Jour. Korean Inst. Mining Geol.
Vol. 23 No. 2, p. 127-133, 1990.

Fluid Inclusions of Granitoids and their Bearing on Mineralization in South Korea.

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ABSTRACT : Relation between fluid inclusions and mineralization has been studied for 30 granitoid specimens from 19 localities in South Korea. Polyphase inclusions are found in granitoid specimens of 9 localities. In the vicinities of 6 localities among them occurs any of W, Cu or Fe deposits of the vein-, stockwork-, skarn-or pegmatite-type. On the contrary, no ore deposit is reported near the granitoids characterized by no polyphase inclusion except only one locality. This fact implies that the occurrence of polyphase inclusions is a good indicator for such kinds of mineralization. Ores and country rocks of some of the deposits contain polyphase inclusions in their quartz crystals. The fact that many polyphase inclusions occur in granitoids and ore constituents suggests that highly saline hydrothermal solution played an important role for the formation of such kinds of deposits. On the contrary, the granite and the ore of the Mugug gold deposit have many fluid inclusions, but are free from the polyphase type.

INTRODUCTION

The most important procedure in mineral exploration is to select the district whose probability of mineralization are higher than others. An area where many ore deposits are found is called a metallogenic province or a metal belt. In Korea, many tungsten and molybdenum deposits of vein-, or skarn-type occur along the belt parallel to 37°N, while many copper and iron deposits occur in the Gyeongsang Basin which is in the southeast end of the Peninsula. Consequently, we can expect tungsten and molybdenum deposits in the former belt, while copper and iron deposits in the latter province with a high probability as compared with other areas. Most of the metallogenic provinces or metal belts have been already known in the world. Thereby, the probability that a new matallogenic province is found should be very low.

Generally, common metallogenic provinces or metal belts are wider than 1000 km^2. On the contrary, common hydrothermal deposits are narrower than 1 km^2. This implies that we must reduce an exploration area by a thousandth or less time, in order to find a mineral deposit on the basis of any available geoscientific informations. This size reduction of the area is the most important and the most difficult task in the exploration.

Many methods have been proposed to focus an exploration target. Fluid inclusions may give us a useful tool, as shown in the Nariwa-Gawa district, southwestern Japan, where many mineral deposits are closely associated with granitic intrusives containing polyphase inclusions(Shoji et al., 1979). Though the correlation had not yet been confirmed in other areas, the same relationship was found in South Korea as stated below. This finding is interesting not only for the confirmation of the correlation, but also for the large difference between the dimensions of the areas : the Nariwa-Gawa district is 25 km^2 in area, while South Korea is $100 \cdot 10^3$ km^2.

GRANITOIDS AND FLUID INCLUSIONS

Several periods of granitic activity are recognized in South Korea(Fig. 1). Roughly speaking, they are Precambrian, Triassic, Jurassic, and Cretaceous. The Daebo granite, which intruded during Jurassic to early Cretaceous ages, occupies the largest area among them, and is distributed all over South Korea. The Bulguksa granite from late Cretaceous to early Tertiary ages is subordinate, and is restricted to the southeastern part of the Peninsula. The granitic rocks of other ages occupy still smaller areas.

Granitoid samples were collected from nineteen localities(Fig. 1) : the central zone southeast of Seoul (Nos. 1-6), the east coast (Nos. 7-12), and the Gyeongsang Basin (Nos. 13-19). Most of them are granite or granodiorite, and

