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# Cauldron Subsidence and Ore Mineralization in the Southeastern Kyongsang basin: A review

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ABSTRACT: Nine cauldrons have been recognized in the PVD (Pusan-Taegu Volcano-tectonic Depression) zone covering an area of nearly 7,000 $km^2$. They form characteristic landscape features with various mountains in the southeastern Kyongsang basin. Economically important ore deposits are also developed either in the ring fracture zone or the central pluton within the resurgent cauldrons or in the marginal area of the PVD, suggesting that these cauldrons played a major role in the distribution of ore deposits in the southeastern Kyongsang basin. Furthermore, the cauldron subsidences were more frequent with the more felsic volcano-plutonic complex, possibly indicating that the amounts of water and volatile components also acted as a controlling factor to cause the caldera subsidence and to concentrate the ore-forming elements in economic concentrations. The review of the relationship and variations of ore mineralization and cauldron subsidence is rather sketchy, but it provides a skeleton to carry out more detailed and quantitative studies related to temporal and spatial relationships between each cauldron subsidence accompanying its own ore mineralization. In the southeastern Kyongsang basin, additional calderas and associated ore deposits undoubtedly can be discovered through future detailed studies. The concept that cauldron subsidence are an important control for the formation of ore deposits will appear to be vindicated.

## INTRODUCTION

During the Cretaceous to early Tertiary, the Kyongsang basin of southeastern Korea ((Fig. 1) was part of an Andean-type continental margin along eastern Asia, where extensive crustal upheaval and non-marine sedimentation took place (Sillitoe, 1977; Kim, 1985; Miyazawa, 1985). In addition, the Kyongsang basin was the major place of extensive igneous activities of the Cretaceous to early Tertiary time, as evidenced by pervasive volcanic and plutonic rocks. The igneous activities occurred from the calc-alkaline magma formed by partial melting of subducted oceanic crust at a compressional plate margin (Jin *et al.*, 1981; Min *et al.*, 1982; Lee *et al.*, 1987). Especially, the great volumes of intermediate to silicic volcanic rocks covering over 7,000 $Km^2$ were erupted mainly as ash-flow and/or fallout tuffs from central volcanoes, including some of the largest known calderas (Hwang, 1978; Cha, 1979, 1980, 1985; Lee, 1979; Cha and Yun, 1982; Cha *et al.*, 1984).

Various ore deposits seem to be related spatially

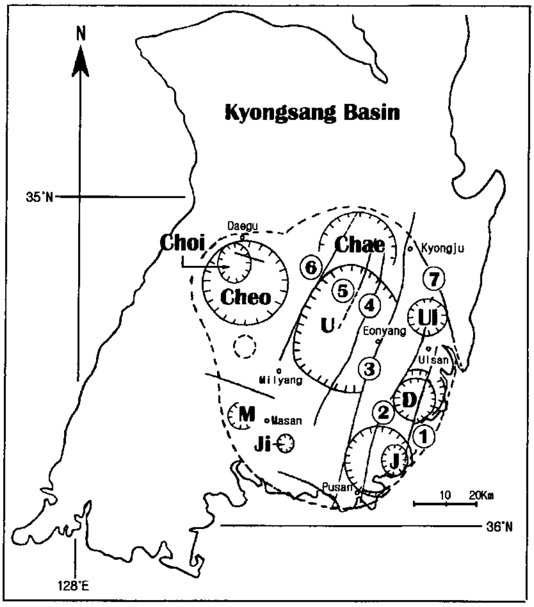


**Fig. 1.** Schematic geological map of the inferred Pusan-Daegu volcano-tectonic Depression zone showing cauldrons and major faults in the southeastern Kyongsang basin (modified from Cha, 1985). **Cauldrons:** Chae; Chaeya-ksan, Cheo; Cheongdo, M; Mageumsan, U; Unmunsa, Choi; Choijeong-san, J; Jangsan, D; Daeunsan, Ul; Ulsan, Jinrye; Ji. **Faults:** 1; Ilkwang fault, 2;Dongnae fault, 3; Yangsan fault, 4; Moryang fault, 5; Milyang fault, 6; Jain fault, 7; Ulsan fault.

