Econ. Environ. Geol.
Vol. 28, No. 6, p. 613-621, 1995.

Significance of Ages of Tungsten Mineralization

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ABSTRACT: It is understood that many big tungsten deposits such as the Sangdong in Korea, Fugigatami in Japan, Yukon in Canada, Pine Creek in U.S.A. and Vostok in Russia were formed at late Cretaceous ages. However, most of tungsten mineralization in China where half the total world tungsten ores is reserved took place in late Jurassic to early Cretaceous ages. While the close association of molybdenum with tungsten mineralization is observed in the deposits related with Cretaceous magma, tungsten deposits in China related with late Jurassic to early Cretaceous show a close association of tin as well as molybdenum mineralization. It is characteristic that tungsten mineralization in China was followed by tin mineralization. The mode of occurrence of tungsten ore deposits in China is various and may represent the origin of tungsten in general, since the larger half of total amount of tungsten ores in the world are reserved in China. In case of Korea, more than 90% of total production of tungsten was occupied by the Sangdong tungsten deposit, which produced molybdenite as a by-product. Even if tin is detected in ppm unit content, no cassiterite is found in the Sangdong tungsten orebody. A similar type of two tungsten deposits is comparatively studied in order to confirm the published data; one is the Moping tungsten deposit in China and the other is the Dehwa tungsten deposit in Korea. Mineral assemblages occurring in quartz veins of both deposits are more or less same except that zinnwaldite and cassiterite occur only in the former deposit. Ages of zinnwaldite and muscovite closely with molybdenite in the former deposit are 181.1 Ma and 167.8 Ma respectively, while muscovites associated with molybdenite in the latter deposit show ages of 80.9 Ma and 80.2 Ma. These results may represent deficient supply of tin from the source granitoid from which tungsten was derived in Korean peninsula during Cretaceous period, while tin supplied during tungsten mineralization tended to increase and the active tin mineralization followed the Jurassic tungsten mineralization in China.

INTRODUCTION

Recent informations of tungsten ore deposits in China have brought a clue to understand the origin of tungsten mineralization. According to 50's data, it was reported that tungsten ore reserves in China occupied 76% of total world reserves (Li and Chang, 1955), even though understood now as about 44% in the recent publication (Table 1A). It is significant that the global tungsten mineralization seemed to have concentrated to China and a country tungsten mineralization in Korea is concentrated to the Sangdong mine.

Distribution of tungsten deposits in China is spatially confined in Jiangxi Province covering about 88 % of total tungsten reserves of China (Li and Chang, 1955). Production of tungsten mines in the world has been reduced remarkably in recent years after gradual decrease in 90's. as shown in Table 1B. It is understood most of major producers in the world besides China are more or less closed.

The typical mode of occurrence in tungsten deposits involves massive, stock, vein types, porphyry and skarn. Many tungsten mines have two or three different types of tungsten ore deposits in a single mine. Particularly Yaogangxian tungsten deposits consist of quartz vein, skarn, stockwork, and pegmatite ore bodies as shown in Fig. 1. The author has confirmed that cross sections of tungsten deposits in China depicted according to drilling exploration data exhibit that granitoids are obviously the original source rock of tungsten mineralization.

As the tungsten deposits of China may represent those of the whole world due to more than half of tungsten reserves in China, so the Sangdong tungsten deposits represent tungsten ore deposits in Korea. There are a number of differences in tungsten mineralization between China and Korea. However, this study has focused only on difference in the ages of tungsten mineralization and it's significance.

CHARACTERISTICS OF TUNGSTEN MINERALIZATION IN CHINA

Tungsten deposits of China may represent the

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Table 1A. World reserves of tungsten.

Country	Reserve base*		
	(kt)	%	Rank
China	1,560	44.0	1
Canada	493	13.9	2
USSR	400	11.3	3
USA	210	5.9	4
Australia	150	4.2	5
Bolivia	110	3.1	6
Korea, R	77	2.2	7
Burma	34	1.0	8
Thailand	30	0.8	9
Other	481	13.6	
Total	3,545	100	

Source; USBM, 1991, p. 177, *Note; Metal content.