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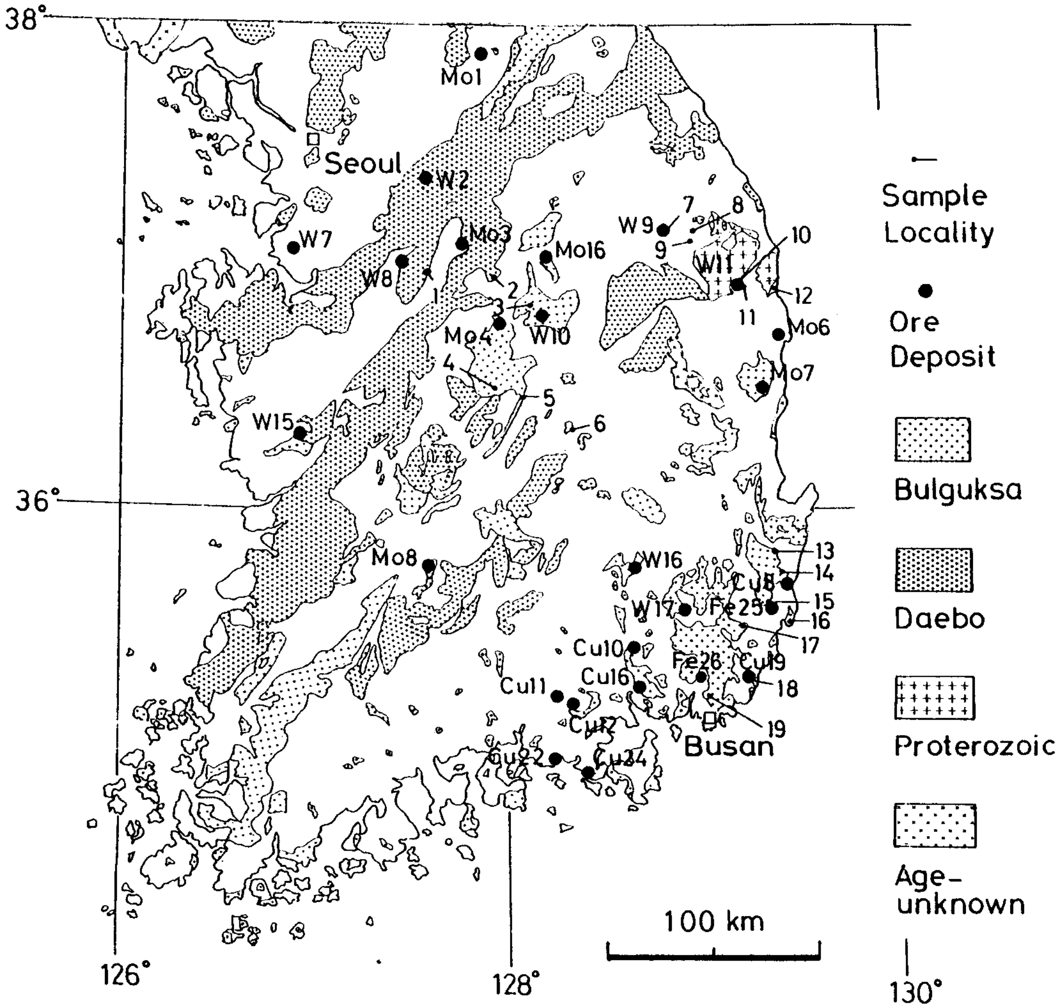

Fig. 1. A map showing distribution of granitoids (simplified from Geological Society of Korea, 1987), locations of relatively large W, Mo, Cu or Fe deposits of vein-, stockwork-, skarn-or pegmatite-type (after Kim and Hwang, 1983), and localities of granitoid specimens examined. The abbreviations showing ore deposits are the same as Kim and Hwang (1983).

the less are pegmatite, quartz porphyry, granite porphyry and granite gneiss(Table 1).

Fluid inclusions are found in quartz crystals of the most specimens. Generally, they are very small, and less than 10 μm. Only a few inclusions, however, are 40 or 50 μm (Table 1). All of them are irregular in shape. A few inclusions are scattered randomly, but most of the inclusions are distributed along healed cracks. The shape and the modes of occurrence suggest that all fluid inclusions are secondary in origin.

Liquid, polyphase and CO_2-rich inclusions are recognized. The most dominants are liquid inclusions consisting of predominant solution and a bubble (A, B, D, and J of Fig. 2). Polyphase inclusions are found in thirteen specimens from nine localities. Common daughter mineral is halite (NaCl), judged from the cubic shape (E, F and M of Fig. 2). Sometimes one or more crystals other than halite are also found in some polyphase inclusions (C, G, H, K, M and N of Fig. 2). The mineral species are not identified

Table 1. Fluid inclusion properties of South-Korean granitoids, and ore deposits located near the granitoid specimens.

