Wubu deposit, a representative lead-zinc mineralization associated with Mesozoic volcanic rocks in China

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Abstract: Lead-zinc deposits in China are classified into five main modes with the major country rocks, such as sedimentary rocks, plutonics, volcanics, metamorphics, and placer in Quaternary sediments in descending order of the size of identified resources. The Wubu deposit represents the volcanic-associated mode located in the coastal and subaerial volcanic field in southeastern China. It occurs in a part of the Wubu fault on the northeastern margin of the Wubu volcanic depression. The hanging wall and footwall rocks of the Wubu deposits belong to the lower Cretaceous and the upper Jurassic, respectively. The hanging wall rocks are mostly composed of welded tuff, reddish sandstone and siltstone, and tuff breccia. The footwall rocks are composed of felsic lava, tuff, volcanic breccia, and welded tuff with clastic rocks. The bulk rock chemical compositions of the typical rocks were analysed and documented with discussions under the scope of alteration.

The ores are composed of sphalerite with chalcopyrite blebs, galena, chalcopyrite, pyrite, barite, and a small amount of silver minerals. Carbonate minerals are also abundant. Sericite and chlorite are the major alteration minerals, and partly replace the silicate phenocrysts and matrix with goethite, carbonate, and sulfide minerals. The lead and zinc enrichment as major mineralization elements in the country rocks are associated with carbonate alteration. Silver, cobalt, chromium, and vanadium are in turn reversely associated with carbonate alteration. Sulfide minerals are distributed not only in the narrow ore zone of ca. 10 kilometers in length along the Wubu fault but also outword for at least 2 kilometers in width. Detecting this wide-spread area of weak mineralization may contribute to the farther exploration. Although more detailed study should be needed, we, at present, hold a genetic hypothesis of the Wubu deposits as a fissure-filling vein type formed by hot water associated with the cauldron subsidence.

Introduction

Lead-zinc deposits associated with subaerial felsic volcanics are widely distributed in the east coast area of south China. Wubu deposit, a representative one, occurs in the volcanic region in the near-shore mountain area of the central part of Zhejiang province, just south of a large city, Shanghai.

In general, there are five main modes of lead-zinc deposits in China in a view point of their host rocks (LIU and LU, 1983; WANG Y., 1983). The first mode is the lead-zinc deposits related to plutonic rocks of mostly ganitic composition. The biggest and representative one of this granite-associated type is the Shuikoushan deposits in Hunan Province which has a long history of the development. The identified resources of the skarn-limestone-replacemental deposits are more than 20 million tons of crude ore. The second mode is the lead-zinc deposits hosted in volcanic rocks of subaerial or marine which are mostly composed of felsic to intermediate volcanics and/or porphyritic rocks. One described in this paper of the Wubu lead-zinc deposit is subaerial one. The identified resources of each deposit in the subaerial volcanic-hosted mode are rather small

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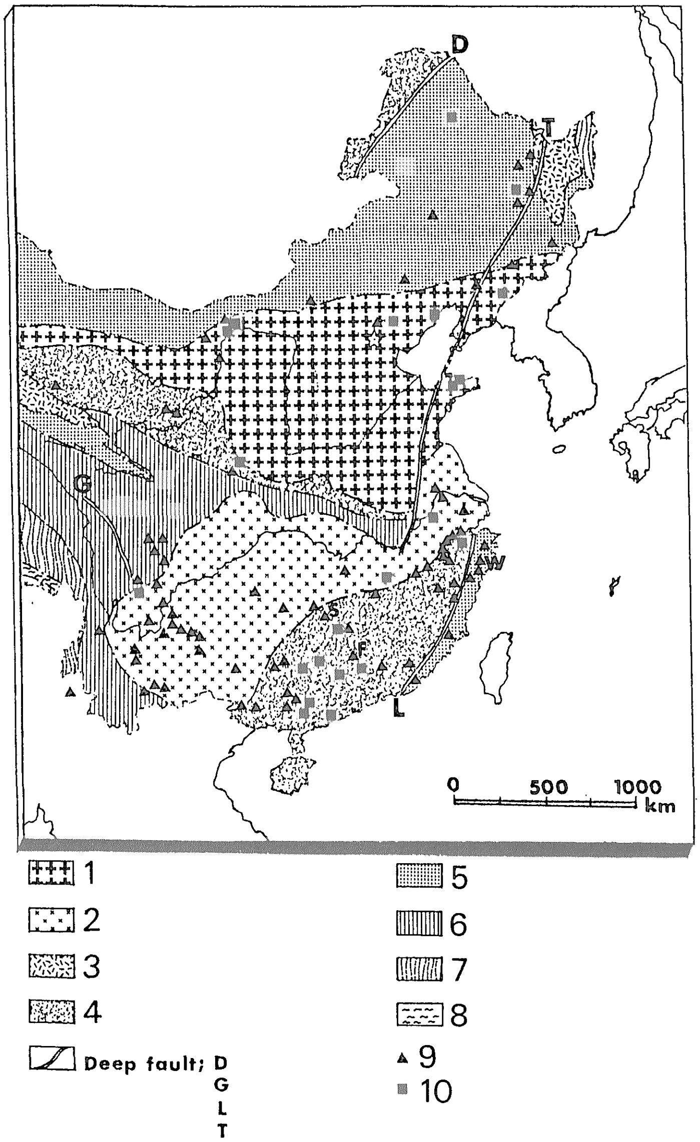

