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# Tin/tungsten-bearing granites in South China and their metallogenetic relations

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**Abstract:** Tin/tungsten-bearing granites in South China mostly belong to the transformation series, formed by multi-cyclic and multi-staged granitization, partial melting and remelting of materials of the continental crust. They are usually rich in silica and alkalis, poor in Fe, Ti, Ca, Mg, and alumino-supersaturated. In trace element geochemistry they are rich in Sn, W, Be, Nb, Ta, F, Li, Rb, Cs, and poor in Sr and Ba. The initial Sr ratios are usually more than 0.710. The oxygen isotope composition is usually $\delta^{18}O>10.0\%$. Sn/W mineralizations began in the Pre-Cambrian and reached their peak during the Yanshanian (Cretaceous) period.

South China is a geochemically anomalous region of Sn and W. The middle to late Proterozoic and lower Paleozoic volcano-sedimentary sequences comprising the crustal basement of this region, are rich in Sn and W, forming important metal source beds. Multi-cyclic tectonic movements and magmatic activities have resulted in higher degree of maturation of South China's continental crust and higher degree of differentiation, readjustment and mobilization of metal elements, and finally, leading to extensive formation of Sn/W-bearing granites and Sn/W deposits in the Yanshanian period.

## INTRODUCTION

South China is the most important region for tungsten deposits and is also one of the most important regions for tin deposits in the world. For a long time the abundant rare metal deposits of South China have been attracting the attention of many Chinese and foreign geologists. As in other parts of the world, the majority of Sn/W deposits in South China are associated with granitic rocks. This paper emphasises the geologic ages, geochemical characteristics and metallogenetic relations of Sn/W bearing granites in South China, and the relationship of their generation with the geotectonic background, the evolution of continental crust and the source beds of tin and tungsten. In this text the following abbreviations will be used:- Sn-bearing granite - SnBG, W-bearing granite - WBG, Sn/W bearing granite - SnWBG.

## GEOTECTONIC BACKGROUND

The study area covers an extensive region. In the north it borders the North China platform, in northwestern and western part it includes the Pre-Cambrian Jiangnan geanticline belt and Sichuan-Yunnan geoaxis, in southwestern part it is limited by the China-Vietnam boundary, and in the eastern and southeastern part it embodies the coastal zone. In global tectonics, South China is situated in the southeastern part of the Eurasian plate but not far from the junction of the Eurasian, the Indian and the West Pacific plates. To the west across the Jinshajiang-Red River suture zone is the Sanjiang Indosinian fold system extending southwards to Burma, Thailand, Malaysia and Indonesia, forming the world-famous tin belt.

The geologic development history of South China is prolonged and complicated. It is characterized by multi-cyclic tectonic movements of the earth's crust and multi-cyclic formations of granitic rocks. It has undergone intermittently, the Donganian (middle Proterozoic), the Xuefengian (late Proterozoic), the early-Caledonian, the late Caledonian, the Hercynian, the Indosinian, the early Yanshanian, the late Yanshanian and the Himalayan movements. Furthermore, directly related to these orogenic movements, multiple generations of granitoids of corresponding ages were also intruded. With renewing geologic age and evolution of the continental crust, the granitoids of South China have developed with a general trend towards the enrichment of Si, K, Na, F, Sn, W and the poverty of Fe, Ti, Ca, Mg etc. (Department of Geology, Nanjing University, 1981).

Based on the results of over 30-years research in the Dept. of Geology, Nanjing University which included materials from W Guangxi, SE Yunnan, S Sichuan and Guizhou provinces, a simplified geotectonic map of South China has been compiled (Figure 1).

The northern and northwestern part of this region is the Donganian-Xuefengian fold system consisting of weakly metamorphosed middle-late Proterozoic eugeosynclinal volcano-sedimentary sequences over 2,000 m thick. It embodies two cratonic-massifs (Jiangnan geanticline and Sichuan-Yunnan geoaxis) and the Sichuan-Guizhou platform with a sedimentary cover.

To the southeast is the South China's Caledonian eugeosynclinal fold system. It includes several important post-Caledonian uplifts and several important Hercynian-Indosinian depressions such as the S. Anhui-Xiushui-Yuanshui marginal miogeosyncline, the Qinzhou Gulf and the Hainan Hercynian-Indosinian remnant geosyncline.

Further to the southeast is the Zhejiang-Fujian-Guangdong Yanshanian volcanic belt, in which the Hercynian-Indosinian basement has been locally exposed. This belt embodies the Zhejiang-Fujian Mesozoic volcanic belt and E Guangdong regenerated Yanshanian geosyncline.

The most eastern geotectonic element of this region is the Taiwan Himalayan fold system. In general,the fold belts of different ages in South China show a migration towards the southeast. The spatial distribution of the granitoids in South China demonstrates the same trend of migration.

## GENETIC SERIES

Based on the studies of granitoids of the different ages found in South China and in the light of the tectonic environment, material source and formation mechanism, the granitoids in South China can be divided into three genetic series: (Xu Keqin *et al.*, 1982, 1983)

### Continental crust transformation series granitoids.

They have been formed from geosynclinal accumulations by repeated transformation activities such as migmatization, granitization, partial melting and remelting processes. This kind of granitoids are really distributed inside the South China continent, usually in the Pre-Cambrian massifs, the post-Caledonian uplifts and in the granite dome areas of the Hercynian-Indosinian depressions, and are mostly represented by the normal granites. Association with consanguineous volcanics is not mandatory. Their initial Sr ratios are usually greater than 0.710. In general, this series is quite similar to S-type granites of Chappell and White (1974).