No	Locality	Group/Remarks	Sample Code	Size[1]	Abundance	Daughter[2]	Ore Deposits[3]
1	Mugug mine	Daebo/Jurassic	MG-GR	<10	common	–	
2	Yujumag	Daebo/Jurassic	7790206	<10	rare	–	
			7790207	<15	common	–	
			7790208		not found		
3	near Suanbo	Bulguksa/Cretaceous	7790218	<10	common	–	Geumsan(W10,V)
4	Naesog-myeon	Bulguksa/Cretaceous	7790201	<20	common	salt(<1)	
5	Oggwan-dong	Bulguksa/unknown age	7790103	<10	rare	–	
6	near Sangju	Bulguksa	7790104	<10	rare	–	
7	Sangdong mine	Bulguksa?/	SD-83/2-730	<40	common	salt(<1)	Sangdong(W9, S)
		Cretaceous	SD-84/3-900	<50	common	salt(<1)	
8	Geodo mine	Daebo/Jurassic	GD-DIKE	<5	rare	–	
9	Nongoeri	Hongjesa/	7790615	<10	common	–	
		Precambrian	PC-GR	<30	common	–	
			88A2301	<20	common	–	
			88A2302	<20	common	–	
10	Ssangjeon mine	?/Pegmatite,	88A2203	<40	common	salt(8)	Ogbang-
		unknown age	88A2204	<40	common	salt(2)	Ssangjeon(W11,P)
11	Ssangjeon	Buncheon/Granite gneiss	88A2202	<30	common	salt(<1)	Ogbang- Ssangjeon
12	Mangyang-Jeong	Bulguksa/Cretaceous	88A2201	<10	common	–	(W11,P)
13	near Gyongju	Bulguksa/GP	7783111	<20	common	salt+opaque(5)	
14	Seoggul	Bulguksa/	88A2105	<15	common	salt(<1)	Geumryeong(Cu8,W)
		Cretaceous	88A2106	<10	rare	–	
			88A2107	<40	common	–	
15	near Ulsan	Bulguksa/Qp	7783107		not found		Ulsan(Fe25, S)
16	Soebu-dong	Bulguksa/Paleogene	7783108	<40	common	–	
17	Gogcheon-ri	Bulguksa/Paleogene	7783106	<10	common	salt+opaque(5)	
18	Ilkwang mine	Bulguksa/	88A2101	<10	common	salt(<1)	Ilkwang(Cu19,W)
		Cretaceous	88A2102	<40	common	salt+opaque(2)	
19	Gupo Quarry	Bulguksa/	7783102	<10	rare	salt(<1)	Mulgeum(Fe26,S)
		Cretaceous	7783103	<5	rare	–	

1 The unit is μm.
2 The figures with parentheses represent proportions (parts per ten) of polyphase inclusions among all fluid inclusions.
3 Relatively large W. Fe, or Cu deposits of the vein(V), stockwork (W) skarn (S), or pegmatite(P) type occurring within 10km from the corresponding granitoid specimen (after Kim and Hwang, 1983). Abbreviations showing ore deposits(W10, etc.) are the same as Kim and Hwang(1983) and Fig. 1.

Table 2. Correlation between the occurrence of polyphase inclusions and mineralization.

		Deposits		
		Present	Absent	Total
Polyphase Inclusions	Present	6	3	9
	Absent	1	8	9
	Total	7	12	18

because of few optical and crystallographic data. Gaseous inclusions are rarely observed (O of Fig. 2). They are restricted in healed cracks. This suggests that they were formed by necking down. Size, abundance and kinds of daughter minerals are summarized in Table 1.

POLYPHASE INCLUSIONS AND MINERALIZATION

Many mineral deposits are known in South Korea. They are summarized in the metallogenic map compiled by Kim and Hwang(1983). Fig. 1 shows the locations of relatively large tungsten, molybdenum, copper and iron deposits of vein-, stockwork-(or pipe), skarn-, or pegma-