Fig. 1 Distribution of lead-zinc deposits in China with main structural massifs.
1: Archean to early Proterozoic massif, 2: late Proterozoic massif, 3: transition massif, 4: early Paleozoic folded zone, 5: late Paleozoic folded zone, 6: early Mesozoic folded zone, 7: late Mesozoic folded zone, 8: Tertiary folded zone, 9: lead-zinc deposits, 10: zinc-copper deposits, F: Fankou deposits, S: Shuikoushan deposits, W: Wubu deposit, Deep faults; D: Deierbugan, G: Garze-Litan, L: Lishui-Haifong, T: Tancheng-Lujiang. (Data are taken from CHIN (1980), Fuji Journal (1980), GUO (1982), LIU and LU (1983), RUI *et al.* (1983), WANG, Y. (1983), ZHANG (1980)).

(several million tons of crude ore), but those in submarine volcanic host rocks are bigger than those in the subaerial mode. The third mode is the lead-zinc deposits occurring in sedimentary rocks which are composed of arenite, dolomite, chert, and/or shale in the most cases. The newly found and biggest one is the Fankou deposits located in the northern part of Guangdong province. The identified resources of the Fankou deposits are up to ca.

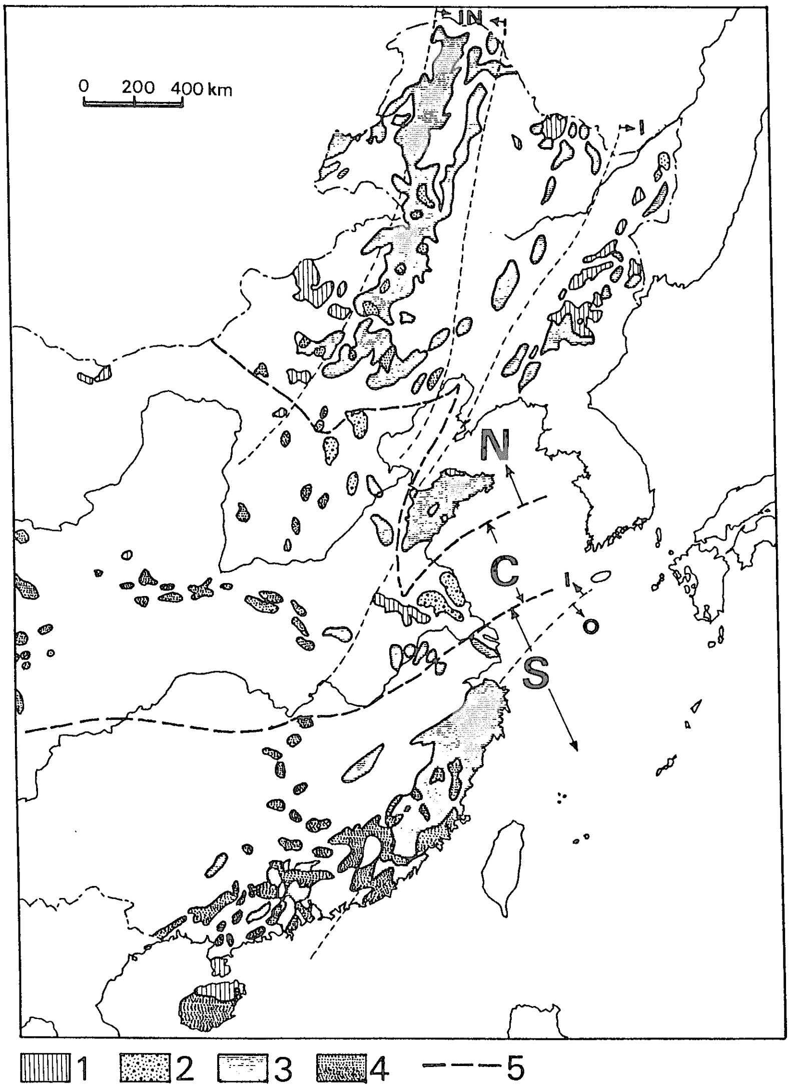

Fig. 2 Distribution of volcanic rocks in east China (redrawn from WU *et al.*, 1982; also from LU, 1982). 1: Tertiary effusive volcanics, 2: Tertiary intrusions, 3: Mesozoic effusive volcanics, 4: intrusive igneous rocks. 5: petrochemical boundaries between thick dashed lines: N: north zone, C: Central zone; S: south zone (WU *et al.*, 1982); interval between thin dashed lines: IN: inner zone, I: intermediate zone, Q: outer zone (LU, 1982).

30 million tons of crude ore. It is suggested that the 74% of the third mode deposits occur in the host rock of dolomite (WANG, W., 1983). The fourth mode of lead-zinc deposits is those in metamorphic rocks. The fifth mode is placer in Quaternary sediments. The identified resources of the latter two modes are much smaller than the former three.

China produced about 150 thousand tons of lead metal and about 120 thousand tons of zinc metal anually (Bureau of Mines, 1980). Inferred reserves were about 3 million tons of lead metal and 5 million tons of zinc metal. Many of the lead-zinc deposits are located rather far from the coastal industrial cities. Lead-zinc deposits in volcanic rocks in the coastal region of southeastern China are the exceptional case which has good access to the highway road which continues to the big industrial cities in a short distance. Although the size of the demonstrated reserves of the subaerial volcanic-associated mode does not yet reach a very large amount, it is worth while studying lead-zinc deposits in the coastal volcanic field of southeastern China because of the good environments for the exploitation.

