hy	Cu-Pb-Zn	cp, gn, sl, py	gn	?
Gyeongju-Pohang-Ulsan	Yeonil57	2362/2650	hy	Pb-Zn	sl, gn, py, cp, mt	gn	?
	Sangla	2395/2490	skarn	Pb-Zn	sl, gn, mt, py, cp	gn	Feldspar-Porphyry
	Daejung	2120/2504	hy	Pb-Zn	sl, gn, cp, py	gn	?
	Daeju	2139/2458	skarn	Pb-Zn	sl, gn, cp, py	gn	Eonyang Granite
Busan-Masan	Ilkwang	2200/2010	hy	W-Cu	asp, bi, py, sl	gn	Granodiorite
	Yanggu-Cu	1734/2190	hy	Cu-Pb-Zn	gn, sl, cp, py	gn	?
	Guimyeong	1742/2110	hy	Pb-Zn	gn, sl, cp	gn	Diorite
	Daewon	1627/2032	hy	Pb-Zn	gn, sl, cp, py	gn	biotite-Granite
	Gyeongjin	1700/1845	hy	Au-Ag	cp, gn, py	gn	biotite-Granite
Haman-Goseong	Samjeong (Yongjang)	1527/1980	hy	Au-Ag	gn, py, bi	gn	Granodiorite
	Samsan (Sambong)	1345/1610	hy	Cu-Pb-Zn	cp, gn, sl	gn	?

Abbreviation : hy=hydrothermal ore deposit, sl=sphalerite, gn=galena, cp=chalcopyrite, mt=magnetite, py=pyrite, bi=bithmuth, asp=asthenopyrite.

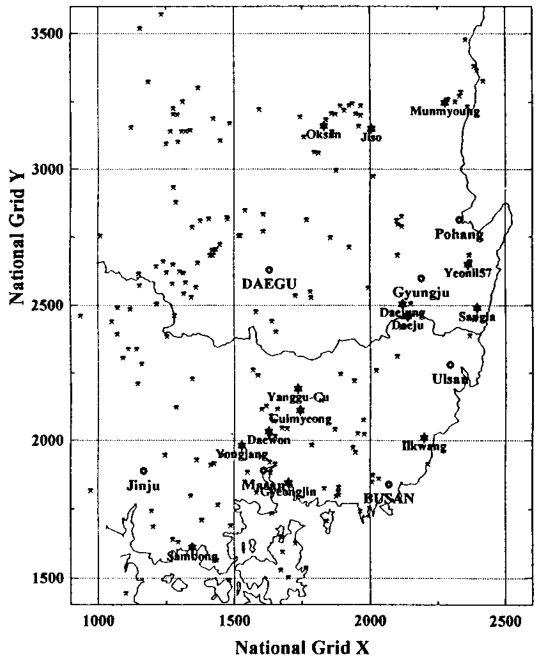

Fig. 1. Location map of mines in the Gyeongsang basin. Star symbols represent the locality of collected galena samples.

the Bulguksa granitic rocks. There are more than 200 mines in the Gyeongsang basin. Brief descriptions of the studied ore deposits are shown in Table 1.

Kwon(1991, 1992) reported Nd and Pb isotopic compositions of granitic rocks in the Gyeongsang basin, Ryongnam massif, and Ogcheon belt. He referred that the granitic rocks in the Gyeongsang basin were less radiogenic and have shown the lead isotopic compositions with a limited range, in comparison with those of the Ryongnam massif and the Ogcheon belt. He explained, from these lead isotopic compositions, that the former was mainly derived from the mantle, and the latter from upper crustal materials. Nd isotope characteristics also suggest slightly higher crustal material contribution to the latter than the former. The Pb and Nd isotopic characteristics coincide with lower Sr initial ratios of the granitic rocks in the Gyeongsang basin, compared with those in the Ryongnam massif and the Ogcheon belt. These isotopic characteristics are summarized in Table 2.