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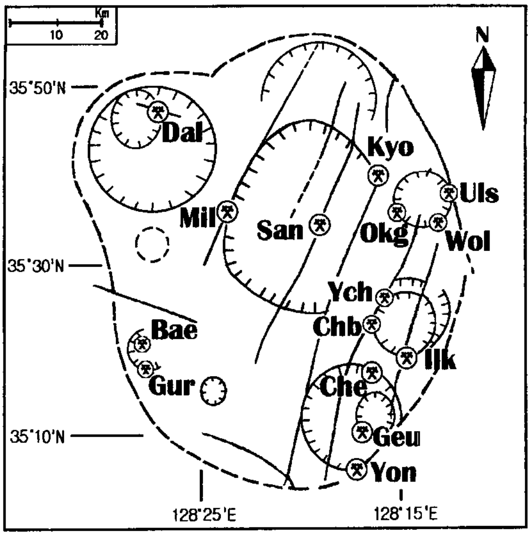


**Fig. 2.** Locations of cauldrons and mining districts listed in Table 1. Dal; Dalsung, Bae; Baegweol, Gur; Guryong, San ; Sannae, Kyong; Kyongju, Mil; Milyang, Geu; Geumyeonsan, Yon; Yongho, Che; Cheolma, Ilk; Ilkwang, Chb; Cheonbulsan, Ych; Yongcheonsan, Uls; Ulsan, Okg; Okgog, Wol; Wolseong.

to volcanic cauldrons in the southeastern Kyongsang basin as shown in Fig. 1, 2 and Table 1, possibly suggesting their genetic association. Although there are many studies to clarify the relationship between granitic intrusion and ore mineralization in the Kyongsang basin (Kim, 1971; Cha *et al.*, 1972; Jin *et al.*, 1982; Lee and Lee, 1982; Lee, 1982), little has known about the major functions of cauldrons in relation to ore deposits. In order to understand the spatial and temporal relationship between volcanic cauldrons and mineral deposits and to suggest important roles of cauldrons for the generation of ore deposits in the southeastern Kyongsang basin, we focused on the evolution of cauldrons and characteristics of ore deposits, based on field surveys and published data.

## REVIEWS OF EVOLUTION OF VOLCANO-PLUTONIC ACTIVITY AND CAULDRONS IN THE SOUTHEASTERN KYONGSANG BASIN

The presence of PVD (Pusan-Taegu Volcano-tectonic Depression: Cha, 1985) zone, covering an area of nearly 7,000 $km^2$ (95 × 75 km in diameters), is delineated by a ellipsoidal topographic feature which consist of concentric volcanic and

**Table 1.** Summary of volucanism, cauldron, and ore mineralization in the inferred Pusan-Daegu Volcano-tectonic Depression, Kyongsang basin.

| Volcanism | Name of Cauldron | Age of volcano-plutonic rocks (data source in parenthese) (Ma) | Dimension of ring structure (Km) | Mode of plutonism |
|---|---|---|---|---|
| Chaeyaksan | Chaeyaksan | 90-98 (Yun and Sang, 1994) | 25×16 | RE |
| Chusansan | Cheongdo | 77-71 (Min *et al.* 1982; Hwang, 1990; Yun and Sang, 1994) | 28×28 | RD, CI |
| | Mageumsan | 104-84* | 10×9 | RD, CI |
| Unmunsa | Unmunsa | 78-63 (Hwang, 1990; Yun and Sang, 1994) | 25×33 | RD, CI |
| | Choijeongsan | 77-71 (Min *et al.* 1982; Hwang, 1990; Yun, and Sang, 1994) | 10×8 | RD, CI |
| | Jangsan | 71-63 (Yun and Sang, 1994) | 5×5 | RD |
| | Daeunsan | 68-66* | 15×15 | RD, CI |
| | Ulsan | 87-60* | 12×12 | RD, CI |
| | Jinrye | 77* | 5×4 | CI |

*,**,*** Ages are taken fromt he KIGAM (1995), KMPC (1981) and KMIPC (1990). RD; Ring Dike, CI; Central Intrusion.