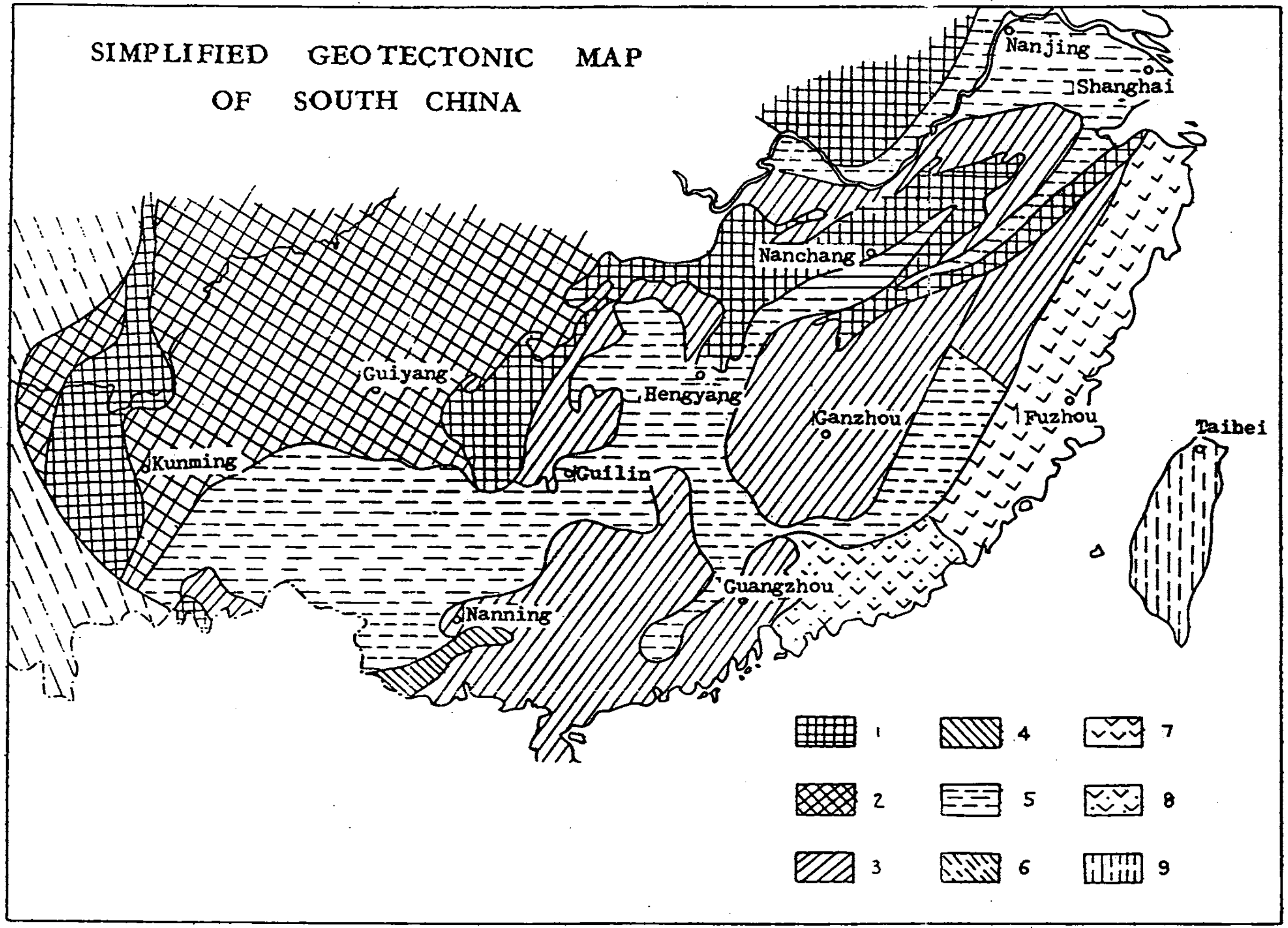


Fig. 1. Simplified Geotectonic Map of South China.

1) Pre-Cambrian massif
2) Platform
3) Post-Caledonian uplift
4) Hercynian-Indosinian remnant geosyncline
5) Hercynian-Indosinian depression
6) Indosinian fold belt
7) Mesozoic-volcanic belt
8) Mesozoic regenerated geosyncline
9) Cenozoic fold belt

**Syntectic series granitoids formed in a transitional crust.**

These have been formed by syntexis, mixing and assimilation when the derivatives of the upper mantle or the magmas of the partially melted rocks of the lower crust have intruded into the sediments of a geosynclinal regime. These granitoids are mostly distributed in the southeastern coastal area, to the east of the Zhenhe-Dapu deep fault (or the active continental margin) and near the Lower Yangzi River deep fault, the NE Jiangxi deep fault, and the Sihui-Wuchuan deep fault. In the SE coastal area of the Mesozoic volcanic activity and in the Mesozoic regenerated geosyncline, the formation of syntectic series granitoids are directly related to subduction of the West Pacific plate. In the deep fault zones the formation of these granitoids are evidently related to the cutting of deeply-seated rocks by deep faults. In this region the already discovered syntectic granitoids are mostly Yanshanian, a few being Indosinian, usually associated with consanguineous volcanics and subvolcanics of intermediate to acidic composition. The initial Sr ratios are usually less than 0.710. This kind of granitoids are similar to I-type of Chappell and White (1974).

**Mantle-derived series granitoids.**

There are very few examples of this type. Only two cases have so far been identified in South China viz. the Bendong tonalite (Donganian,1340-1550 Ma) and Xiqiu quartzdiorite (Xuefengian, late Pre-Cambrian), both of which are found in the southern flank of Jiangnan geanticline. They are small intrusions, with exposure areas of 40 and 9 $km^2$ respectively. They are genetically related to the ophiolites and mafic volcanics, being the late stage differentiation product of mafic magma (Wang Dezi *et al.*, 1982). The initial Sr ratios are less than 0.705.

A-type granitoids have been found along the Nanao-Changle deep fault zone in the southeast sea coast forming a NE treding belt of late Yanshanian alkaline granitoids 500 km long and 60 km wide. The largest representative is the Quigi alkaline granite body. Their hypabyssal environment of emplacement, miarolitic structure, enrichment of alkalies, low content of water and some other characteristics indicate that they were the product of the late alkaline stage of evolution of a syntectic magma. The initial Sr ratio is 0.711. Therefore, the A-type granitoids in this zone can be considered as a subgroup of the syntectic granitoids, or can be simply called syntectic - A type (Yuan Pu, 1983).

Along the western boundary of this region near the Jinshajiang - Red River suture zone there occurs another NS trending alkaline belt (Tu Guangchi *et al.*, 1982), but of the Cenozoic age. Their formation mechanism is poorly understood, but some are certainly related to the differentiation of a mafic magma.

## TIN/TUNGSTEN-BEARING GRANITES

The majority of industrial Sn/W deposits in South China are found genetically in association with the transformation series granitoids. Only a few SnWBG are found in the active continental margin and in deep fault zones, genetically associated with volcanics and subvolcanics of crust-mantle mixed source. Examples of the latter type are Lianhuashan W deposit, E Guandong; Changpu Sn deposit, E Guandong; Yangchuling W deposit, N Jiang Xi; Fenling and Yunpin W deposits, NE Jiangxi. The A-type alkaline granitoids and the mantle-derived granitoids at present state of knowledge are Sn/W free.

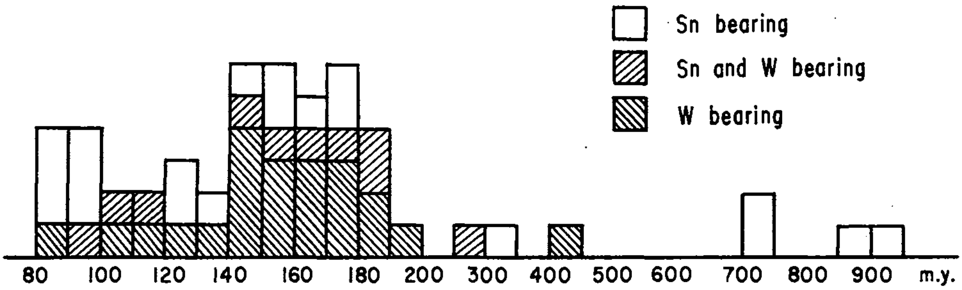


Fig. 2. Isotopic ages of 52 Sn/W bearing granites in South China.

The characteristic features of SnWBG of the transformation series are as follows: they are mostly the late-cyclic, late stage small rock bodies of composite intrusives, or form the apical and peripheral parts of relatively large bodies. They are fine to medium grained in texture, acidic to ultra-acidic in composition with enrichment of alkalies and intense hydrothermal alteration (especially K-feldsparthization, albitization and greisenization). They are enriched with W, Sn, Be, Nb, Ta, U and some other ore-forming elements, rare alkalies Li, Rb, Cs, and volatiles F, B and water, and show the appearance of topaz, fluorite, tourmaline and some other accessory minerals. The initial Sr ratios are high, ranging from 0.710 to 0.735 and averaging 0.720. The oxygen isotope composition is relatively high with $\delta^{18}O$ values from 9.3% to 14.0% and averaging 11.0%.

Quite a few descriptions and summaries on the mineralogy, petrochemistry and petrology of granitoids of different ages have been reported previously (Department of Geology, Nanjing University, 1965, 1980, 1981;Guiyang Geochemical Institute, 1979; Xu Keqin *et al.*, 1982). The emphasis in this paper is put on some new geochemical data which can provide important information and to discuss the ore-bearing potential of granitoids and the mechanism of granite generation.

## ISOTOPIC AGES

The isotopic ages of 52 SnWBG (by Rb-Sr method and K-Ar method) have been collected and a histogram of isotopic ages has been plotted (Figure 2). This clearly indicated that the formation of SnWBG begins from the late Proterozoic, and continues to late Mesozoic. Furthermore, there also exists some difference between the ages of SnBG and those of WBG.