Geological Environment of Wubu Deposit

Thick piles of volcanics and number of intrusive rocks are present in eastern China from the northeastern to the southeastern coastal regions (Fig. 2). The age of igneous activity is mostly concentrated to the Yanshanian age from Jurassic to Cretaceous. The volcanic regions are generally divided into three; the northern, central, and southern zones (WU *et al.*, 1982; LU, 1982). Petrochemically speaking, the northern and southern zones contain intermediate to felsic rocks which belong to calc-alkaline type in the most cases. Felsic volcanics are generally abundant in the southern zone. The central zone is peculiar because of the occurrence of alkaline rocks associated with ultramafics.

Tectonic lines of the volcanic regions run along the trends of north-northeast to south-southwest and northwest to southeast with a minor trend of north-northwest to south-southeast. The northeast to southwest trend is also common in the southern zone where big lead-zinc deposits occur. In the southern zone, there is a peculiar type of volcanic structures, which is called a ring structure. The ring structures have studied in detail in Zhe-

Table 1 Stratigraphical units of the Wubu area.
— conformable, --- non- or dis-conformable

Age	Group	Formation	Cycle	Member	Dominant lithofacies
Lower Cretaceous	Guangtou	C			red-brownish rhyolitic welded tuff
		B		upper	felsite, tuff breccia, agglomerate
				middle	volcanic bomb, welded tuff
				lower	welded tuff
				basement	glassy tuff
	Zhaochuan	A	3rd	upper-middle	volcaniclastics, sediments, lenticular tuff breccia, with the intercalation intermediate to basic volcanics
				lower	glassy tuff, welded tuff
			2nd	upper	basic tuff breccia
				middle	tuff and tuff breccia, welded tuff, shale
				lower	tuff and tuff breccia, welded tuff
			1st	upper	intermediate crystalline to glassy tuff, intermediate lava
				lower	black shale, shale, conglomerate, sandy conglomerate with olivine basalt breccia
Upper Jurassic	Moshishan	Upper			rhyolitic to dacitic lava
		Middle			tuff, welded tuff, ash-flow, ash-fall, glassy tuff, volcanic breccia, siltstone, sandstone, shale
		Lower			rhyolitic to dacitic welded tuff, sediments, volcaniclastics, basement