**Table 1.** Continued.

| Volcanism | Name of Cauldron | Associated ore deposite | Age of mineralization (data source in parenthese) (Ma) | Host rock | Mineralization type |
|---|---|---|---|---|---|
| Chaeyaksan | Caeyaksan | Not Reported | | | |
| Chusansan | Cheongdo | Dalsug (W-Cu, Au) | late Cretaceous*** | andesite | breccia-pipe |
| | Mageumsan | Baegweol (Pb, Zn-Cu) | late Cretaceous** | andesite | fissure-filling vein |
| | | Guryong (Cu-Mo) | late Cretaceous** | | fissure-filling vein |
| Unmunsa | Unmunsa | Saannae (W-MO) | 65±1.4 Ma (Fletcher and Rundle, 1977) | granitic rock | fissure-filling vein |
| | | Kyongju(pyrophyllite) | late Cretaceous (Sang, 1992) | dacitic tuff | hydrothemal alteration |
| | | Milyang(pyrophyllite) | late Cretaceous (Chung, 1991) | rhyolitic tuff | hydrothemal alteratiion |
| | Choijeongsan | Not Reported | | | |
| | Jangsan | Geumyeonsan (Cu) | late Cretaceous (Cha & Yun, 1982) | andesite | fissure-filling vein |
| | | Yongho (Cu, Au) | late Cretaceous (Cha & Yun, 1982) | andesite | fissure-filling vin & hydrothemal alteration |
| | | Cheolma (Cu, Zn, Ag) | late Cretaceous (Cha & Yun, 1982) | andesite | fissure-filling vein |
| | Daeunsan | Ilkwang (Cu-W) | 69±2.6 Ma (Fletcher and Rundle, 1977) | granitic rock | breccia-pipe |
| | | Cheonbulsan (pyrophyllite) | late Cretaceous (Kim, 1987) | rhyolitic welded tuff | hydrothemal alteration |
| | | Yukwang (pyrophyllite) | late Cretaceous (Sang, 1992) | rhyolitic tuff | hydrothemal alteration |
| | | Yongcheon (pyrophyllite) | late Cretaceous (Sang, 1992) | rhyolitic tuff | hydrothemal alteration |
| | Ulsan | Ulsan (Fe-W, As) | ? | carbonate rock | ? |
| | | Okgok (Mo, W) | late Cretaceous | granitic rock | disseminated |
| | | Wolseong (As-Zn) | 65* | rhyolitic tuff breaccia | disseminated |
| | Jinrye | Not Reported | | | |

granitic ring complexes and the basement sedimentary rocks dipping toward the central part. The plutonic rocks are associated with contemporaneous volcanic rocks ranging in composition from basalt and andesite through dacite and rhyodacite to rhyolite. This reflects that they are comagmatic (Jin *et al.*, 1981; Hong, 1987; Lee *et al.*, 1987; Hwang, 1990).

Nine cauldrons have been recognized in the southeastern Kyongsang Basin (Fig. 1; Hwang, 1990; Yun *et al.*, 1996). Cauldrons form characteristic landscape features making up various mountains. The inner subsided blocks may be sized up to 35 km in diameters, whereas the outer ring-fracture zone which was intruded by granitic rocks extends up to several kilometers. Volcanic rocks show a dome structure in the central part of the cauldrons. The cauldrons commonly show a negative Bouguer anomaly, –5 to –10 *mgal* (Choi, 1986). Within the inferred PVD zone, the largest inner cauldron, so-called Unmunsa caldera (25×35 km in diameters), is developed. The other eight cauldrons are developed at peripheral parts of the PVD and contain granitic rocks which intruded along the ring fracture zone. These informations including distribution patterns, shapes and structures of the volcanic rocks, together with rock compositions, suggest that the volcanic cauldrons belong to the Valles-type (Smith and Bailey, 1968; Lipman, 1984).

Igneous activities in the PVD can be grouped into four stages (Won *et al.*, 1978; Hwang, 1978; Cha, 1980, Cha and Yun, 1982; Kim, 1982; Lee *et al.*, 1987; Yun and Sang, 1994; Yun, 1998). (1) the first Chaeyaksan alkali-basaltic volcanism and the caldera-fill deposit, (2) the second Chusasan andesitic volcanism, (3) the third Unmunsa rhyolitic ash-flow volcanism, (4) the fourth Bulguksa silicic intrusion.