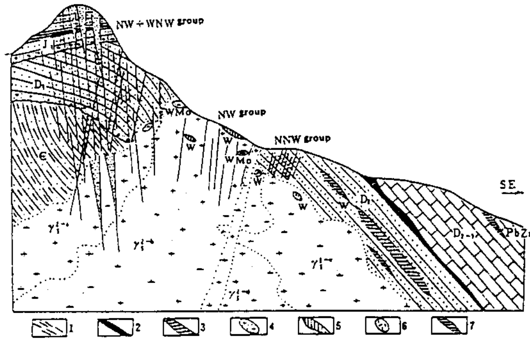

Fig. 1. Schematic geological section of the Yaogangxian tungsten deposit (Kang *et al*., 1992).

whole story of tungsten mineralizations of the world in terms of genesis, mode of occurrence, and ages of mineralization. Most of tungsten deposits reveal that tungsten is derived from granites. As shown in Table 2, all different types of tungsten deposits occur in China. Ages of the granites related with tungsten mineralization range from the middle of Jurassic to the early Cretaceous periods, while most of significant tungsten ore deposits in other countries have formed before or after the periods of tungsten mineralization in China.

Most of tungsten mineralization in China took place in two stages of orogenic movements by emplacemt of Yanshanian granites and Qianlishan granites (Table 3). It is well known that the most close gangue mineral of tungsten mineral is a quartz which is always associated with scheelite or wolframite and also either scheelite or wolframite from all kinds of tungsten deposits has a close association of mica as a secondly abundant gangue mineral. This association is common in all tungsten deposits of the world, however, the association of ore minerals with tungsten minerals such as tin and molybdenum ore minerals is quite different in between the middle Jurassic to the early Cretaceous deposits and the late Cretaceous deposits or between China and Korea.

The close association of two elements such as W and Mo is detected and observed even in a scheelite crystal, as the scheelite in the Sangdong occur as a solid solution of powellite ($CaMoO_4$) and scheelite ($CaWO_4$). The association of Sn-W elements in tungsten deposits is not the same as that of W-Mo. It meams that tin does not accommodate in tungsten minerals, however, they go together as separate minerals in tungsten deposits of China. The close association of cassiterite and wolframite in China is characteristic different from the poor occurrence of cassiterite in tungsten deposits of late Cretaceous ages.

AGES OF TUNGSTEN MINERALIZATION IN THE WORLD

A few occurrence of tungsten ore deposits during Precambrian period is reported; Startabound scheelite deposits in the Precambrian basement of San Luis, Argentina (Brodtkorb and Brodtkorb (1977) and skarn-type scheelite deposits in central Sweden (Ohlsson, 1979) are described in details, however, their relationship between the skarn orebody and adjacent granites is ambiguous in some respect.

Important tungsten deposits in the world are reported to have occurred from 340's Ma to 60's Ma. Besides Chinese deposits, the Panasqueira deposit in Portugal was well known as one of the largest tungsten deposits as same as the Sangdong mine in Korea. It was confirmed by the author that the Panasqueira was the biggest producer as wolframite-bearing quart vein type deposit and the Sangdong as scheelite-containing skarn type deposit in 1980s.

Clark (1970) obtained K-Ar dates of 289 to 290 Ma for muscovites in the freshest available Panasqueira Granite and in the crosscutting tin-tungsten veins, which shows similar mode of occurrence of wolframite to Chinese deposits as shown in Fig. 2. Aberfoyle deposit in Australia has quartz veins containg wolframite and cassiterite. At Aberfoyle and Storeys Creek, the location of the sheeted vein systems are clearly related to cupolas of greisenized aplite; muscovite from the aplite has been dated by K-Ar methods as 367 Ma (Solomon and Groves, 1994). These wolframite-cassiterite bearing quartz veins show similar mode of occurrence of the Chinese W-

Table 1B. World mine production of tungsten (from Metal Content). (unit; metric tons)