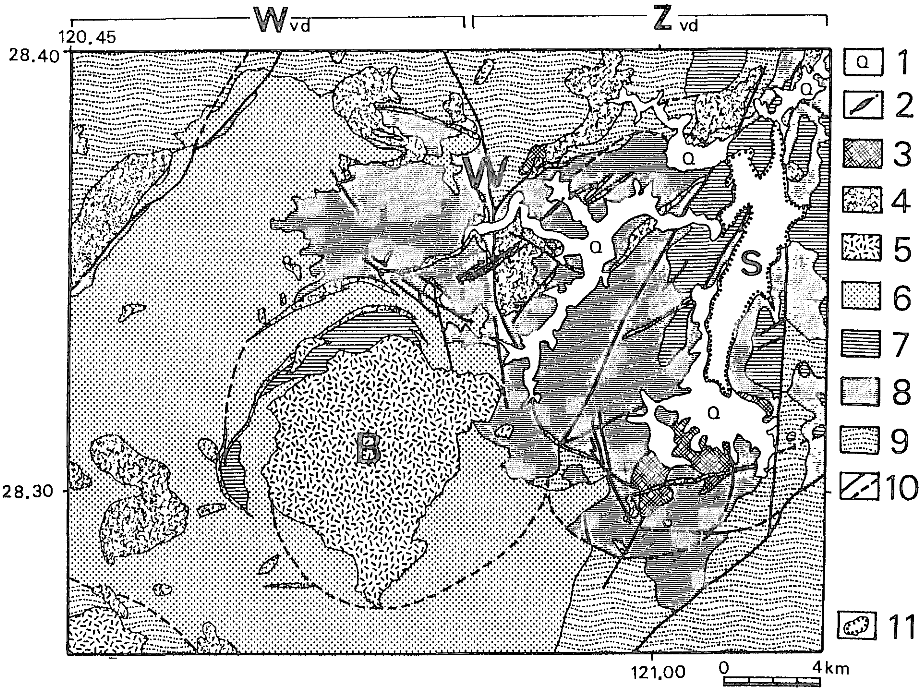

Fig. 3 Geological map of the Wubu area (redrawn from HUANG *et al.*, 1983).
1: Quaternary, 2: later stage dikes, 3: andesite, 4: felsic volcanics, 5: porphyritic quartz monzonite, 6: lower Cretaceous: C, 7: lower Cretaceous: B, 8: lower Cretaceous: A, 9: upper Jurassic, 10: fault, 11: lake Shuiku, W: Wubu deposits with the Wubu fault (trend of NNW-SSE), B: Banshan porphyritic quartz monzonite, Wvd: Wubu volcanic depression, Zvd: Zhantang volcanic depression.

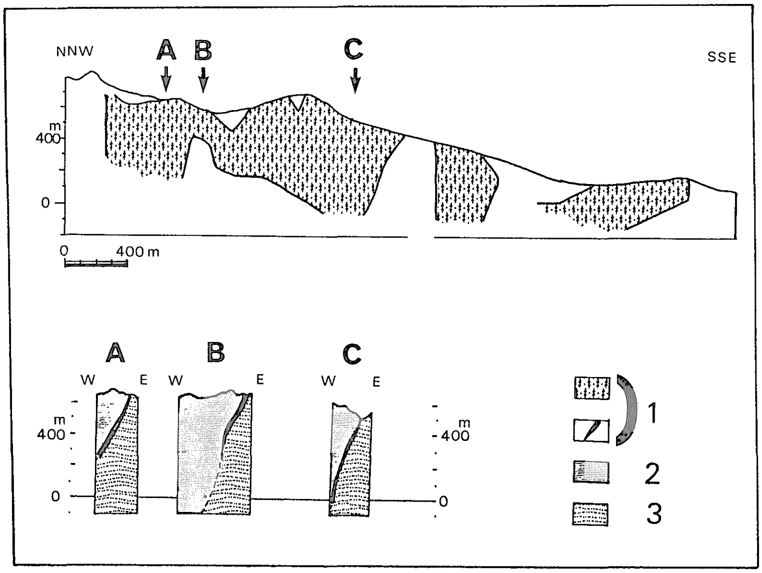

Fig. 4 Crossections of the Wubu deposit (modified from HUANG *et al.*, 1983; also from ZHENG and XI, 1984).
1: ore zone, 2: lower Cretaceous: A, 3: upper Jurassic. The arrows with A, B, and C in the upper section parallel to the Wubu fault indicate the positions of the lower sections normal to the Wubu fault.

jiang province (SHUI, 1981).