The Chaeyaksan Volcanics representing the early igneous activities have a narrow and remarkably arcuate distributions (Cha *et al.*, 1985; Yun, 1998). They show a marked topographic relief around the northern margin of the PVD, and strike parallel to the edge of the PVD. They are mainly composed of pyroclastic deposits with intercalations of alkali basaltic lava flows in the middle part, which gradually transfer into lahar deposits toward the upper horizons. Pyroclastic rocks are composed of tuff, lapilli tuff, and tuff breccia, whereas lahar deposits are composed of tuffaceous conglomerate, sandstone and shale. The overlying Geoncheonri Formation also shows the similar distribution pattern with the Chaeyaksan Volcanics, and is dipping toward the center of the Chaeyaksan cauldron complex comprising the Chaeyaksan Volcanics and Geoncheonri Formation. As shown in Fig. 1, only northern part of the Chaeyaksan cauldron is still remained, whereas the other half has been destroyed by the following Chusasan volcanism and/or eroded away due to differential erosion (Yun, 1998).

The Chusasan Volcanics are distributed at the overall area of the PVD, and represent the late Cretaceous intermediate volcanic rocks of the lower Yucheon Group (Fig. 1). They are mainly composed of calc-alkaline andesitic pyroclastics with minor lavas and local sedimentary intercalations. The Jayangsan Formation overlying the Chusasan Volcanics is composed of alternating andesitic lapilli tuff, tuffaceous reddish shale, white to greyish shale and tuff, and is distributed within the Cheongdo cauldron as intra-caldera fill deposits. Two cauldrons, Cheongdo and Mageu-msan cauldrons, are thought to belong to the Chusasan Volcanics since they show the similar andesitic rock compositions to typical Chusasan volcanic rocks. The structures of these two cauldrons are complicated and characterized by concentric and radial joint systems, ring faults, and ring dikes forming a composite volcanics-ring dike complex.

The Unmunsa Volcanics are predominantly distributed in the central part of the PVD and consist of the late Cretaceous felsic volcanic rocks of the upper Yucheon Group. They are mainly composed of dacitic to rhyolite ash-flow tuff, and are distributed at the inner side of the subsided cauldron. It is probable that copious outpouring of silicic tuff have caused a sudden emptying of the magma chamber and thus, resulted in the surface cauldron subsidence. Six cauldrons including Unmunsa, Choijeongsan, Jangsan, Daeunsan, Ulsan, and Jinrye cauldrons belong to the Unmunsa Volcanics.

During the Cretaceous to early Tertiary, plutonism began with the intrusion of granitic rocks into a thick sequence of terrigeneous sedimentary and volcanic rocks of the Cretaceous Kyongsang Supergroup. The plutonism typically occurred along the circular weak structures which were formed owing to the predated cauldron subsidence. Therefore, the Cretaceous to early Tertiay granitic rocks show either no foliations or no schistosity, showing the characteristics of post-tectonic granites in field and thin sections (Lee, 1987). At the western and northeastern margin of the PVD, granites intruded along the marginal ring fractures and may be a part of the giant outer ring-structure. A rectangular structure of the Unmunsa cauldron in the central part of the PVD may be also controlled by the regional fault system with a NNE-SSW trend (Fig. 1). A few felsite and rhyodacites exposed at the northern part of the Unmunsa cauldron are petrographically similar with those in the ring dike and part of the inner ring-structure.

The Bulguksa granitic rocks occur as either ring or central intrusions. Ring intrusions were emplaced by the ring-fracture stoping into the ring fault of the volcanic cauldron and along the marginal ring-fracture zone of the PVD. Central intrusions were emplaced by the magmatic stoping associated with uprising of magma due to resurgence of the magma chamber beneath the volcanic cauldron. Granitic ring complexes are characterized by a central pluton bounded by ring dikes or ring intrusions and by downfaulted intra-caldera volcanics. These structures indicate the subvolcanic features analogues of the resurgent cauldrons.

## ORE DEPOSITS IN THE PVD ZONE

As shown in Table 1 and Fig. 2, various hydrothermal metallic ore mineralization and hydrothermally-altered deposits are developed in the PVD. Most ore deposit exhibit typical hydrothermal mineralization including Mo, W, Pb, Zn, Cu, Au, Ag and pyrophyllite (Fletcher and Rundle, 1977; KIER, 1983). Fluid circulation driven by magmatic heat played a major role in ore mineralization as evidenced by various fluid inclusions and alteration patterns at ore deposits (Jin, 1975; Fletcher, 1977, 1979; Shelton *et al.*, 1986; Yang and Lee, 1998). The followings are brief descriptions on characteristic features of ore deposits in the PVD. They include Mo-W fissure-filling deposits of the Sannae mine, hydrothermally-altered pyrophyllite deposits of the Cheonbulsan and Milyang deposits, magnetite deposits of the Ulsan mine, disseminated As-Zn deposits of the Wolseong mine, and Cu breccia-pipe deposits of the Ilkwang mine. All of these deposits including other deposits listed in Table 1 are hosted within the ring-fracture zone of cauldrons.