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
EUROPE										
Austria	1911	1967	1526	1455	1548	1134	1407	1075	1583	506
France	745	733	980	–	–	–	–	–	–	–
Portugal	1313	1533	1500	1657	1368	1350	1400	955	1064	452
Spain	569	462	483	80	–	–	–	–	–	–
Sweden	388	388	357	327	179	–	–	–	–	–
United Kingdom	–	–	–	–	–	–	–	–	–	–
Total	4926	5083	4846	3519	3095	2484	2807	2070	2647	958
AFRICA										
Namibia	–	–	–	–	–	–	–	–	–	–
Rwanda	291	167	13	11	22	105	156	175	175	100
Uganda	–	–	–	14	–	–	–	–	–	–
Zaire	30	18	17	20	20	20	20	20	20	–
Zimbabwe	25	15	8	1	1	1	1	1	1	1
Total	346	200	38	46	43	126	177	196	196	101
ASIA										
Burma	1170	1163	629	456	501	248	310	224	341	350
India	30	28	28	50	19	16	13	14	5	1
Japan	475	557	562	–	127	142	122	135	168	23
Malaysia	3	600	9	10	3	3	3	3	5	2
South Korea	2703	2580	2455	2177	1831	1924	1499	860	210	–
Thailand	742	586	496	635	610	575	276	229	114	100
Turkey	104	120	50	50	50	50	–	–	–	–
Total	5227	5634	4229	3396	3141	2958	2223	1465	843	476
AMERICA										
Canada	3327	3197	1416	–	–	–	–	–	–	–
U.S.A.	1174	983	780	34	350	400	400	200	100	100
Argentina	80	21	39	14	13	20	16	15	15	15
Bolivia	2387	1672	1380	804	1165	1410	1278	1215	1073	330
Brazil	1037	1090	875	800	898	679	316	233	200	200
Mexico	274	276	294	213	206	170	183	194	152	–
Peru	754	771	742	259	545	1110	1372	1232	802	398
Total	9033	8010	5526	2124	3177	3789	3565	3089	2342	1043
OCEANIA										
Australia	1709	1971	1600	1150	1281	1339	1086	237	164	23
New Zealand	10	10	10	10	10	10	–	–	–	–
Total	1719	1981	1610	1160	1291	1349	1086	237	164	23
Total	21251	20908	16249	10245	10747	10708	9858	7057	6192	2601
OTHER COUNTRIES[1]										
Czechoslovakia	50	50	50	45	50	74	83	80	80	80
U.S.S.R.	9100	9200	9200	9200	9200	9300	8800	8000	8000	8000
China[2]	18860	15000	15000	21000	30000	30200	32000	25000	17000	15000
North Korea	1000	1000	1000	500	500	500	1000	1000	400	–
Total	29010	25250	25250	30745	39750	40074	41883	34080	25480	23080
World Total	50261	46158	41499	40990	50497	50780	51741	41137	31672	25681

This table shows the tungsten content of ores and concentrates produced. Notes: 1; Estimated, 2; Exports only.

Sn deposits.

King Island scheelite skarn type ore deposit in Australia which reserves 1/3 tungsten ores of Sangdong scheelite deposit was also one of the largest tungsten producers in 1980s. Age of the granite contacted with skarn orebody is about 340 Ma. Salau tungsten deposit in France has similar to the King Island deposit as skarn-type and Hercynian granitoid related with mineralization (Soler, 1977). Costabonne W skarn deposit is described as having relation with quartz monzonite pluton in age of 200 Ma (Guy, 1979).

Besides above examples, most of tungsten minera-

Table 2. Comprehensive table of genetic types of tungsten deposits in China (from Kang *et al.*, 1995).