A few Proterozoic SnBG with economic significance have been found in the Pre-Cambrian massifs, especially in the Sichuan-Yunnan Geoaxis and the SW end of Jiangnan Geanticline belt. Economically significant Caledonian SnBG have not yet been found. However, there is some cassiterite concentration in the Devonian sandstone in S. Jiangxi. Therefore we have no reason to exclude the possibility of existence of the Caledonian SnBG in this region. Hercynian-Indosinian SnBG occur in the W. Guangzi and Central Hunan provinces. The Indosinian (Upper Triassic) SnBG have been discovered in N Guangxi but are of minor economic importance and several SnBG have been found in the adjacent Sanjiang Indosinian fold system.

The early Yanshanian SnBG are usually at the same time W-bearing, especially the Jurassic ones. Subsequently, towards late Jurassic, the independent SnBG begin to appear, mostly in the NE. Guangxi Province. Important SnBG with the largest economic significance have been formed in the late Yanshanian period. (i.e. the Cretaceous). The isotopic ages are concentrated in the range of 80-130 Ma. Among these SnBG, the late Cretaceous ones with the ages of 80-100 Ma are most important. They are mostly distributed in the Hunan-Guangxi-N Guangdong-SE Yunnan Hercynian-Indosinian depression.

The concentration of tungsten in granites also begins from the Proterozoic, but it is usually found in association with Sn and therefore its economic significance is negligible. Economic Caledonian WBG have been found in W. Hunan Province. Some Hercynian-Indosinian SnBG may also sometimes be W-bearing. The most important WBG are of the early Yanshanian age (190-137 Ma). They are extensively distributed in the South China's Caledonian geosynclinal fold belt, especially in the S Jiangxi Post-Caledonian uplift and adjacent to it in the periphery of the Hercynian-Indosinian depression. Many early Yanshanian WBG are also Sn-bearing which is clearly expressed on the histogram (Figure 2). Some WBG have also been formed in late Yanshanian period, but they are either associated with Sn, or related to the syntectic granitoids occurring in the continental margin and deep fault zones.

The isotopic age data of SnWBG in South China reflect the features of heritage and development in the generation of SnWBG more clearly than those of South America (Bolivia, Brasil) and Southeast Asia (Thailand, Malaysia, Indonesia).

## STRONTIUM AND OXYGEN ISOTOPES

Table 1 shows the initial Sr ratios $(^{87}Sr/^{86}Sr)_i$ of 12 SnWBG in South China. The last two are syntectic type of W-bearing subvolcanic granitoids, i.e. Lianhuashan W-bearing quartz porphyry and Yangchuling W-bearing granodiorite with the initial Sr ratios of 0.709 and 0.707 respectively. This indicates the incorporation of crustal materials in a rising deep-seated magma in the active continental margin and deep fault zone respectively.

All other 10 SnWBG belong to the transformation series formed inside the South China continent. Their $(^{87}Sr/^{86}Sr)_i$ values vary from 0.710 to 0.735, averaging 0.720. These Sr

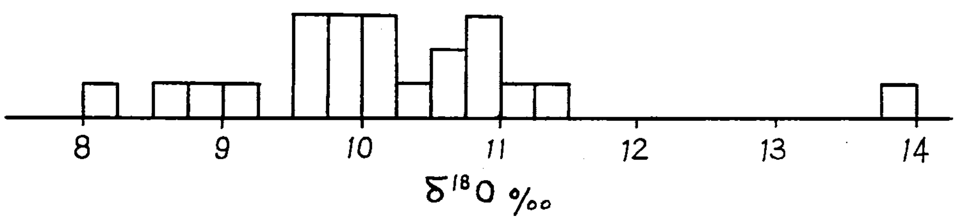


Fig. 3. Histogram of $\delta^{18}O$ values of 22 Sn/W bearing granite bodies in South China.

**TABLE 1**

INITIAL SR RATIOS OF SOME SN/W GRANITES IN SOUTH CHINA

| Locality | Rock Type | $(^{87}Sr/^{86}Sr)_i$ | Source |
|---|---|---|---|
| Dachang, Guangxi | biotite granite | 0.7202-0.7222 | Wu Qinsheng *et al.*, 1982 |
| Huangsha, Jiangxi | granite | 0.7273 | " " " " |
| Laochang, Gejiu, SE Yunnan | equigranular leucocratic granite | 0.7107 | Wu Qinsheng *et al.*, 1983 |
| Malage Gejiu, SE Yunnan | medium-grained porphyritic biotite granite | 0.7142 | " " " " |
| Xiaonanshan, W Guangdong | biotite granite | 0.710 | Zhaozijie *et al.*,1982 |
| Zengjialong, N Jiangxi | granite | 0.7324 | Wang Liankui *et al.*,1982 |
| Xingluokeng, W Fujian | granite | 0.715 | Institute of Geology, Fujian Province, 1981 |
| Dengpuxian, E Hunan | granite | 0.725,0.735 | Department of Geology, Nanjing University,1982 |
| Qianlishan, S Hunan | granite | 0.728 | Wu Yanzhi *et al* 1982 |
| Qitianling, S Hunan | granite | 0.724 | " " " " |
| Yangchuling, N Jiangxi | granodiorite | 0.709 | Institute of Geology, Jiangxi Province,1981 |
| Lianhuashan, E Guangdong | quartz porphyry | 0.706 | Li Tung *et al.*, 1982 |

isotopic characteristics evidently show that during their generation these SnWBG have taken their sources from the geosynclinal accumulations rich in radiogenic $^{87}Sr$.

The average oxygen isotope ($\delta^{18}O$) composition of whole-rock samples from 23 SnWBG (Zhang Ligang *et al.*, 1982; Li Tung *et al.*, 1982; Xu Keqin *et al.*, 1982; Wang Weiyu, 1984) varies from 9.3 to 14.0% (Figure 3). The maximum frequency occurs in the range 10.5-11.6 %, averaging 11.0%. The $\delta^{18}O$ of aforementioned two W-bearing subvolcanics are 11.5-10.8% respectively, falling in the same range of maximum frequency. This kind of relatively heavier oxygen composition indicated that the source materials of these SnWBG, to a great extent, have undergone accumulation and weathering process on the earth surface. These data in combination with initial Sr ratios consistently agree with the fact that the magmas responsible for most of the SnWBG in South China are generated from the middle-late Proterozoic and lower Paleozoic geosynclinal volcano-sedimentary sequences.

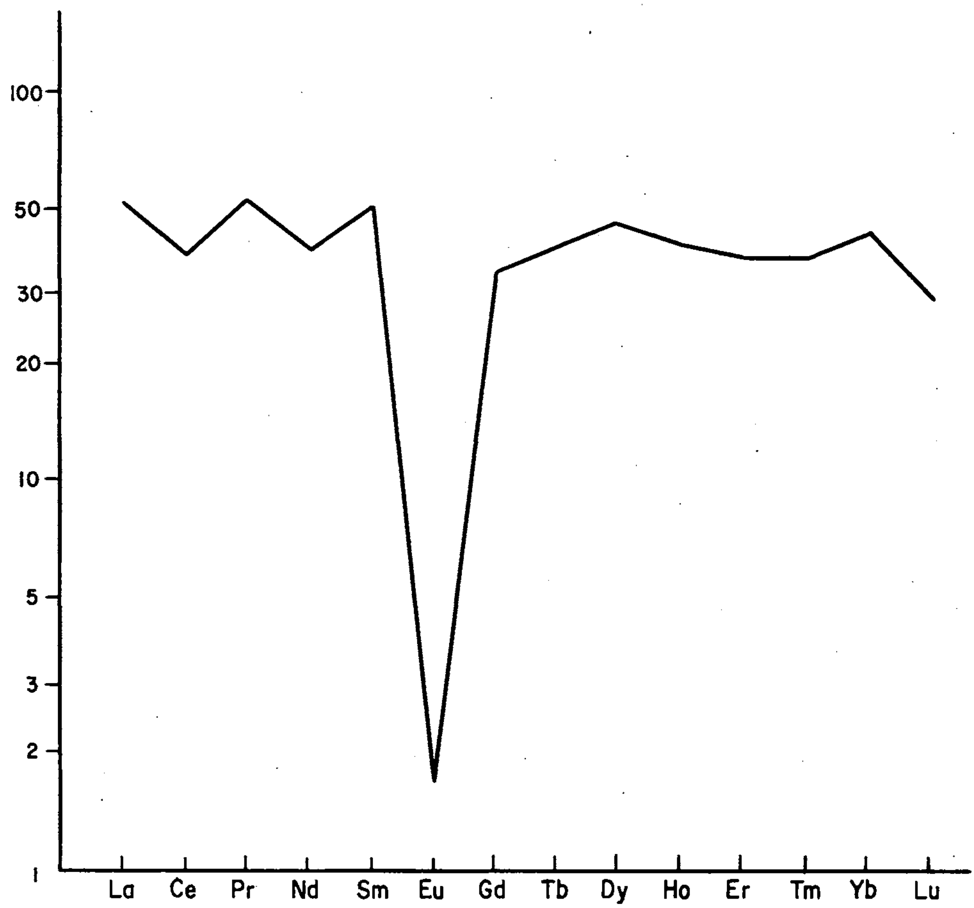

Fig. 4. Chondrite-normalized REE pattern of Gejiu Sn-bearing granite.