The Ulsan mine is developed within the Ulsan cauldron, and contain magnetite and serpentinite deposits occur together at the mine. They are spatially related with micrographic granitic rocks which are altered at the mine area. The origin of the Ulsan carbonate rocks and magnetite deposit is controversial (Park and Park, 1980; Choi, 1983; Choi, 1988; Kim, *et al.*, 1990). Some workers believe the deposit is a skarn-type and the host carbonate rocks are related with Paleozoic limestone (Park and Park, 1980; Choi, 1983; Kim, *et al.*, 1990). On the other hand, Choi (1988) suggested that the unique pipe-type occurrence of the carbonate rocks associated with ultramafic rocks which is now hydrothermally altered to serpentinite indicate a igneous origin. Regardless of its origin, it is obvious that the deposit was controlled by mechanical stresses since numerous dikes and calcite veins as well as many tectonic fault lines are developed at the mine area.

The Weolseong As-Zn deposit and associated Weolseong diatreme are related spatially to the emplacement and cooling of the Chisulryoung Volcanic Complex in the Ulsan cauldron. The volcanic activities predated the intrusion of granitic rocks (Reedman *et al.*, 1989). The ages of granodiorite and granitic rocks are 87.9±6.3 Ma and 63.9±1.8, respectively, whereas that of the As-Zn mineralization is 65.1±1.8 Ma (Reedman *et al.*, 1989). This suggests that ore fluids were supplied at later period of the Chisulryoung volcanism. The volcanism probably provide a permeable fault zone for descending ground water to encounter ascending magma (Park and Kim, 1985). Magma body emplaced at relatively shallow depth either exsolved or encountered a voluminous supply of water causing significant volume expansion of water. As a result, tremendous pressure building-up was formed and resulted in intensive radial fracturing. The ore body is distinctly circular and funnel-shaped at center of the diatreme. Thus, the vent area of diatreme served as channel ways for mineralizing hydrothermal fluids (Park and Kim, 1985).

In the area of the Ulsan cauldron, Ulsan and Dongrae faults are developed both the west and east side of the above two Ulasan and Weolseong mines. Furthermore, the Yangsan fault lies on the left side of the Weolseong mine and Dongrae fault and another Onsan fault is crosscutting the Dong-rae fault. The presence of these faults indicate that there were considerable tectonic movements in the area, which probably provided ideal conditions for circulations of hydrothermal or mineralizing fluids. These tectonic movements were probably associated with cauldron subsidences (Cha, 1985). The combination of induced fracturing and thermal anomalies provide a highly permeable setting which supports convective circulation of hydro-thermal fluids.

The Sannae Mo-W mine consists of a hydrothermal vein-type deposits which were developed within the Unmunsa cauldron in the PVD (Table 1). A large number of subparallel fissure-filling quartz veins are associated with molybdenite-tungsten mineralization. The ages of the host granite and the Mo-W mineralization are 75.5±1.2 Ma (Choo and Kim, 1981) and 65±3 Ma (Fletcher and Rundle, 1977), respectively, showing almost 10 Ma difference. It may suggest that the ore mineralization resulted from the formation of resurgent cauldrons followed by the granite emplacement. Fluid ascent was probably initiated with faulting which postdated the intrusion of host granitic rocks.

Pyrophyllite deposits associated with the late Cretaceous volcanic rocks are widely distributed in the PVD (Table 1). Pyrophyllite deposits were formed by hydrothermal alteration around the ring fracture zone. Most of their host rocks are andesite through rhyodacite devitrified tuff to rhyolitic welded tuff. These rocks are localized within ring fractures of the cauldron or volcanic vent, and altered by acidic hydrothermal solutions supplied from the upper part of the magma chamber. For example, the Cheonbulsan and Milyang pyrophyllite deposits appear to be genetically related with the Daeunsan and the Unmunsa cauldrons, respectively (Sang, 1986, 1992). As shown in Fig. 1 and 2, these two deposits lie in the ring-fracture zone and are controlled by Jain and Dongrae fault of approximately N30E trend. These deposits show zonal patterns of hydrothermal alteration about the center of fractures (Sang, 1986).