Group	Subgroup	Type	Typical ore deposit
Rock-controlled tungsten deposit	Metallogenic subgroup of granite from continental crust reformation	Granite veinlet dissemination type	Xingluokeng of Fujian, Xiatongling of Jiangxi
		Albite granite type	Dajishan of Jiangxi (No. 69 intrusive body)
		Greisen type	Hongshuizhai of Jiangxi
		Granite pegmatite type	Baishigang of Guangdong
		Skarn type	Baoshan of Jiangxi, Xintianling of Hunan
		Quartz-fluorite type	Xianghuapu of Hunan
		Quartz (feldspar) vein type	Jubankeng of Guangdong, Xihuashan of Jiangxi
		Altered breccia type	Babuling of Guangxi, Hujiajian of Jiangxi
		Breccia pipe type	Shiziya at Dahutang of Jiangxi
	Mixed crustmantle syntectic granite (diorite) metallogenic subgroup	Porphyry type	Lianhuashan of Guangdong, Yangchuling of Jiangxi
		Breccia pipe type	Taizidong and Ligongling of Jiangxi
		Volcanics type	Guangping of Fujian
Stratabound tungsten deposit	Stratabound reworking metallogenic subgroup	Skarnoid type	Gaohu and Heshangtan of Jiangxi
		Sedimentary reworking type	Woxi of Hunan
	Stratabound superimposition metallogenic subgroup	Migmatite-skarnoid type	Yongfeng of Jiangxi, Nanyangtian of Yunnan
		Quartxz vein-skarnoid type	Gangushan of Jiangxi, Ta'ergou of Gansu
		Quartzite-complex skarn type	Shizhuyuan of Hunan
		Quartz vein-metasomatite type	Damingshan of Guangxi, Aishang of Jiangxi
Modern supergene tungsten deposit		Oxidation leaching type	Dabaoshan of Guangdong, Taqian of Jiangxi
		Alluvial placer type	Fengtian of Jiangxi

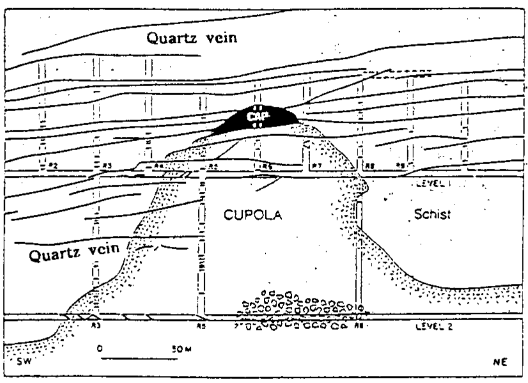

Fig. 2. Cross section of Panasqueira wolfrmite-bearing quartz vein type deposit (Kelley and Rye, 1974).

lization in skarn took place during the late Cretaceous magma activity as shown in Table 4. These skarn deposits suggest that the same geological environment had brought the similar mode of occurrence and formed skarn replacing limestones. Among the skarn deposits, the Sangdong skarn formed the largest skarn orebody with zonal distribution of minerals by overprinting, since about 500 m distance between the skarnized limestone and the granite was

Table 3. Ages of granitoids related with tungsten mineralization in China (from Kang *et al.*, 1992).

Name of Deposits	Source rock	Ages(Ma))
Xingluokeng	granite	143.5
Dajishan	granite	180
Xihuashan	granite	145~139
Yaogangxian	granite	178
Lianhuashan	granodiorite	135~116
Shizhuyuan	biotite-granite	143~196

maintained during hydrothermal mineralization. As the author observed, most of skarn deposit formed by contact of granitoids are not so big as the Sangdong deposit, because the limestone and the granitoid are directly contacted.

It may prevent from evolution of hydrothermal mineralization with retrograde metasomatism. It was confirmed that the age of mica from the skarn orebody was dated as similar as the muscovite of the concealed granite in the Sangdong mine. However, it is significant that the similar ages of granitoids related with tungsten mineralization may give some information of generation of similar fluid from a magma chamber, which results in W-Mo association. These

Table 4. Ages of intrusive rocks related with skarn tungsten deposits in the world.

Name of skarn deposits	Host rock	Intrusive rocks, Age (Ma)	Ore reserves (million tons. W)
MacMillan Pass, Yukon, Canada	Cambrian to Silurian	quartz monzonite, 90	63 (0.95%)
Canada W N.W Terr., Canada	Cambrian	quartz monzonite, 90~92	>%6 (1.6%)
Pine Creek, Bishop, U.S.A.	Upper Paleozoic	quartz monzonite, 92	>6 (0.5%)
Fujigatani, Kuga district, Japan	Carboniferous	granodiorite, 92	moderate
Sangdong, Kangwondo, Korea	Cambrian	granite, 84	30 (1.5%)
Salau, France	Cambrian-Ordovician	granodiorite Hercinian	0.8 (1.44%)
King Island, Australia	Upper Protero-Cambrian	quartz monzonite, 345	14 (0.8%)
Brown's lake/Lost Creek, Montana, U.S.A.	Pennsylvania	quartz monzonite, 69~71	0.6 (0.35%)
Osgood Mountain, Nevada, U.S.A.	Cambrian	granodiorite, aplite, 89~92	1.4 (0.45%)
Costabonne, France	Cambrian	quartz monzonite, 300	0.7 (0.35%)
Ingichke, Uzbek, U.S.S.R.	Paleozoic	granite	
Vostok, Primor'e	Upper Permian	granitoid, 84, Cambrian	