ANALYTICAL PROCEDURE

Galenas collected from Pb-Zn mines were separated by hand picking and their impurities were removed through stereo-microscope. Separated galena samples were dissolved in aqua regia(HCl:HNO3=3:1) on hot plate and were loaded directly on the Re-filament, using standard silicagel-phosphoric acid technique. Lead isotopic ratios were measured with VG 54-30 mass spectrometer with static mode at Korea Basic Science Center. The analysed data were normalized using the NBS SRM 981 standard, to correct errors produced from isotope fractionation during analysis. Used acids and water were purified with quartz subboiling system and two bottle

Table 2. **Previously reported isotope data of granitic rocks in the Gyeongsang basin, the Ryongnam massif, and the Ogcheon belt (Kwon, 1991, 1992; Jin et al., 1982; Hong, 1985; Choo, 1987, 1988, 1989; Choo and Chi, 1990, 1991; and Lee, 1991).**

	Granitic rocks in the Gyeongsang Basin	Granitic rocks in the Ryongnam Massif and Ogcheon Belt
^{206}Pb/^{204}Pb	18.2~18.3	17.3~18.4
^{207}Pb/^{204}Pb	15.56~15.59	15.55~15.78
^{208}Pb/^{204}Pb	38.3~38.5	38.5~39.6
U/Pb(μ)	low	high
Th/U(ω)	low	high
εNd(o)	0~+3	−12~−21
^{87}Sr/^{86}Sr initial ratio	low(<~0.705)	high(>~0.705)

subboiling system. Experiments were performed in a clean room. Total blank level was much less than 1 ng for lead.

RESULTS

Table 3 shows the lead isotopic compositions of the samples. For comparison, a galena collected from Wondong Pb-Zn skarn deposit in the Taebaegsan area was also analyzed. The lead isotopic compositions of galenas in the Gyeongsang basin show very limited ranges of ^{206}Pb/^{204}Pb=18.156~18.377, ^{207}Pb/^{204}Pb=15.482~15.682, and ^{208}Pb/^{204}Pb=37.953~38.605, whereas that of Wondong skarn deposit shows more radiogenic characteristics. Based on continuously changing earth model (Cumming and Richard, 1975), μ(^{238}U/^{204}Pb) and ω(^{232}Th/^{204}Pb) values were recalculated from the previously reported K-Ar ages of individual ore deposits. Unknown mineralization ages of some ore deposits were estimated to 65 Ma, which is the average of the mineralization ages reported from the ore deposits in the Gyeongsang basin. Recalculated μ and ω values were 10.15 to 10.36 and 37.83 to 40.56, respectively. Wondong Pb-Zn skarn-deposit shows higher μ and ω values than the ore deposits in the Gyeongsang basin.

COMMON LEADS IN THE GYEONGSANG BASIN

Lead evolution models

In the two stage model of Stacey and Kramer(1975), in which lead started with primordial isotopic ratios in 4.57 Ga years ago, they suppose that lead evolved from 4.57 Ga to 3.70 Ga in a reservoir with uniform μ and ω values, and at 3.70 Ga, μ and ω values were changed by geochemical differentiation due to the formation of proto-crust. This two stage model was established from the lead isotopic compositions of ore leads, pelagic sediments, marine volcanics, and ancient granitic rocks. The lead isotopic ratios on the evolution curve of this model can be considered as the average crustal lead compositions according to ages.

Cumming and Richards(1975) constructed a continuously changing earth model, in which the geochemical distribution of U-Th-Pb was not changed episodically but increased linearly with time. This model is also established from the isotopic compositions of global common leads. The lead growth curve of this model is placed upon the two stage evolution curves of Stacey and Kramer(1975).

The plumbotectonic models were introduced from the lead isotopic ratios calculated from mass balance equation, by considering that materials have been exchanged among three individual reservoirs designated upper crust, lower mantle, and mantle with the intervals of every 0.4 Ga age(Doe and Zartman, 1979, Zartman and Doe, 1981). These models were modified to the models with intervals of 0.1 Ga age(Zartman and Haines, 1988). The modified models are useful to the study on the source materials of lead.