The Cu-W mineralization of Ilkwang mine was associated with explosive brecciation and exsolution of magmatic hydrothermal fluids (Yang and Lee, 1998). The breccia pipe consists of brecciated fragments and various cementing minerals such as quartz, scheelite, arsenopyrite, pyrrhotite, and chalcopyrite, forming a network. The ore fluid had chemical and isotopic signatures consistent with deep-seated water suggesting that extensive reactions with overlying sedimentary rocks generated a type of magmatic water (Kim *et al.*, 1998). The Ilkwang breccia pipe is found close to the ring fracture system associated with the Daeunsan cauldron complex, indicating that hydrothermal activities and favorable structures either played roles for generating favorable P-T conditions or mutually provided the sufficient energy to form a breccia zone (Yang and Lee, 1998).

## DISCUSSIONS AND CONCLUSIONS

It is likely that late Cretaceous volcanic cauldrons played a major role in the distribution of ore deposits in the southeastern Kyongsang basin. Late Cretaceous to early Paleogene mineral deposits seem to be largely controlled by volcanic centers including nine volcanic cauldrons in the PVD. These mineral deposits lie in the ring fracture zones or the central plutons within the resurgent cauldrons or on the marginal area of the PVD (Table 1). The close relationship between volcanogenic or volcano-plutonogenic sulfide ore deposits and the formation of calderas, especially resurgent cauldrons, has been reported by many authors (Smith and Bailey, 1968; Steven, 1969; Steven *et al.*, 1974; Koide and Bhattacharji, 1975; Bethke *et al.*, 1976; Lopman *et al.*, 1976; Kouda and Koide, 1978; Matsuhisa *et al.*, 1980; Sillitoe, 1980; Noble and Mckee, 1982).

By combining with published informations and the results of field surveys in the present study, ore deposits within PVD seem to be genetically associated with cauldrons in the following ways. As described in previous sections, cauldrons in the PVD are comparable with Valles-type. Thus, we may apply the model of Valles-type to the formation of cauldrons in the PVD.

First, the main stage of eviscerating ash-flow tuff eruptions have dispersed some metallic trace elements and concentrated the elements in the volatile-rich cupolars of the magma chamber. In this stage, the elements were not concentrated them into ore deposits (Elston *et al.*, 1975). In many deposits, including the Ilkwang, Weolseong and Sannae mines, the relatively large age gap (> 10 Ma) is recognized between ore mineralization and host volcanic rocks (Fletcher and Rundle, 1977; Choo and Kim, 1981; Reedman *et al.*, 1989). This age gap suggests that the concentration of ore metals were later events compared with the main stage of ash-flow tuff eruption.

Second, volatile components have concentrated at the roof zone of a magma chamber during a resurgent magma pulse. Fracturing of the roof zone probably occurred during the previous eruption. No eviscerating eruptions occurred during the resurgent stage. However, the magma and heated hydrothermal fluids were escaped from the magma chamber toward ring fractures and intruded preexisting cauldron fill deposits. Some ore deposits began to form at this stage.

Third, the circulation of hydrothermal fluids was active during and after the resurgences. Some of mineralizing fluids seem to have originated in the magma chamber but meteoric water also acted as an important source of hydrothermal fluids. Metals dissolved in the hydrothermal fluids have been partially derived from the magma chamber but also leached from wall rocks. Ore deposits occur as veins, skarns, and disseminations in and/or around the intrusions of resurgent magma pulse.

Fourth, geologic structures associated with volcanic cauldrons provided the sites for late intrusions and mineralizing fluids, long after the cauldrons has ceased their activities. Alteration and mineralization associated with cauldrons were widespread in ring fracture zones (Table 1).

Finally, calc-alkaline magma-type volcanic cauldrons have formed and associated with deposits of the chalcophile base metals such as copper, lead, and zinc in the PVD. Furthermore, silicic vitric tuff, either welded or non-welded, have been easily altered by ascending hydrothermal fluids, and have formed pyrophyllite deposits when the fluids were strongly acid containing high sulfur or $H^+$. These fluids may have caused strong leaching of all alkalies from the rocks.