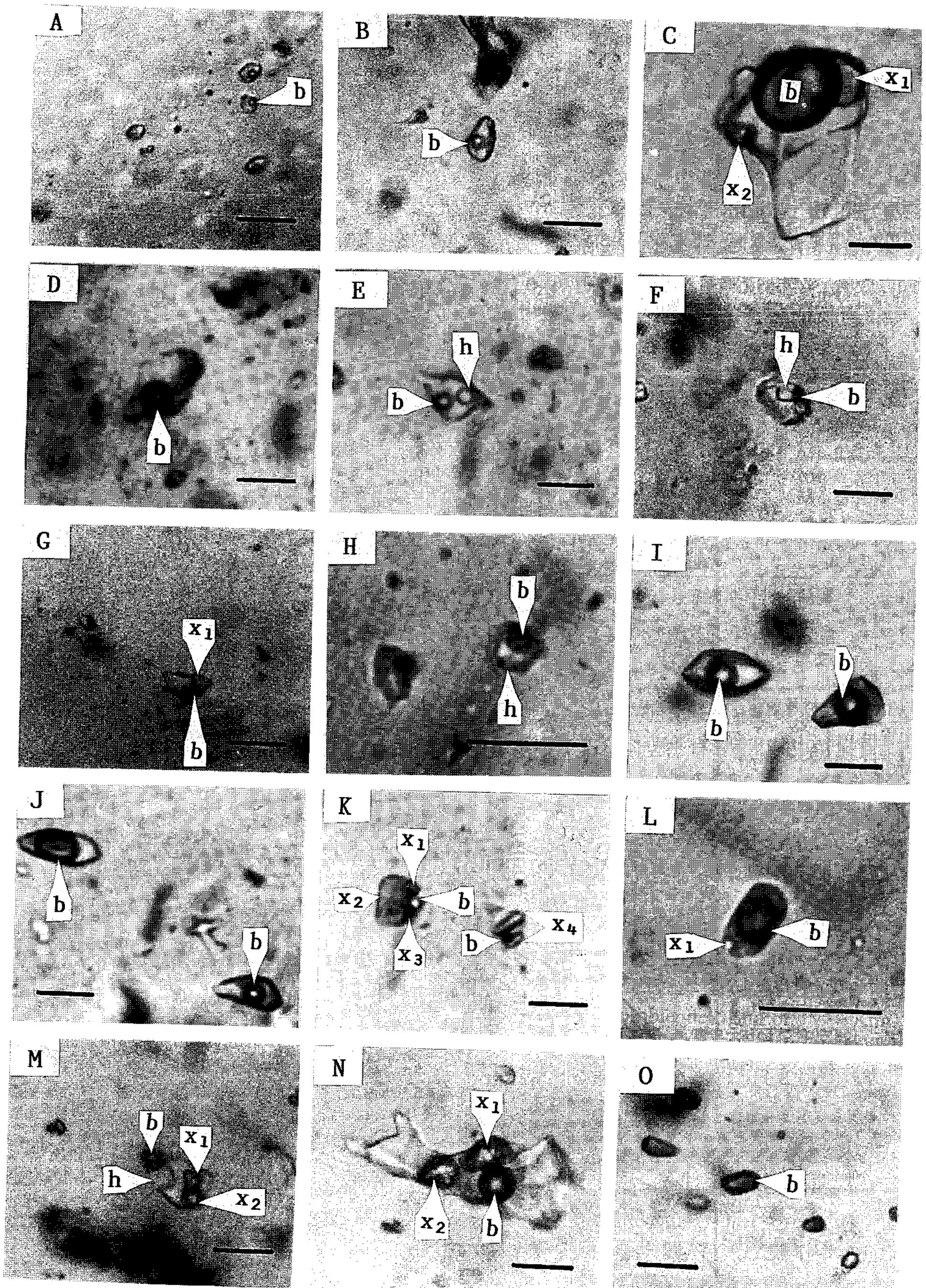

Fig. 2. Some typical fluid inclusions found in quartz crystals of South Korean granitoids. Scale bars represent 10 μm. Abbreviations : b = bubble ; h = cubic crystal (probably halite) ; l_1 = aqueous solution ; l_2 = liquid carbon dioxide ; x_1, x_2, x_3, x_4 = unidentified crystals. Sample codes shown in Table 1 : A = MG-GR ; B = 779027 ; C = SD-84/3-900 ; D = PC-GR ; E, F = 88A2203 ; G = 88A2202 ; H = 88A2105 ; I, J = 7783108 ; K = 7783106 ; L = 88A2101 ; M,N,O = 88A2102.

tite-type among them. Most of the plotted deposits are located along the 37°N belt and in the Gyeongsang Basin (Fig. 1). They are considered to be formed from hydrothermal solutions of high temperature with close relationship to granitic activities.