Fig. 2 shows the lead isotope evolution curves and the lead isotopic compositions of ore deposits in the Gyeongsang basin and the Wondong skarn deposit in the Taebaegsan area. In ^{207}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb diagram (Fig. 2), galenas of Pb-Zn ore deposits in the Gyeongsang basin are plotted between mantle and orogene curves, while that of Wondong skarn deposit is plotted above upper crust curve. In ^{208}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb diagram(Fig. 2), all of galenas in these two areas are plotted up to upper crust curve, which indicates high ω environments.

The lead isotopic characteristics of the ore deposits in the Gyeongsang basin are similar to those of the ore deposits before Miocene in the south-western part of Japanese island(Sasaki, 1987). This isotopic similarity suggests that the tectonic environments of the Gyeongsang basin and the south-western part of Japanese island correspond to active zone of plate margin and that a portion of the lead was introduced from mantle.

As shown in ^{207}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb diagram(Fig. 2), two galenas from the Gyeongsang basin are plotted near mantle curve. They have typically low radiogenic lead composition anomalous to others. They are from Yongjang and Sambong mines located in the Haman-Goseong areas. The K-Ar ages of the ore deposits and the granitic rocks in these areas are older than those in other areas of the Gyeongsang basin(Table 3). The older ages seem to reflect the beginning of the igneous activity of the Bulguksa granitic rocks, and the low radiogenic

Table 3. Lead isotopic compositions of galenas collected from Pb-Zn ore deposits in the Gyeongsang basin.

	Mines	$^{206}Pb/^{204}Pb \pm 2\sigma$	$^{207}Pb/^{204}Pb \pm 2\sigma$	$^{208}Pb/^{204}Pb \pm 2\sigma$	Mineralization* Age(K-Ar) Ma	μ	ω
Cheongsong-Yeongdeok	Munmyung	18.343 ± 0.005	15.607 ± 0.006	38.513 ± 0.020	74.6 ± 2.1(2)	10.34	40.23
	Dongcheok (Oksan)	18.287 ± 0.0006	15.538 ± 0.0006	38.327 ± 0.0014		10.26	39.32
	Cheongsong (Jiso)	18.298 ± 0.0008	15.558 ± 0.0006	38.365 ± 0.0016	60.2 ± 1.3(3)	10.26	39.45
Gyeongju-Pohang-Ulsan	Yeonil57	18.299 ± 0.002	15.581 ± 0.001	38.436 ± 0.003		10.27	39.81
	Sangla	18.337 ± 0.0005	15.581 ± 0.0004	38.413 ± 0.0012	53.9 ± 1.4(2)	10.30	39.61
	Daejung	18.291 ± 0.0006	15.523 ± 0.0006	38.261 ± 0.0013	53.8 ± 1.4(2)	10.25	38.93
	Daejung	18.377 ± 0.003	15.628 ± 0.002	38.261 ± 0.007		10.36	40.56
Busan-Masan	Ilkwang	18.357 ± 0.0008	15.560 ± 0.0006	38.372 ± 0.0017	69 ± 2.6(4)	10.35	39.56
	Yanggu-Cu	18.279 ± 0.0005	15.543 ± 0.0005	38.312 ± 0.0013		10.25	39.26
	Guimyung	18.279 ± 0.0005	15.543 ± 0.0005	38.349 ± 0.0046		10.29	39.42
	Daweon	18.319 ± 0.0008	15.533 ± 0.0007	38.294 ± 0.0017		10.30	39.18
	Gyeongjin	18.282 ± 0.0010	15.566 ± 0.0008	38.261 ± 0.0024		10.26	39.51
Haman-Goseong	Samjeong (Yongjang)	18.156 ± 0.0007	15.482 ± 0.0006	37.953 ± 0.0019	84.8 ± 2.1(2)	10.15	37.83
	Samsan (Sambong)	18.276 ± 0.0005	15.489 ± 0.0006	38.103 ± 0.0023	84.8 ± 2.1(2)	10.28	38.50
Taebaeg	Wondong	18.912 ± 0.002	15.801 ± 0.002	39.165 ± 0.005	51.79 ± 1.8(1)	10.95	42.92

*Reported mineralization ages after (1)Park et al.(1988), (2)Park et al.(1994), (3)Lee et al.(1993), and (4)Fletcher & Rundle(1977).