In conclusion, the fundamental factor controlling the location of ore deposits in the PVD is believed to be the presence of structurally weak zones (stockworks) preferentially in the roofs of magma chambers. These fractures probably caused by cauldron subsidence make it possible to ascend the solution with various dissolved elements. Ore deposits associated with cauldrons largely have formed later than the formation of calderas. In addition, the cauldron subsidences were more frequent with the more felsic volcano-plutonic complex, possibly indicating that the amounts of water and volatile components also acted as a controlling factor to cause the caldera subsidence and to concentrate the ore-forming elements in economic concentrations. In the southeastern Kyongsang basin, additional calderas and associated ore deposits undoubtedly can be discovered through future detailed studies (Hwang, 1990; Yun *et al.*, 1996).

The concept that cauldron subsidence are an important control for the formation of ore deposits will appear to be vindicated. The review of the relationship and variations of ore mineralization and cauldron subsidence is rather sketchy, but it provides a skeleton to carry out more detailed and quantitative studies related to temporal and spatial relationships between each cauldron subsidence accompanying its own ore mineralization.

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## REFERENCES

Bethke, P.M., Barton, P.B. Lamphere, M.A. and Steven, T.A. (1976) Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado, II. Age of mineralization. Econ. Geol. v. 71, p. 1006-1011.

Cha, M.S., Kim, J.J. and Yoon, S. (1972) Study on the igneous activity and mineralization in the vicinity of the Dongnae-Eonyang, Pusan. J. Korea. Inst. Min. Geol. v. 5, p. 151-162. (*in Korean with English abstract*).

Cha, M.S. (1979) Study on the late Cretaceous acid volcanic rocks in southeastern area of Milyang, Kyeongsang Nam-do. J. Sci. Pusan Nat. Uni. v. 27, p. 141-153. (*in Korean with English abstract*).

Cha, M.S. (1980) Geology and petrology of the Unmunsa acid volcanic rocks. J. College Edu. Pusan Nat. Uni. v. 7, p. 17-27. (*in Korean with English abstract*).

Cha, M.S. (1985) Ring structures in the southeastern Kyeongsang basin (I). J. college Edu. Pusan Nat. Uni. v. 11, p. 369-386. (*in Korean with English abstract*).

Cha, M.S. and Yun, S.H. (1982) Cretaceous volcanism in the vicinity of the Pusan city, Korea: -special reference to the remnant of the Jangsan caldera-. J. Sci. Pusan Nat. Uni. v. 34, p. 377-390. (*in Korean with English abstract*).

Cha, M.S., Yun, S.H. and Hwang, I.H. (1984) Daeunsan cauldron, Yangsan-gun, Kyeongsang Nam-do, Korea. J. College Edu. Pusan Nat. Uni. v. 8, p. 265-284. (*in Korean with English abstract*).

Cha, M.S., Yun, S.H. and Ahn, G.G. (1985) Ring structures in the south-eastern Kyeongsang basin, Korea, -special reference to Chaeyaksan andesite-. J. Sci. Pusan Nat. Uni. v. 40, p. 337-347. (*in Korean with English abstract*).

Choi, K.S. (1986) A study on the gravity in the southern part of the Korean Peninsula. Unpub. Ph. D. Dissertation, Seoul Nat. Univ. 110p.

Choi, S.G. (1983) Skarn evolution and iron-tungsten mineralization and the associated polymetallic mineralization at the Ulsan mine, Republic of Korea. Unpub. Ph. D. Dissertation, Waseda Univ. 271p.

Choi, S.Y. (1988) A study of the origin of serpentinite in Ulsan mine area. Unpub. Ph. D. Dissertation, Pusan Nat. Uni. 87p.

Choo, S.H. and Kim, D.H. (1981) Rb/Sr age determination on Yoocheon granite, Changweon granite and Andong granite and granitic gneiss. Geosci. Min. Res. (Seoul) Rept. v. 12, p. 183-185.

Chung, W.W. (1991), Mineralogy and genesis of hydrothermal deposits in the Miryang mine Kyeongsanfnamdo, Korea. Ph. D. thesis, Pusan Nat. Univ. 85p. (*in Korean with English abstract*).

Elston, W.E., Rhodes, R.C. and Erb, E.E. (1975) Control of mineralization by mid-Tertiary volcanic centers, southwestern New Mexico. Spec. Pub. Geo. Soc. New Mexico. v. 5, p. 125-130.