(from Skarn Work Shop, Economic Geology Research Unit. James Cook University, Townsville, Queeensland, Australia. Sept. 10~15, 1982)

Table 5. Ages of major tin mineralization in China(from Kang *et al.*, 1992).

Name of Deposits	Source rock	Ages (Ma)	Reference
Limu Sn-rare metal deposit in Guanxi	granite	104~134	cassiterite disseminated in granite
Lailishan, Yunnan	granite	53.5~58.9	greisen type
Changyingling (shanhu), Guangxi	granite	106~111	vein type
Huanggang skarn Inner Mongolia	K-feldspar granite	67~115, 111~173	cassiterite, scheelite in skarn ore-body
Chahe in Sichuan	granite	829	sulfide with cassiterite stannite in shatter zone
Gejiu, Yunnan	porpyritic biotite granite	64~106.5, 83.5~103	stanniferous skarn type cassiterite sulfide type
Dachang, Guangxi	granite porphyry	73~115	cassiterite polymetallic sulfide type
Yinyan, Guangdong	granite porphyry	80~83	cassiterite, wolframite sulfide vein type
Fengdishan, Guangdong	subdacite porphyry	161~170	cassiterite vein

skarn-type deposits of the late Cretaceous ages in the world are characterized by a close association of scheelite and molybdenite with little cassiterite.

DIFFERENCE IN AGES OF TUNGSTEN MINERALIZATION AND ITS' SIGNIFICANCE

Reported ages of granitoid related with tungsten mineralization in China are as shown in Table 4. Tungsten mineralization in China took place from 180 Ma to 116 Ma. It indicates that Jurassic magma activity and orogeny extending to the early Cretaceous period has brought various tungsten ore deposits in China. It is interesting that a significant tungsten mineralization has not occurred in other countries during the period of tungsten mineralization in China. Tungsten mineralization was always accompanied by tin mineralization in China. Most tungsten mines produce mainly wolframite from stock and quartz vein type orebodies with cassiterite as by-product. Tungsten mineralization is eventually followed by tin mineralization, which forms various types of tin ore deposits in China. Ages of tin mineralization are summarized as shown in Table 5. Most of tin mineralization took place during Cretaceous period, in which major tungsten mineralization, particularly skarn type, took place in other countries.

MINERALIZATION AGES AT THE MOPING IN CHINA AND THE DAEHWA IN KOREA

Even though we had age dating data of intrusive

Table 6. Mineralogical compositions of the Daehwa W-Mo deposit (Park *et al.*, 1985).

Minerals	W veins	Mo veins	Remarks
Native element			
Bismuth	S	S	○
Sulfides			
Ag-Fe sulfide	R		○
Argentite	R		○
Arsenopyrite	R		○
Bismuthinite	C	C	
Chalcopyrite	C	C	
Galena	R	R	
Marcasite	C	C	○
Molybdenite	C	C	
Pyrite	C	C	
Pyrrhotite	S	S	
Sphalerite	C	S	
Stannite	S	R	○
Sulfosalts			
Ag-Bi sulfosalt	R		○
Bi-sulfosalt	R	R	○
Tetrahedrite	R		○
Telluride			
Bi-telluride	R		○
Oxides			
Cassiterite	S		
Ilmenite	R		○
Magnetite	R	R	○
Rutile	R		○
Tungstates			
Scheelite	C	R	
Wolframite	C	R	
Silicates			
Beryl	S		
Muscovite	C	C	
Quartz	C	C	
Halide			
Fluorite	C	C	
Carbontes			
Ankerite	S	S	
Calcite	C	C	
Dolomite			◑
Siderite	S	R	

Abundance: C; common, S; sparse, R; rare, ○; newly reported in present study, ◑; previously reported (unconfirmed in present study).

rocks related with mineralization, we had not obtained data of mineral ages from orebodies. Two deposits were selected to obtain reliable age data to compare two deposits between Korea and China. The Daehwa tungsten deposit is located in the central area of south Korean peninsula. The Mopying tungsten deposit is located in Jiangxi Province. These two deposits are typical quartz vein-type W-Mo deposits.