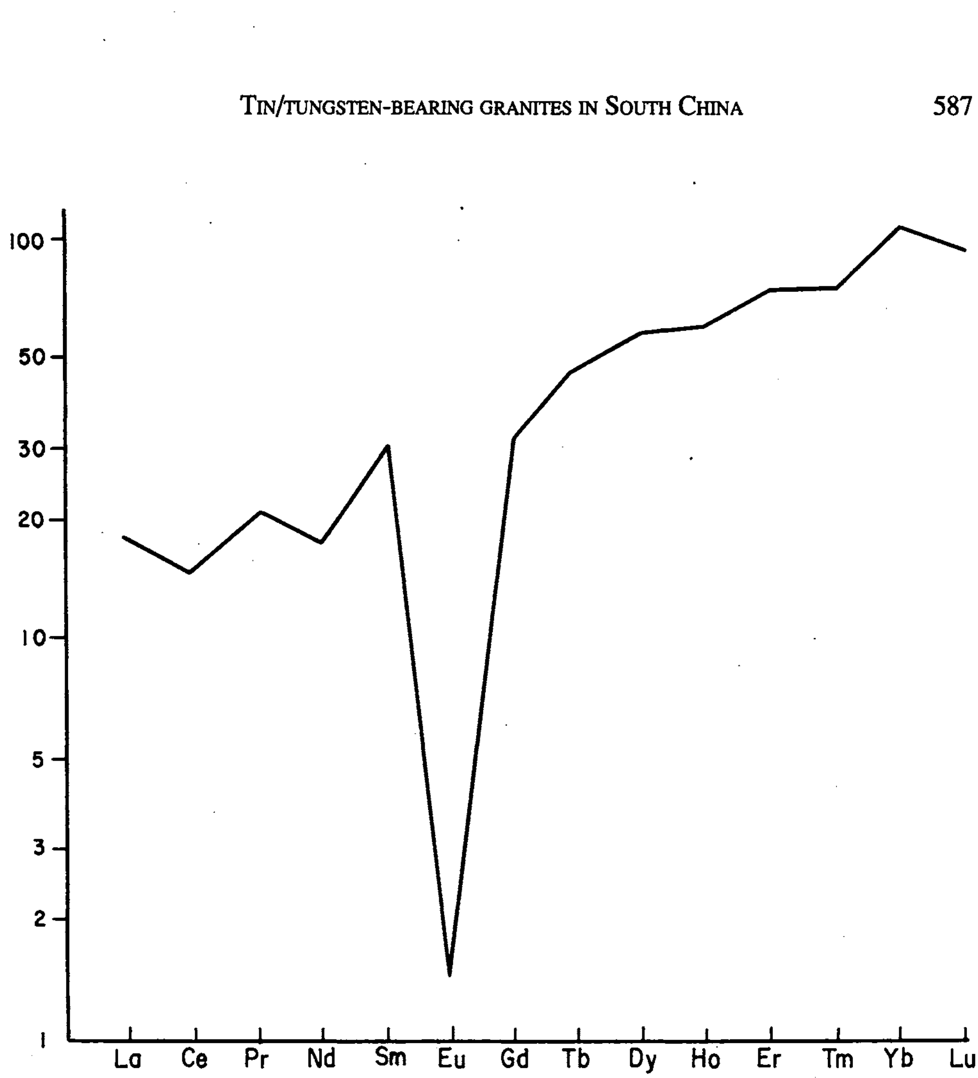


Fig. 5. Chondrite-normalized REE pattern of Xihuashan W-bearing granite.

## RARE EARTH ELEMENT DISTRIBUTION PATTERNS

There are many common characteristics in the Rare Earth Element (REE) distribution patterns of SnWBG in South China. The different SnWBG bodies also often have their specific features depending upon the REE patterns of granites themselves, and the behavior and intensity of hydrothermal alterations they have suffered, and the sampling localities. Analyses of REE contents of some 20 SnWBG bodies in South China reveal the following common features in their REE distribution for most unaltered and weakly altered SnWBG of transformation series in South China. The total REE concentration (ΣREE) is usually lower (mostly 100-250 ppm, sometimes n x 10 ppm) than that of the average granite calculated by Vinogradov in 1962 (285 ppm). There is an enrichment of the heavy REE relatively to the light REE, LREE/HREE being close to 1.0 or less than 1.0. The Eu depletion is usually very strong, with a δEu value less than 0.2 sometimes even less than 0.1. The chondrite-normalized curves are usually symetrically V-shaped (Figure 4). For some granite bodies, such as Xihuashan W-bearing biotite granite, the HREE could be much more enriched, and considerable amount of ΣY-containing minerals (gadolinite, xenotime etc.) may be present, resulting in left inclined in V-shaped curves (Figure 5). During the hydrothermal alterations, especially the albitization, greisenization and tourmalinization, the REE elements are usually selectively leached out from the granites, resulting in a reduction of the ΣREE, sometimes leading to a disappearance of the negative Eu anomaly. For example, the ΣREE of weakly altered SnBG No. 271 is only 50-60 ppm. In the albitized and greisenized granites the ΣREE are significantly decreased, and the negative Eu anomaly disappears (Figure 6). Another important feature of the SnWBG in South China is the similarity of the REE patterns of some the late stage acidic dykes and the hydrothermally altered rocks showing genetic relations between these dykes and the altered rocks.

The REE distribution patterns of SnWBG in South China seem to indicate that the fractional crystallization of partially melted magma under the low fugacity condition has caused $Eu^{2+}$ to replace $Ca^{2+}$ in the crystal lattice, and thus kept in the plagioclase and some