Ore deposits which occur within 10km from any of the localities of granitoid specimens are listed in Table 1. Any of tungsten, copper and iron deposits is located near eight localities. Table 2 shows the correlation between the occurrence of polyphase inclusions and the mineralization. Locality 15 is excluded from Table 2, because no fluid inclusion was found in the rock. At nine localities, polyphase inclusions are preserved in quartz crystals of the granitoid specimens. Ore deposits occur in the vicinities of six localities among them. Accordingly, the proportion of the mineralization is 65% (6/9) for the granitoids characterized by the presence of polyphase inclusion. On the contrary, the granitoid specimens are free from the polyphase inclusion at other nine localities. Among these localities, an ore deposit occurs only in the vicinity of locality 3 near Suanbo. Accordingly, the proportion of the mineralization is 10% (1/9) for the granitoids characterized by the absence of polyphase inclusion. The correlation shown in Table 2 suggests that the presence of polyphase inclusions in granitoids is a good indicator for the hydrothermal mineralization neighboring the granitic intrusives. The probability of the presumption is more than 70% (14/18)*.

Plural specimens were examined at seven localities. All specimens have polyphase inclusions at three localities (7, 10, 18 in Table 1) among them, and all specimens are free from the polyphase inclusion in two localities (2, 9). At only two localities (14, 19), some specimens have polyphase inclusions, and others have no polyphase inclusion. This fact suggests that a single specimen can almost indicate the fluid inclusion property of the host granitoid.

As shown in Table 1, all specimens of the Daebo type granitoids are free from polyphase inclusions. If this fact is general, it is very important. However, it is not certain whether this fact is general or not, because the Daebo type samples were collected from only three localities.

*In order to avoid preconception, one of the authors (T. Z.) observed the specimens without any information concerning the sample localities where the other (T. S.) had collected them.

FLUID INCLUSIONS IN OTHER MATERIALS

Fig. 3 shows fluid inclusions found in quartz crystals of ores and country rocks. The properties are summarized in Table 3. Some remarkable suggestions are given, as far as this unsystematic study allows.

The Mugug mine is one of the most active gold producers in Korea. Many auriferous quartz veins run from north-northwest to south-southeast in the granite of the Daebo type. The vein system has two sets of fractures running N-S and N45°W-S45°E. The Mugug granite is free from polyphase inclusions (Table 1). The vein quartz contains many fluid inclusions, but has no polyphase inclusion (P and Q of Fig. 3). This implies that the absence of polyphase inclusion in granitoid does not indicate no mineralization of gold.

The Sangdong mine is one of the largest producers of tungsten in the world. The ore deposit belongs to the skarn-type replacing limestone beds of the Choseon System of Cambrian to Ordovician ages(e. g. Moon. 1988). The granitic intrusion beneath the deposit has quartz containing polyphase inclusions as shown in Table 1. The presence of polyphase inclusion has also been reported from the ore constituents such as scheelite, quartz and pyroxene (Moon, 1985). These facts suggest that a highly saline solution played an important role in the formation of the deposit. The lowest member of the Choseon System is quartzite. Polyphase inclusions are observed in the quartz crystals of the quartzite (R of Fig. 3). The solution trapped in the polyphase inclusions seems to be the fossilized mineralizing fluid from which the Sangdong deposit was fomed. If it be so, the occurrence of polyphase inclusions in the quartzite gives a valuable key for the exploration in this area, because the occurrence should indicate pathways of the mineralizing fluid.