The Wubu deposit occurs at a part of the northeastern margin of the Wubu volcanic depression as a ring structure. The Wubu volcanic depression (Fig. 3) is just adjoin at the east by the Zhangtan volcanic depression. The southern part of the Wubu fault is located along this boundary of the two depressions. The Wubu volcanic depression spreads in an east-west direction for about 20 kilometers and in a north-south direction for 30 kilometers. The Zhangtan volcanic depression is smaller in diameters in an east-west direction for about 10 kilometers and in a north-south direction for 20 kilometers. The Wubu deposit is located in the northern part of tectonically weak zone, the Wubu fault, which developed between a couple of major depressions (Fig. 3). The southern end of the Wubu deposit is a little bit apart from the northern end of the conected fault zones of both the volcanic depressions. All the rocks distributed in and around the two depressions are Jurassic and Cretaceous in age. The Wubu deposit occurs along the boundary between the Jurassic and Cretaceous rocks. Stratigraphic succession of the Wubu area is shown in Table 1.

HUANG *et al.* (1983) reported the age of country rocks of the Wubu deposit, on three rock types of welded tuff, quartz porphyry, and rhyolite porphyry, the last of which occurs very close to the ore body. Lead isotope ages are 103, 290, and 290 Ma, respectively, whereas K-Ar ages are 85.1, 80.0, and 105 Ma, respectively. HUANG *et al.* (1983) considered that the difference between lead isotope and K-Ar ages was possibly caused by the large variance of the values of lead isotope during measurements, or by the later stage alterations affecting on K-Ar ages. They also considered the reason of older lead isotope age derived through the circulating water in the underlying pre-Jurassic rocks. In any case, the cauldron subsidence appears to have occurred around 103-105 Ma. If this is true, the mineralization may have occurred around or after the time of cauldron subsidence and terminated before 80 Ma of the K-Ar age of host rocks which possibly indicates the time of related alterations.

The depression areas are mostly filled with the terrestrial volcaniclastics, non-marine sedimentary rocks, and dikes of the Cretaceous age. The outer areas are covered by upper Jurassic volcanic piles with small amount of clastic sediments. In the center of the Wubu volcanic depression, there is a large intrusion named Banshan porphyritic quartz monzonite which extends in an east-west direction for about 8 kilometers and in a north-south direction for 10 kilometers (Fig. 3). The Banshan porphyritic quartz monzonite is accompanied by ring dikes of quartz porphyry and felsic rocks. The Wubu volcanic depression fills with rhyolitic welded tuff, lava, and dikes. Terrestrial clastic sediment and tuff and their alternation are widely distributed with mafic lava of the lower Cretaceous in the northern part of the Wubu volcanic depression and in the most part of the Zhangtan depression. Thus, these two volcanic depressions are considered as cauldrons occurred in the lower Cretaceous age.

Mode of Occurrence of Volcanics and Clastic Sediments

Jurassic rocks of the footwall are composed of felsic lava, lapilli tuff, tuff breccia, and welded tuff with small amount of shale and sandstone. Mafic minerals are scarce. Quartz, K-feldspar, plagioclase, and magnetite are common as phenocrysts and altered to sericite, chlorite, sulfate, carbonate, hematite, goethite, sulfide ore minerals, etc. Altered rocks occur even in areas far from the ore deposits. It is very common that the sulfide minerals replace the silicate phenocrysts of the country rocks. The welded structure is often found in altered part of devitrified groundmass under the optical microscope. The fragmental plagioclase and quartz in shale and sandstone are generally not authigenic as cements or pore-filling materials but clastics from igneous rocks.

Lower part of the hanging wall rocks is the complex of shale, basaltic andesite lava, and felsic to intermediate welded tuff which belong to the Cretaceous age. The phenocrysts of volcanics are of quartz, K-feldspar, plagioclase, and hornblende with magnetite, hematite, goethite, carbonate, etc. as accessory minerals. Only hornblende is the mafic mineral observed in the hanging wall rocks. Shales are often altered to form chlorite and sericite with pyrite, sphalerite, and galena which replace clastic grains of quartz and feldspar. Magnetite is also frequently found in shales.

Upper part of the hanging wall rocks is mostly composed of welded tuff with volcanic breccia, bomb, agglomerate and felsite. They also contain phenocrysts of quartz, K-feldspar, plagioclase, hornblende and magnetite. The groundmass of welded tuff is devitrified and then altered to chalcedonic quartz, chlorite and illite. The grade of alteration of the upper units is not so strong as the lower ones.