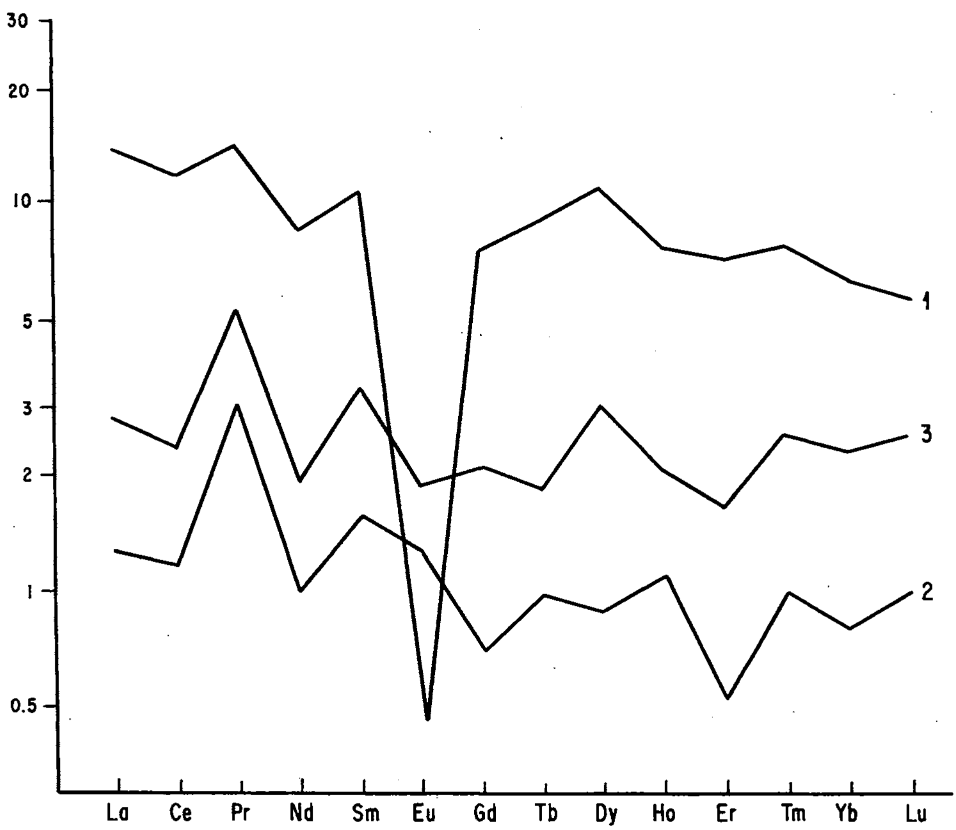


Fig. 6. Chondrite-normalized REE Pattern of No. 271 Sn-Bearing Granite. 1) weakly altered granite, 2) albitized granite, 3) greisenized granite.

**TABLE 2**

AVERAGE W AND SN CONTENTS OF SELECTED ORE-BEARING GRANITES IN SOUTH CHINA.

| Locality | W ppm | Sn ppm |
|---|---|---|
| Xihuashan, Jiangxi | 7 - 70 | 32 - 52 |
| Huangsha, Jiangxi | 16 - 32 | 37 - 42 |
| Hongshuizhai | | 12.4 |
| Qianmutian | 8 | |
| Denpuxian | 50 - 103.6 | 28.7 |
| Qianlishan | 18 - 39 | 43 - 71 |
| Yaogangxian, Hunan | 10.4 | |
| Gejiu, Yunnan | | 16 - 25 |
| Dachang, Guangzi | | 15 - 43 |

other Ca-containing minerals at the deeper part of the magma, resulting in obvious Eu depletion. The same features may be caused by partial remelting of the more easily fusible materials including sodic plagioclase. The activities of F-rich fluids at the late-magmatic and post-magmatic stages have caused the relative enrichment of HREE, during hydrothermal alterations and Sn/W mineralizations.

## SN AND W CONTENTS

Based on the studies of granitoids of different ages in Southeastern China the Geology Department of Nanjing University has obtained the average Sn and W contents in the granitoids of different ages in Southeastern China in 1965 and made some correction in 1981. These Sn and W values are given below respectively (in ppm): Donganian, 5, ?; Xuefengian, 7.2, 0.9; early Caledonian, 4.6,1.33; late Caledonian, 11.2, 2.4; Indosinian, 8.5, 2.8; early Yanshanian, 22.9, 10.2; late Yanshanian, 19.4, 8.0. A general conclusion was made that the background values of Sn and W in SE China as a whole are relatively high, being several times those of the average granite of the world. With the advance in evolution, Sn and W contents build up at the later geologic ages. The Guiyang Geochemical Institute (1979) calculated that the average background content of Sn and W in the granitoids of South China to be 32 ppm, and 3.44 ppm respectively.

The Sn and W contents in SnWBG of South China are usually several times the average values for granitoids of South China. Table 2 shows the Sn and W contents in 9 SnWBG of South China. The relatively high background values of such metallic elements provide favourable conditions for derivation of the ore-forming materials.

The SnWBG in South China are mostly multiple staged composite bodies. The general trend of evolution of these multiple-staged bodies in petrology, petrochemistry, geochemistry and Sn/W contents is quite the same as the general trend of the granitoids of different geologic ages. From the earlier to later stages Sn, W, Be, Nb, Ta tend to be concentrated. Table 3 shows three examples, Xihuashan WSnBG, Denbuxian WBG and No 271 SnBG, each of which has three rock-forming stages.

TABLE 3

VARIATION OF SN/W CONTENTS IN SELECTED ORE-BEARING GRANITES (IN PPM)

| Locality | | Stage I | Stage II | Stage III |
|---|---|---|---|---|
| Xihuashan, Jiangxi | W | 7.0 | 8.9 | 70 |
| | Sn | 42.1 | 32.1 | 49.2 |
| Denbuxian | W | 50.0 | 69.3 | 103.6 |
| 271, Guangxi | Sn | 6.4 | 12.1 | 15.1 |

## TRACE ELEMENTS

Beside being abundant in Sn, W, Be, Nb, Ta and some other metallic elements the SnWBG of the transformation series in South China are also rich in volatiles F, B, rare alkalies Li, Rb, Cs, and poor in Sr and Ba. Based on the present data and using the data of Xu Jinfang (1981), Liu Yingjung *et al.* (1982), Sun Chengyuan *et al.* (1983), and Wang Weiyu (1984), some important results have been obtained.

The F contents of SnWBG of transformation series are mostly higher than 2000 ppm. For Qianlishan and Huangshan WBG the fluorine contents are over 3000ppm, and for Yaogangxian WBG and No 271 SnBG - over 5000 ppm. Whereas, for the Sn/W free granites the F contents are lower than 1000 ppm, averaging only about 750 ppm.

The total rare alkalies Σ(Li+Rb+Cs) in SnWBG reach 600-1600 ppm, averaging 1000 ppm; while Σ(Sr+Ba) contents are less than 100 ppm, averaging about 50 ppm. For the Sn/W free granitoids Σ(Li+Rb+Cs) are usually 150-600 ppm, averaging about 300 ppm, while Σ(Sr+Ba) are usually more than 400 ppm, averaging about 700 ppm. These two groups of elements sensitively reflect the history of generation, development and evolution of the granitoids, which plays an important role in the studies on the geochemical behaviour or ore-bearing granitoids.

The SnWBG of syntectic series, such as Lianhuashan quartz porphyry and Yangchuling granodiorite, like ore-free ones, are characterized by low contents of F, rare alkalies and high contents of Sr and Ba. This kind of correlation between Sn/W and rare elements depends, first of all, on the nature of source materials or strictly on the proportion of crystal and mantle materials. During the sedimentation, metamorphism, granitization, partial melting and remelting processes of source materials responsible for the formation of the transformation granitoids, directed differentiation and evolution occurred.

Figure 7 is a Σ(Sr+Ba) versus Σ(Li+Rb+Cs) diagram of 11 SnWBG bodies of the transformation series and 12 Sn/W free ones. All the SnWBG contain Σ(Li+Rb+Cs) > 600 ppm, Σ(Sr+Ba) < 100 ppm, Σ(Li+Rb+Cs)/Σ(Sr+Ba) usually > 10, averaging about 20; Whereas the Sn/W free ones usually contain Σ(Sr+Ba) > 400 ppm, Σ(Li+Rb+Cs) < 600 ppm, Σ(Li+Rb+Cs)/Σ(Sr+Ba) <1, averaging 0.3.