The Ssanjeon tungsten deposit consists of complex pegmatite emplacing along the contact between the Buncheon granite gneiss and the Wonnam Formation (Kim, 1988). According to Youn and Park (1982), the salinity of the fluid inclusions in quartz crystals ranges from 4.5 to 9.5 wt. % NaCl equivalent. However, polyphase inclusions are observed in all ore specimens of the present study (T and U of Fig. 3). This fact means that the salinity of the deposit must range to a higher value. CO_2-rich inclusions are also found in this deposit. This fact is interesting, because CO_2-rich inclusions have been reported

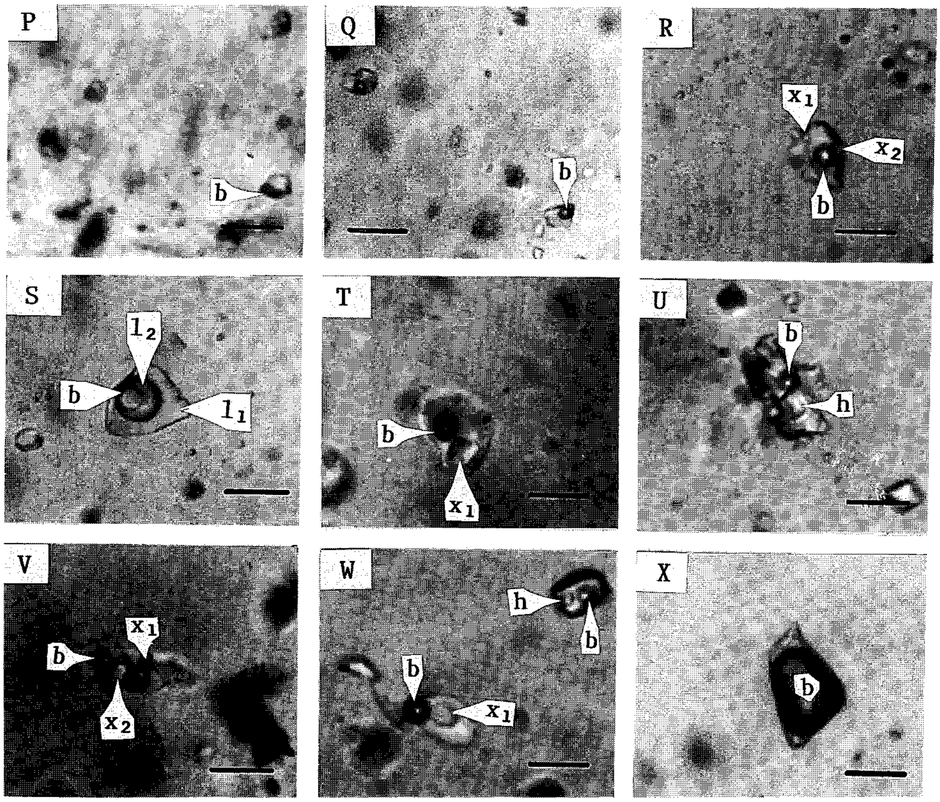

Fig. 3. Some typical fluid inclusions found in quartz crystals of ores and country rocks in some ore deposits of South Korea. Scale bars and abbreviations are the same as Fig. 3. Sample codes shown in Table 3 : P = 3 Brother ; Q = # 8 vein ; R = Jansan qtz ; S = 88A2205 ; T = 88A2207 ; U = 88A2209 ; V = 88A2103 ; W, X = 88A2104.

Table 3. Fluid inclusion properties of ores and country rocks in some ore deposits of South Korea.

Sample Code	Material	Locality	Size[1]	Abundance	Daughter[2]
3 Brother	Vein quartz	Mugug mine	<10	common	–
# 8 vein		do.	<10	common	–
Jangsan qtz	Jangsan quartzite	Sangdong mine	<40	common	salt(<1)
88A2205	Ore	Ssangjeon mine	<50	common	salt(2)
88A2207	Scheelite ore	do.	<30	common	salt(2)
88A2209	Wolframite ore	do.	<40	common	salt(2)
88A2103	Vein quartz	Ilkwang mine	<20	common	salt(<1)
88A2104	Cp ore	do.	<50	common	salt(2)

1 The unit is μm.
2 The figures with parentheses represent proportions(parts per ten) of polyphase inclusions among all fluid inclusions.

from many other pegmatite deposits (e. g. Roedder, 1972 ; Thomas and Spooner, 1985 ; Enjoji, 1978).