There are 6 quartz veins operating among 13 quartz veins with thickness of 50 to 150 cm in the Mopying mine. Detailed microscopic study of minerals from the Moping has not been done. Megascopic observation identifies that ore minerals are mainly composed of wolframite, molybdenite, cassiterite, chalcopyrite with minor sphalerite, pyrite, bismuthinite, and galena and gaunge minerals are chiefly composed of quartz, beryl, muscovite, zinnwaldite, fluorite with minor biotite, plagioclase, chlorite, and calcite.

There are more than 10 quartz veins with thickness of less 10 to 50 cm in the Daehwa mine. About nine veins were mined until 1980s. Detailed microscopic study has been done as shown in Table 6 (Park *et al.*,1985).

It seems that two deposits have more or less similar mineralogy. They may be different in proportion of abundance of component minerals. However, a big difference in mineralogical composition is found at sparse distribution of cassiterite in the Daehwa and little scheelite in the Moping. The occurrence of zinnwaldite may indicate tin mineralizations accompany tungsten mineralizations in the Moping deposit. In fact, sparse distribution of cassiterites in the Daehwa was not confirmed by author.It means that the occurrence of cassiterite in the Daehwa is ignorable because of non-economic abundance.

Muscovites and zinnwaldites were taken from the quartz vein containing abundant molybdenite in the Moping, while muscovites were taken from the Daehwa quartz veins containing molybdenites. It is common that molybdenite dominant quartz veins occur separately from the wolframite dominant quartz veins in both mines.

The ages of these minerals were obtained by K-Ar dating method as shown in Table 7. As expected according to data of the granite ages, two minerals from the Moping was dated as 168 Ma to 181 Ma, while the Dehwa was dated as 80 to 81 Ma. These results have confirmed that ages of mineralization are closely related to ages of granitoids. It reveals that ages of tungsten mineralization in China and Korea are obviously different from each other. Tungsten mineralization in China took place from the early Jurassic to the early Cretaceous magma activity and late Cretaceous magma activity in Korea.

Molybdenites from both mines were analysed for sulfur isotopes. The result indicates that two deposits were formed in a quite different sulfuric environment, since $\delta^{34}S = -1.6$ permil was obtained from the molybdenite of the Moping, whereas the molybdenite from the Daehwa shows $\delta^{34}S = +3.7$ permil, which is within the range of sulfur isotope values of tungs-

Table 7. Anaytical data of K-Ar age dating from biotite and zinnwaldite.

Mineral	K (%)	^{40}Ar RAD (mol/g)	^{40}Ar RAD (%)	Age (Ma)	Color	Locality
zinnwaldite	7.40	2.610×10^{-9}	94.88	181.12+6.26	dark brown	Moping mine
muscovite	7.80	2.379×10^{-9}	89.57	167.80+3.64	white	Moping mine
muscovite	9.32	1.337×10^{-7}	74.06	80.86+1.72	white	Daehwa mine
muscovite	9.27	1.319×10^{-9}	88.41	80.24+1.14	white	Daehwa mine

(Analysed by Mr. S. J. Kim, KIGAM).