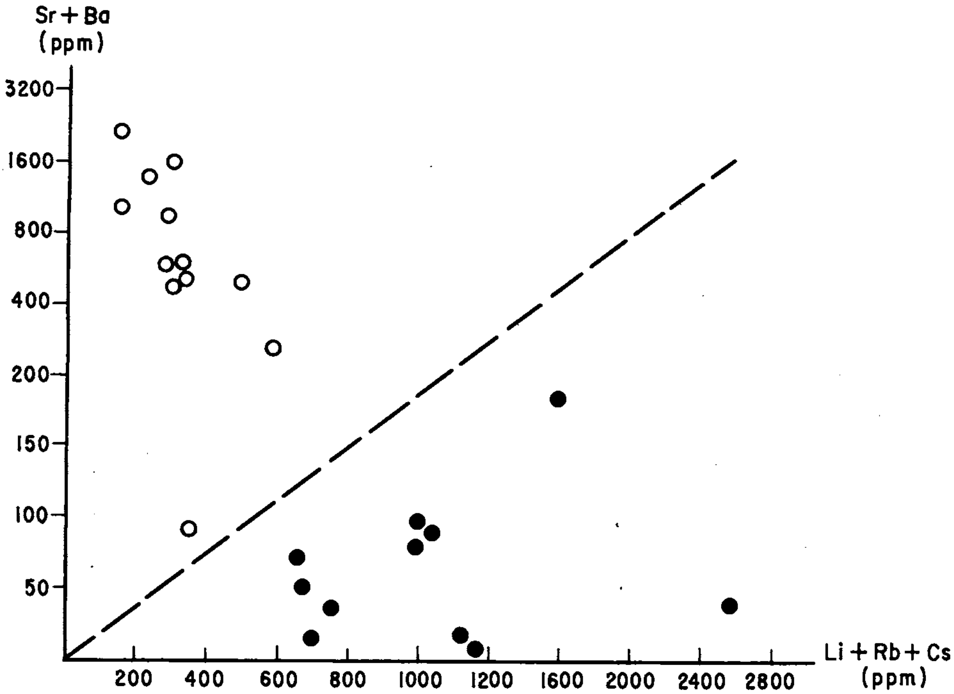


Fig. 7. (Sr+Ba) versus (Li+Rb+Cs) diagram of some Sn/W bearing and Sn/W free granites in South China. Solid circles, Sn/W bearing; empty circles, Sn/W free.

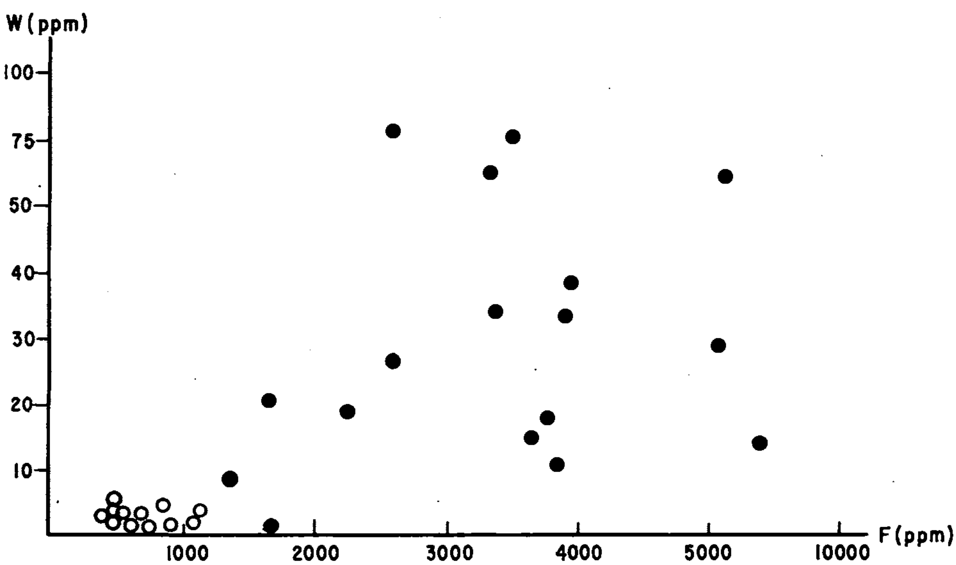


Fig. 8. W - F diagram of some Sn/W bearing and Sn/W free granites in South China. Solid circles, Sn/W bearing; empty circles, Sn/W free.

Figure 8 is a W-F diagram of 16 SnWBG bodies and 13 Sn/W free ones. The W contents of SnWBG are usually > 10 ppm, F contents > 1500 ppm, often > 3000 ppm, sometimes > 5000 ppm; while the Sn/W free ones contain W < 7 ppm, F < 1200 ppm.

## DISCRIMINATION OF ORE-BEARING POTENTIAL

In the studies of granitic rocks the ratios of element-pairs with different direction of evolution are generally applied to discriminate the ore-bearing potential.

For the granitoids in South China the most sensitive trace-element pair ratios are Rb/Sr, Li/Mg, K/Rb, Σ(Li+Rb+Cs)/Σ(Sr+Ba), $TiO_2$/Ta and some others. For example, the Rb/Sr ratio of SnWBG is an important criterion in estimating the degree of magmatic evolution, differentiation and ore-forming potential, is usually > 30, while that of the Sn/W free ones, usually < 10, sometimes < 1.

Using these element pair ratios and Sn/W contents in their different combinations, different diagrams can be plotted, and the SnWBG and Sn/W free ones can be distinguished. For discussion two examples are taken below.

Figure 9 is a lg(1000XLi/Mg) versus K/Rb diagram of 17 SnWBG bodies and 32 Sn/W free ones. For the SnWBG K/Rb < 120, lg(1000 Li/Mg) > 1.2, or Li/Mg > 0.016. In most cases, K/Rb < 75, Li/Mg > 0.063; while for the Sn/W free ones K/Rb > 75, lg(1000 Li/Mg) < 2.25, or Li/Mg <0.178. In most cases, K/Rb > 150, Li/Mg < 0.04. A small overlapping field of SnWBG and Sn/W free ones is also shown on this plot.

Figure 10 is a Sn content versus lg(Rb/Sr) diagram of 17 transformation series SnWBG bodies and 10 Sn/W free ones. The Sn contents in SnWBG in South China are usually > 10 ppm, Rb/Sr usually > 25, quite often > 100. A singular example of SnBG with low Rb/Sr ratio

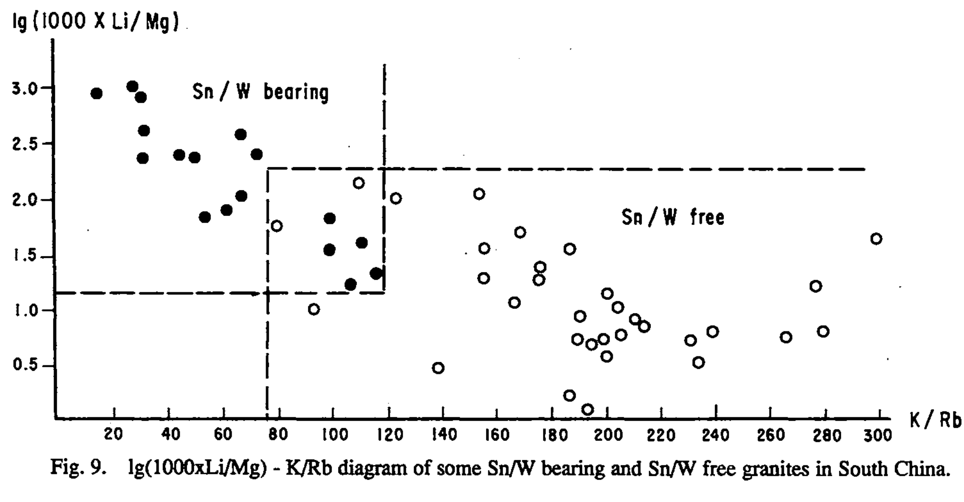


Fig. 9. lg(1000xLi/Mg) - K/Rb diagram of some Sn/W bearing and Sn/W free granites in South China.