The copper-tungsten deposit of the Ilkwang mine occurs in a tourmaline-bearing breccia pipe (Fletcher, 1988). The ore consists of chalcopyrite, wolframite, scheelite and other ore minerals with quartz, tourmaline, garnet and other gangue minerals. Polyphase inclusions are found in quartz crystals of both the ore (V and W of Fig. 3) and the host quartz monzonite(Table 1). Accordingly, the deposit should have been also formed under a highly saline hydrothermal condition. Gaseous inclusions are frequently found(X of Fig. 3). The coexistence of polyphase, liquid and gaseous inclusions should give an important information for the discussion on the genesis of this deposit. For instance, boiling of the mineralizing fluid is inferred from the evidence that liquid inclusions and gaseous ones are distributed randomly.

CONCLUDING REMARKS

Fluid inclusions are commonly trapped in quartz crystals of the South Korean granitoids. Polyphase inclusions are found in 12 granitoid specimens from 9 localities among 30 specimens from 19 localities. Any of tungsten, copper or iron deposits of the vein-, stockwork-, skarn-or pegmatite-type occurs in the vicinities of 6 localities characterized by the presence of polyphase inclusion, while no deposit occurs near the granitoids characterized by the absence of polyphase inclusion, except only one locality. Polyphase inclusions are also found in quartz crystals of ores and country rocks of the tungsten or copper deposits. Therefore, it is concluded that highly saline hydrothermal solutions played an important role in the formation of Korean tungsten, copper and iron deposits. This implies that the occurrence of polyphase inclusions is a good key for such kinds of mineralization.

Acknowledgments : Most of the examined specimens were collected during the field excursions of the 7th Meeting of Circum-Pacific Plutonism Project of IGCP (1977), the 16th Pacific Science Congress (1987), and the 4th International Symposium of Tin/Tungsten Granites in Southeast Asia and the Western Pacific of IGCP (1988). We would like to thank the tour guides of the excursions. Acknowledgments are also given to Prof. M. S. Lee of Seoul National University, Dr. M. Enjoji of University of Tsukuba, and Dr. H. Kaneda of the University of Tokyo for their valuable suggestions and critical reading of the manuscript.