**Pb isotope ratios were corrected using NBS 981

***μ and ω values were recalculated using continuously changing earth model (Cumming & Richards, 1975). Unknown mineralization ages of ore deposits were estimated to 65 Ma.

isotope characteristics indicate that the parent magmas of the granitic rocks in the Hamman-Gosung areas were less contaminated by crustal materials than those in the other parts of the Gyeongsang basin.

Mixing isochron of galenas in the Gyeongsang basin

The lead isotopic compositions reported from several Pb-Zn ore deposits(Yeonwha, Janggun, and Wooljin) in the Taebaegsan area(Chang et al, 1992) were used, in comparison with those in the Gyeongsang basin. The range of the common lead isotopic compositions of the former is shown as hatched area in Fig. 3, which shows good linear array. Considering this linear array as a secondary isochron, the age of source materials of the common leads in the Taebaegsan area can be considered as 2.2 ± 0.3 Ga. This age is similar to that obtained by Sasaki(1987).

The linear array($R^2=0.59$) of the common leads in the Gyeongsang basin can be inferred as the mixing isochron between crustal materials such as gneissic basement rocks and materials with relatively low U/Pb ratios. But there is no enough informations on the lead isotopic compositions of basement rocks in the study area. According to Park et al.(1993), the lead isotopic compositions of Precambrian gneissic rocks in the northeastern Ryongnam massif are very radiogenic and they vary with a wide range of $^{206}Pb/^{204}Pb=18.42$ to 57.35 and $^{207}Pb/^{204}Pb=15.74$ to 20.50. Precambrian gneissic basements rocks deep-seated in the Gyeongsang basin can be considered as one of crustal materials enriched in uranium. From the lead isotopic compositions of several ore deposits in the Taebaegsan area corresponding to the northeastern Ryongnam massif(Chang et al., 1992, Chang et al., 1995 in this issue), the average value of μ of the ore deposits may be estimated at 10.97 by using Cumming and Richard growth model(1975). This μ value may be considered as that of end member enriched in uranium in the mixing isochron(Fig. 3). The μ value of end member depleted in uranium may be considered as 10.28. It was assumed from the isotopic compositions of the ore deposits in the Haman-Goseong areas(Table 3). These ore deposits show the least radiogenic signature among Pb-Zn ore deposits in the Gyeongsang basin.

The linear array of the common leads in the Gyeongsang basin corresponds to the 0.2 Ga primary isochron between two growth curves in Fig. 3. For the precise interpretation of the mixing trend, we should have additional data about the lead isotopic composition of basements, sedimentary rocks, and mantle-derived materials in the Gyeongsang basin.

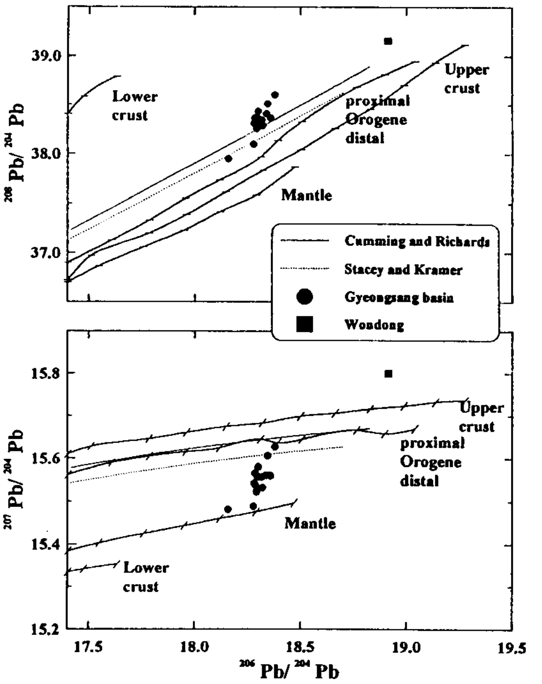

Fig. 2. ^{208}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb and ^{207}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb plots for Pb-Zn ore deposits in the Gyeongsang basin and Wondong skarn deposit in the Taebaegsan area. Lead isotope evolution curves are from two stage model(Stacey and Kramer, 1975), ore lead growth model(Cumming and Richards, 1975), and plumbotectonics model IV (Zartman and Haines, 1988). Tick marks along each curve indicate progressively older time in 0.1 Ga increments.