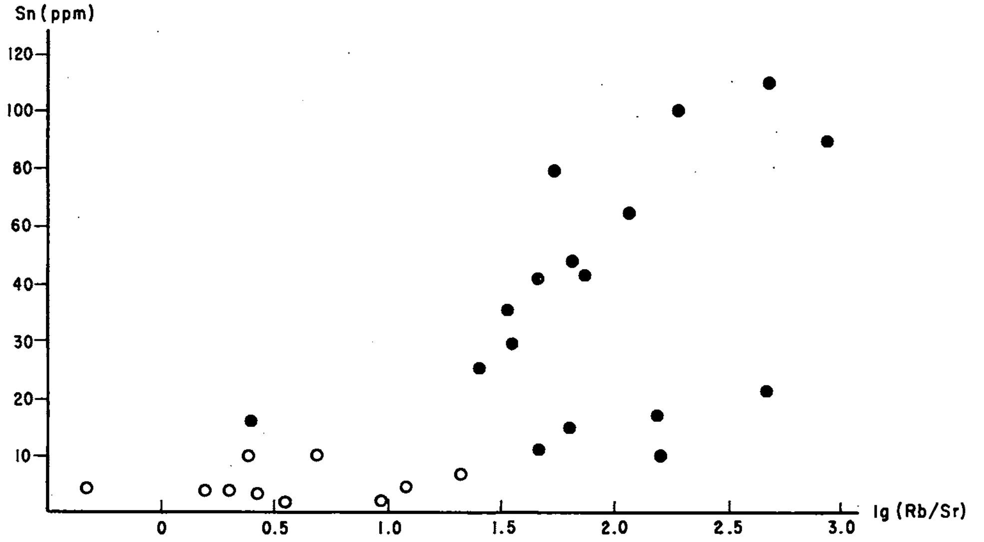

Fig. 10. Sn - lg(Rb/Sr) diagram of some Sn/W Bearing and Sn/W free granites in South China. Solid circles, Sn/W bearing; empty circles, Sn/W free.

(only 2.5) is given by Malage medium-coarse grained porphyritic biotite granite in Gejiu area. For the Sn/W free ones the Sn contents are usually < 10 ppm, Rb/Sr are usually < 20.

Above-mentioned are typical cases in distinguishing SnWBG and Sn/W free ones using some important geochemical criteria. Good results can usually be obtained. However, in practical application, these criteria must be synthesized and rationally interpreted.

## METALLOGENETIC RELATIONS

The late-magmatic and post-magmatic activity is a necessary prerequisite in the formation of Sn/W deposits. On the one hand, it causes intense pervasive metasomatic alteration expressed in K- feldsparthization- albitization-greisenization, in space from the deeper level upward, and in time from the early to late stage. On the other hand, it transports and precipitates W, Sn, Be, Nb, Ta, REE and other ore-forming elements. During the metasomatic alteration the metal carriers, such as biotite, amphibole, plagioclase, Ti-Fe oxides etc., are replaced by "clear" minerals. Large amounts of metallic elements are released, and concentrated in certain favourable localities.

Through many years of studies on Yaogangxian, Xihuashan, No 414, Qianlishan, Xianhualing, No 271 and some other Sn, W, Be, Nb, Ta and REE-bearing granites Department of Geology, Nanjing University, 1965, 1981; Hu Shouxi, 1984; Zhu Jinchu *et al.*, 1984) it is evident that there is a vertical zonation which has universal significance for granite-type mineralization in South China for W, Sn, Be, Nb, Ta, REE. In accordance with this zonal distribution of hydrothermal alterations, the loci of concentration of metal elements must also have a spatially zonal arrangement, that is from the deeper level upward, $\Sigma Ce \rightarrow \Sigma Y \rightarrow Nb \rightarrow Ta \rightarrow Be$, W, Sn. Generally speaking, REE mineralizations occur in the K-feldspartization zone and the lower part of the albitization zone (the LREE are concentrated at a lower level, while HREE - a higer level). Nb mineralizations appear mostly in the albitization zone while Ta mineralizations are formed at the upper part of the albitization zone and the lower part of greisenization zone. The W, Sn, and Be mineralizations begin to develop at the upper part of the albitization zone, but mainly in the greisenization zone.

This universal regularity of close spatial, temporal and genetic relation between the types of hydrothermal alterations and varieties of metal concentrations has led to the establishment of a synthesized model (Figure 11, Department of Geology, Nanjing University, 1980, slightly revised in this paper). This model suits not only the ore-bearing granites in South China, but also in the world.

For the relatively open system with more developed fractures the hydrothermal alterations of granites are not so intense, and the alteration zonation is not so complete as in the previous case. The Sn, W and other metal elements can be migrated along fractures by hydrothermal solutions to a considerable distance from the ore-bearing parental granites. The most important industrial type of tin deposits in South China, cassiterite-sulfide ores in carbonate sequences, has been formed in such an environment.

Figure 12 is a synthesized scheme of Gejiu cassiterite-sulfide deposit slightly simplified and modified after No 308 Geological Team of Yunnan Province. Three types of primary ore bodies are shown: the skarn type, the fracture controlled type and the stratabound type. Emphasis should be put on the last type which occupies a large percentage in overall reserves of tin for both Gejiu and Dachang tin mines, and which are of great economic and genetic significance. The stratified, rhythmic and foliated structures are common. The sulfur isotope compositon is largely dispersed. The main country rocks contain abundant Pb, Zn, Cu, S and sometimes Sn (Ye Jun *et al.*, 1984). All these facts indicate that during the formation of cassiterite-sulfide ores, a majority of polymetals and sulfur (and possibly some part of the tin) were directly derived from the Devonian or Triassic sequences. Heated by the granitic magma and released from the granitic rocks, the Sn-containing hydrothermal solution absorbed the Pb, Zn, Cu and S from the country rocks rich in these elements. Consequently, the stratabound cassiterite-polymetalic deposits were formed.

## ORE SOURCE BEDS

The extensive distribution of ore-bearing granites with high Sn/W contents is caused by the abundance of Sn/W in the source materials of SnWBG. As it has been mentioned above, the SnWBG are mostly of transformation series, formed by repeated transformation of South China's continental crust (mainly consisting of middle-late Proterozoic and lower Paleozoic geosynclinal volcano-sedimentary sequences) in the long course of the geologic history.

Since begining of 1970's, the Sn/W contents of the basement volcano-sedimentary rocks and the ore-source beds in South China have attracted many geologists' attention and

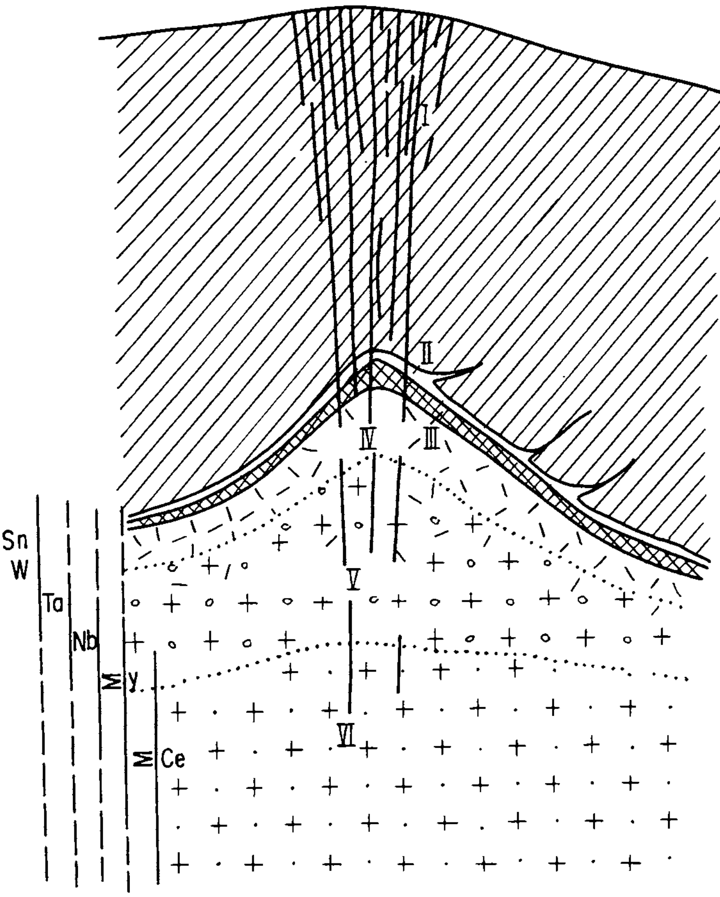


Fig. 11. Scheme of zonation of granite type Sn/W ore formation. I. W-Sn quartz veins. II. quartz "crust". III. pegmatoid layer IV. greisen V. albitization zone. VI.K-feldspathization zone.