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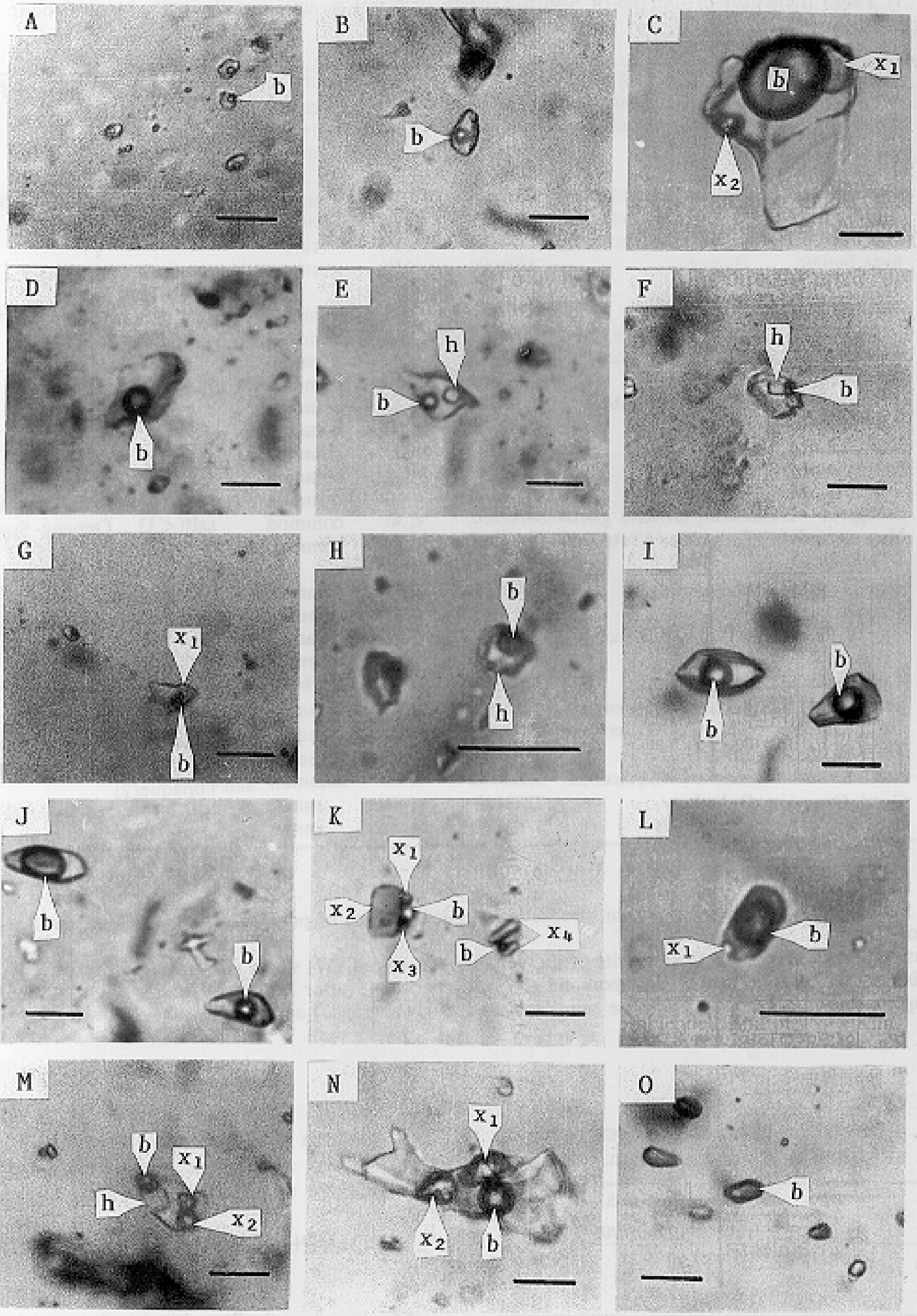
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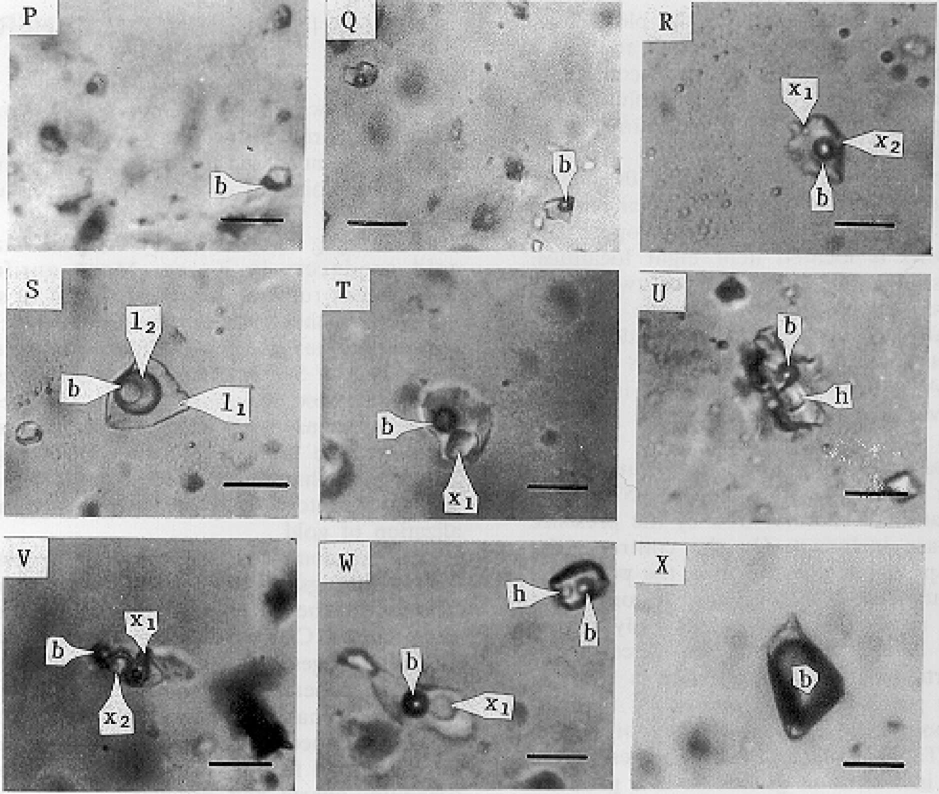

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