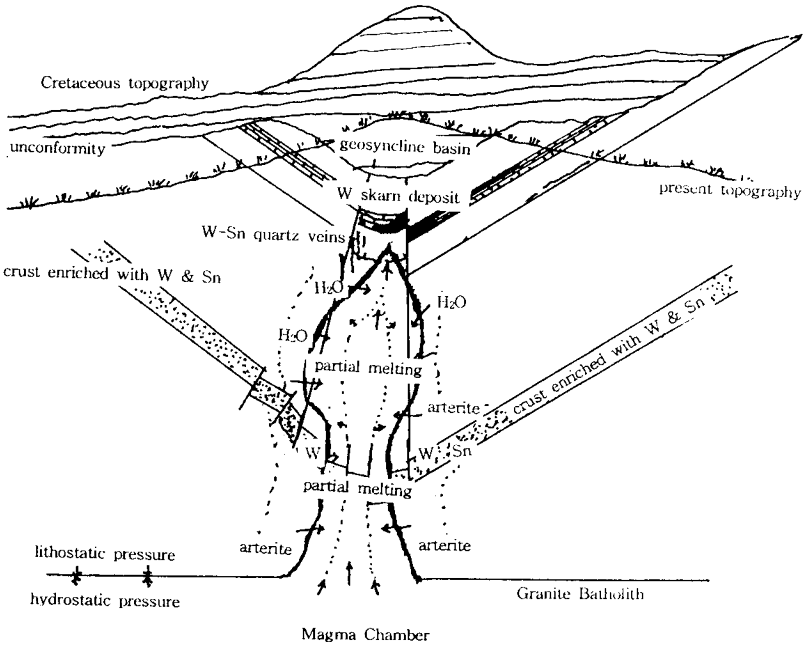

Fig. 3. Assumed drawing of acting magma from which hydrothermal fluids emitted. The acting magma was derived from a batholitic magma and volatile elements including substantial amounts of tin or tungsten from the crust were added into the acting magma with the partial melting.

ten deposits in Korea.

DISCUSSION

It is a question that major tungsten mineralization could concentrate in China during the middle Jurassic to the early Cretaceous periods, in which no significant tungsten mineralization has been reported in other countries. A large amount of tungsten element in the lower continental crust or subsiding sediments enriched with tungsten may be attributed to the tungsten rich magma which formed more than half tungsten reserves of the world in China. It is to larger extent related to the tungsten-bearing sedimentary formation of the continental crust (Kang *et al.*, 1992). In the major host strata of South China, Precambrian averagely contain W 9.33 ppm; Sinian, 8.84 ppm; Cambrian, 10.05 ppm; Devonian, 11.16 ppm; and Carboniferous, 5.60 ppm. It is reported high contents of tungsten ranging from 32 ppm to 60 ppm are detected in volcanogenic sedimentary schists in Northwest China. These strata also commonly have high abundance of such associated ore elements as Sn, Bi, Mo and Be.

Common association of tin minerals with tungsten minerals in Chinese deposits, Panasqueira deposit, and Aberfoyle deposit may be attributed to sufficient tin element supplied with tungsten element from magmas. In the Daewha deposit, the occurrence of cassiterite in minor amount was described as shown in Table 5, and substantial amounts of tin element were detected in the garnet-pyroxene skarn from the Sang-

Table 8. Substantial amounts of tin element in Daewha deposit.

Part of zonal distribution		Content of tin(Sn)
Early formed	wollastonite skarn	1339 ppm
	pyroxene skarn	1213 ppm
	garnet skarn	413 ppm
Later formed	amphibole skarn	200 ppm
	quartz-mica skarn	26 ppm

dong tungsten deposit as Table 8 (Moon, 1983).

It is obvious that only little tin was involved in the Sangdong tungsten mineralization in Korea. Tin compound is more volatile than tungsten compound, This behavior of tin may explain the aspect of depletion of tin content with retrograde metasomatic product by hydrothermal mineralization. The early tin was accommodated in garnet and pyroxene instead of forming independent tin crystal, due to physicochemical condition. During replacement of the early formed garnet-pyroxene skarn by hydrothermal fluid enriched with tungsten, tin accommodated in the early formed skarn escaped into open space with CO_2 gas as volatiles rather than participating in forming quartz-mica-scheelite ore. It is obvious that tin was not sufficiently contained in the silicate fluid enriched with tungsten compound, deriving from the late Cretaceous magma in Korea.

It is assumed that the tin-bearing molecule in the magma would be much more volatile than the WO_3. Most of a little tin containing in the magma reached to replace the limestone to form the early skarn while tungsten remained in the magma. It is concluded that a little amounts of tin as sufficient as accommodating in the early crystallized skarn minerals was supplied from the late Cretaceous magma.