interests (Xu Keqin *et al.*, 1981; Research Group on Nanling Tungsten Deposits, Ministry of metallurgy, 1981; Liu Yinjun *et al.*, 1982). Studies by the staff and students of Nanjing University have shown that the W content in Dayu area, S. Jiangxi, the Sinian and Cambrian sediments is 7-80 ppm, and in the Yudu area, S. Jiangxi, 16-63 ppm; However, the sediments of the same age, but at a distance further from the mining districts, contain only 2 ppm. The Research Group on Nanling Tungsten Deposits analysed more than 1000 samples of rocks for W and Sn from the Proterozoic to Triassic ages in South China, and obtained the average contents of W and Sn in the pre-Triassic rocks as being 9.53 ppm and 9.74 ppm respectively. Among them the middle to late Proterozoic spilite-keratophyre formation, intermediate-acidic volcano-clastic formation, siliceous formation, graywacke formation and flysch

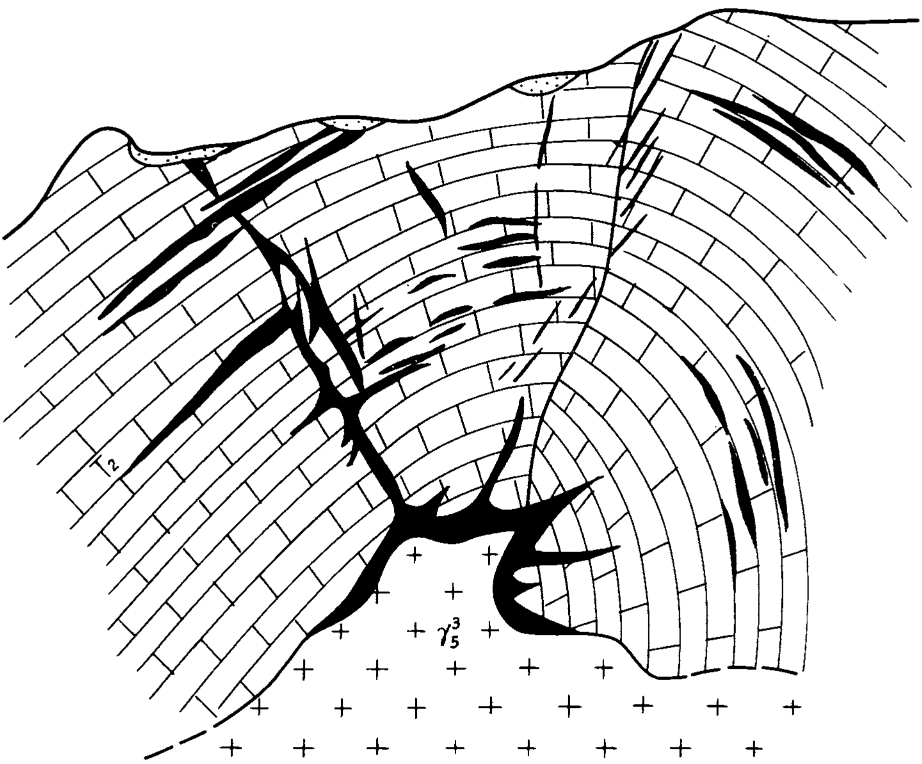


Fig. 12. Scheme of Gejiu cassiterite-sulfide deposit. Slightly modified after No 308 Geological Team of Yunnan Province.

formation which totals over 20000 m in thickness in the Jiangnan Geanticline belt contain on average 7.78-11.28 ppm W and 7.69-19.97 ppm Sn in average. The stratiform W-Sb-Au deposits and stratiform-stratabound sheelite deposits are formed in these Pre-Sinian volcano-sedimentary sequences. In the Sichuan-Yunnan Geoaxis the background Sn/W contents of the Pre-Sinian basement is also high.

According to the Research Group on Nanling Tungsten Deposits (1981) in the areas of Caledonian uplifts, the W and Sn contents of the geosynclinal volcano-sedimentary sequences of the Sinian, Cambrian and Ordovician ages are as follows (average, in ppm): Sinian, 9.84 and 12.04; Cambrian, 10.45 and 13.10; Ordovician, 8.96 and 6.45. In S Jiangxi and N Guangdong where the most famous wolframite deposits occur, the upper Cambrian sediments contain on average 17.54 ppm W.

The detrital sediments of the Hercynian-Indosinian structural layer of the platform regime in South China usually contain less Sn/W than the geosynclinal accumulations of the basement. Nevertheless, their Sn/W contents are much higher than the other platform regions of the world. In some localities the anomalous Sn/W contents do occur. For example, near the Yaogangxian W mine there exists a layer in the Devonian sequence that contains W 0.01-0.1%. In Dongpu W mine area, the Devonian sediments contain W 1.3-18 ppm (Xu Keqin et al., 1981). In some localities of NE Guangxi the Devonian detrital sediments contain an average 6.2-10.0 ppm Sn. In SE Yunnan high Sn background values are also observed in the Triassic sediments.

It is obvious that partial melting of these volcano-sedimentary sequences with anomalous Sn/W contents must lead to generation of SnWBG. Subsequently, under the favourable structural and country rock conditions economic deposits can be formed. Therefore, we call these volcano-sedimentary sequences of different ages with anomalous background metal contents, ore source beds. They are not only suppliers of most common elements of the SnWBG, but also the suppliers of Sn, W and other trace elements.

The concentration of Sn and W in the deep source materials has also interested a wide group of geologists. Some basic rocks in Jiangxi contain W 2.2 ppm (Xu Keqin *et al.*, 1981). Some Carboniferous andesitic pyroclastics in Dongxian area are rich in W (> 100 ppm, Zhu Jinchu and Zhang Chenhua, 1981). The Jurassic and Cretaceous volcano-sedimentary rocks in the E. Guangdong regenerated geosyncline contain 15-106 ppm Sn, 2.1-3.3 ppm W (analysis of some 100 samples).

In recent years some new information has been obtained on Sn concentration in the Pre-Cambrian basic and ultrabasic rocks in N Guangxi and Sichuan-Yunnan areas. Here the average Sn contents reach 17-18 ppm and 20-45 ppm respectively (Cheng Xianyou and Huang Yude, 1984). Within or near some basic and ultrabasic bodies a few tin ore bodies of economic interest have been discovered. Such basic and ultrabasic rocks with high Sn background contents can serve as another type of ore source beds.

The above-mentioned stratigraphic sequences, granitoids and deep-seated materials of different geologic ages and the different types in South China are all characterized by high Sn/W background values. This indicates that the upper crust, lower crust and upper mantle of South China probably have much higher Sn/W background contents than other parts of the world, and that South China is an anomalous region for tin and tungsten.

In the long course of development of the continental crust, multiple-cyclic and multiple-staged granitization, partial melting and remelting led to multiple-phased readjustment and mobilization of the crustal materials. In this way the ore-forming elements, such as Sn and W, with their originally relative low background in the crust can be greatly concentrated in the late-cyclic and late-stage granites, and finally, the ecomomic deposits can be formed.

## CONCLUSION

The long course of formation of Sn/W bearing granites and Sn/W deposits can be summarized in the following simplified scheme:

heterogeneity of upper mantle (anomalous regions of Sn/W)

↓ exogenic process | volcanism

ore source beds of different ages

↓

multiple-cyclic granites

↓ favourable structure | favourable country rocks

Sn/W bearing granites

↓ hydrothermal alterations | differentiation of elements

industrial Sn/W deposits

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