CONCLUSIONS

1) The lead isotopic compositions of galenas collected from 14 Pb-Zn mines in the south-eastern parts of the Gyeongsang basin show the variation with the very limited range (^{206}Pb/^{204}Pb=18.156~18.377, ^{207}Pb/^{204}Pb=15.482~15.638, and ^{208}Pb/^{204}Pb=37.953~38.605), compared with those in the Taebaegsan area.

2) Their lead isotopic compositions were characterized by low radiogenic lead contents, compared with those of the Taebaegsan area. Therefore, a portion of leads of Pb-Zn ore deposits in the Gyeongsang basin can be considered to be derived from depleted mantle or material with particularly low U/Pb and Th/U ratios.

3) In ^{207}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb diagram. The linear trend of the lead isotopic compositions of galenas in the Gyeongsang basin can be interpreted as the mixing isochron between crustal materials such as the Ryongnam massif and materials derived from sources depleted in uranium(depleted mantle) such as mantle-derived materials.

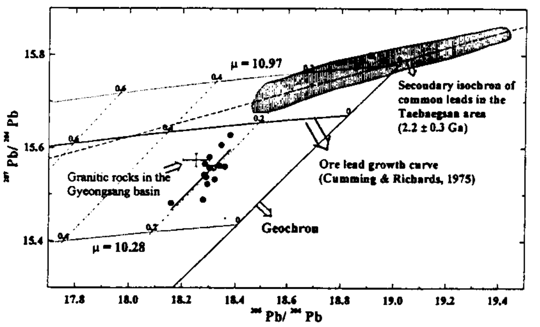

Fig. 3. ^{207}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb plot. Cross bar indicates the range of the lead isotopic compositions of granitic rocks in the Gyeongsang basin(Kwon, 1992). Hatched area shows the range of the lead isotopic compositions of common leads of several Pb-Zn ore deposits in the Taebaegsan area(Chang et. al, 1992). Symbols are the same as in Fig. 3.

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경상분지 동남부 연·아연광상에 대한 납 동위원소 연구

장병욱·장호완·정창식

요　약 : 경상분지의 동부와 남부에 분포하는 연·아연광상에서 산출되는 방연석의 납 동위원소 비로부터 광상을 형성한 납이 어떤 기원물질로부터 유래하였는가를 연구하고, 이를 태백산 광화대 내 일부광상들의 납 동위원소 비와 비교 연구하였다. 경상분지내 연·아연광상들의 보통납(common lead)의 동위원소 비는 ^{206}Pb/^{204}Pb=18.156~18.377, ^{207}Pb/^{204}Pb=15.482~15.638, 와 ^{208}Pb/^{204}Pb=37.953~38.605로서 매우 제한된 영역의 변화를 보인다. 또한 납 동위원소 비들은 광상 납 성장곡선(Cumming과 Richards, 1975)과 평균지각 납 진화곡선(Stacey와 Kramer, 1975)의 선상 혹은 하부에 점시되어 맨틀성분의 개입이 많음을 지시하는 반면, 태백산 광화대의 경우는 진화곡선 상부에 점시 되어 지각 물질의 개입이 많음을 나타내었다. Plumbotectonics Model IV (Zartman과 Haines, 1988)에서는 경상분지의 납들은 대부분 맨틀과 조산대 사이의 영역에, 태백산 광화대의 자료들은 대부분 상부지각선의 선 상이나 그 상부에 점시 된다. 위와같은 납 동위원소 조성이 보여주는 특징과 더불어 경상분지 보통납의 동위원소 비들이 나타내는 선형관계는 낮은 U/Pb와 Th/U의 비를 갖는 기원물질 혹은 결핍맨틀(depleted mantle) 물질과 기반암과 같은 지각 물질간의 혼염에 의한 혼합 아이소크론(mixing isochron)으로 추정된다.