While tungsten mineralization took place in Korea, tin mineralization took place in China. Tin was involved in tungsten mineralization within increasing trend of tin in China. Eventually tin mineralization follows tungsten mineralization.

Abundant tungsten-tin ore deposits may be attributed to different compositions of the Chinese continental crusts, from which tungsten and tin were derived during generation of a magma by partial melting in the crust.

Important tungsten skarn deposits in the world occurred in small ranges of geological period indicate that similar topographic condition of limestone beds provided with appropriate geological condition to reach tungsten silicate fluid derived from the anatectic magma which was generated by partial melting of the crust during the late Cretaceous period. The crust generating the magma might contain insufficient tin comparing to that of China.

Ages of tungsten mineraliztion suggest the the most approprite geological conditions and environments were provided in China during the middle Jurassic to the late Cretaceous periods.

Fig. 3 has drawn to generalize the genesis of tungsten mineralization by hydrothermal fluids derived from a magma. It is assumed that a huge batholith was not concerned with hydrothermal fluids. The acting magma derived from magma chamber (batholith) injects into the weak crust deformed by orogenic movements such as faulting and folding. The acting magma increases its volume by melting the crust (country rocks) from which H_2O, W, and Sn were introduced into the acting magma. Close association of cassiterite (Sn mineral) and wolframite is attributed to afluent addition of tin and tungsten together into the acting magma by melting country rocks (crust) enriched with these elements. The batholic magma emplaced in an appropriate depth from the surface where lithostatic and hydrostatic pressures reach equilibrium. The depth of the acting magma controlled types of granitic rocks.

CONCLUSIONS

Major tungsten mineralization took place mainly in China from the middle Jurassic to the early Cretaceous period, while no significant tungsten deposits in other countries occurred in the same periods of Chinese tungsten deposit have been reported.

Tin is cloely associated with tungsten mineralization, but the late Cretaceous tungsten deposits in the world hardly accompany tin minerals with tungsten minerals.

It is assumed that the association of tin mineral, cassiterite, in tungsten deposit was attributed to the intercontinental crust from which tin as much as tungsten was introduced into the acting magma generated by partial melting of the crust. It is concluded that formation of different systems such as W-Sn-Mo and W-Mo ore deposits may be attributed to the above assumption.

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Manucript received 20 October 1995

重石 鑛化作用 時期의 意義

문 건 주

요 약: 한국의 상동광상을 비롯한 일본, 미국, 구러시아 등지의 중석광상은 백악기 후기에 형성되었다. 그러나 세계 매장량의 반을 차지하는 중국의 중석광상은 쥬라기 후기로부터 백악기 초기에 형성되었다. 백악기 후반의 중석광상에서는 휘수연의 광화작용이 중석광화작용과 밀접히 수반되는 한편 중국의 중석광상에서는 휘수연 뿐만 아니라 주석도 밀접한 수반관계를 보인다. 중국의 중석광상은 세계 매장량의 과반수를 차지하기 때문에 이들의 산상은 다양하며 대체로 세계 중석광상의 성인을 대표하고 있다고 하겠다. 한국의 경우 90% 이상의 생산량을 보인 상동광상에서는 휘수연석이 부산물로 생산되었다. ppm 단위의 주석이 감지되지만 실제 석석은 상동광체에서 관찰되지 않았다. 수집된 기존 자료를 확인하기 위해 중국의 모평광상과 한국의 대화광상을 비교해 보았다. 두 광상의 석영맥에서 산출되는 광물은 거의 유사하나 특이한 점은 중국 모평에서는 진발다이트와 석석이 다량 산출된다는 점이다. 모평광상의 휘수연-석영맥중 채취한 진발다이트와 백운모의 연령은 181.1 Ma와 167.8 Ma이고, 대화의 휘수연-석영맥중 백운모는 80.9 Ma와 80.2 Ma를 각각 얻었다. 한국의 백악기 후기 마그마로부터 공급된 중석 광화용액 중에는 주석이 중국처럼 그 양이 증가하여 중석광화작용에 후속되리만큼 충분히 공급되지 않았기 때문에 한국의 중석광상에서는 주석이 수반되지 않았다고 추정된다.