Intrusives are also abundant in both the footwall and hanging wall. They occur as dike and sheet of several to 10 meters in width and mostly basaltic and granitic in composition. Along the Wubu fault zone, quartz porphyry occurs in and around the lead-zinc ore bodies. Some of them cut the ores, but the others are concordant to the ore. The phenocrysts of the quartz porphyry are of quartz, K-feldspar, and plagioclase with carbonate minerals. The groundmass is composed of altered finer-grained minerals of chlorite, sericite, quartz, and carbonate. Ore minerals also occur in the quartz porphyry. They are sphalerite, galena, pyrite, hematite, goethite, and chalcopyrite.

Intrusions or lavas of quartz porphyry occur, together with felsite, in the collapsed Cretaceous area. The Banshan porphyritic quartz monzonite intrudes in the central part of the depressed area which is covered by the latest Cretaceous rocks. The quartz monzonite contains xenolith of the surrounded rocks in the peripheral zone. The chilled margin of the Banshan rock body is seen near the boundary with hornfelses of the country rocks. A breccia dike cuts the southern part of the Wubu fault zone. The breccias in the dike consist of the rocks from the footwall and hanging walls and porphyritic quartz monzonite as well. The phenocrysts of the porphyritic quartz monzonite are of quartz, K-feldspar, plagioclase, hornblende, and magnetite. The groundmass is partly altered to quartz, chlorite, and sericite with hematite.

Alterations of intrusive rocks show various grade in volumetric content of alteration minerals. Some diabase dikes in the ore zone are less altered than the felsic intrusive rocks.

Bulk Rock Chemical Compositions

Representative volcanics and sediments are analysed by methods of wet chemical (C, CO_2, FeO, S, Cl, F) and inductively coupled plasma (the other elements) in Technical Service Laboratory Inc. of Canada. The results are displayed in Table 2.

The analysed rocks include one series of drilling core, ZK46, which penetrates from the lower Cretaceous of hanging wall to the upper Jurassic of footwall rocks. Other samples are taken from the subsurface cutting face and the surrounded surface area. The localities of samples are given in the Appendix (and also see Geol. Surv. Japan ed., 1985). Many elements achieve a good agreement with the recommended values of standard rocks (JB1 and JG1 of Geological Survey of Japan and recommended shale). Only FeO is systematically deficient about 30% from the recommended values.

Correlation ratios of all the elements are calculated. Highly correlated couples of elements are selected and depicted in Table 3. The highest ratio is seen between the loss of ignition (LO1) and CO_2, which is scored as 0.97. The CO_2 content often exceeds 1 wt.

Table 2 Bulk rock chemical analysis of the Wubu area.

Serial	5	6	7	8	9	10	11	12	13	14	15	16
No.	06-2-42	06-2-43	06-2-48	06-3-01	06-3-15	06-4-26	07-2-34	07-3-00	07-3-45	07-4-14	07-4-30	07-4-51
Code	CZWBMS.HW.	CZWBBS.HW.	CZWBDB.HWD	CZWBQP.FWD	CZWBLT.FW.	CZWBQP.HWD	CZWBTB.FW.	CZWBBD.FWD	CZWBDB.FW.	CZWBTB.HW.	CZWBWTHW..	CZWBFS.HW.
(wt%)												
SiO2	68.51	45.53	50.09	75.15	53.11	70.01	68.07	74.17	48.24	72.45	72.76	74.98
TiO2	.38	1.32	1.00	.17	.34	.11	.54	.21	1.36	.28	.23	.17
Al2O3	14.07	15.73	15.95	11.14	12.13	9.29	15.31	12.31	17.34	13.85	14.03	11.93
Fe2O3	1.55	5.26	4.85	.69	1.17	.31	2.74	.83	4.41	1.99	1.53	1.14
FeO	1.20	6.16	3.63	.44	.99	.55	.88	.55	5.94	.33	.32	.21
MnO	.53	2.12	.24	.73	2.06	5.67	.09	.05	.18	.12	.09	.02
MgO	1.88	8.06	7.05	.26	1.40	.20	1.01	.33	6.70	.44	.28	.02
CaO	2.19	1.87	5.03	.64	9.73	1.85	2.90	.84	10.48	.92	1.13	.03
Na2O	.02	2.24	1.73	2.88	5.05	4.14	3.98	2.97	2.17	3.88	3.83	4.18
K2O	4.43	1.80	3.22	4.16	1.80	.56	3.81	4.75	1.02	4.34	4.94	4.45
P2O5	.03	.43	.40	.07	.12	.03	.16	.07	.45	.12	.08	.03
C.	.12	.20	.22	.01	1.30	.06	0.00	.02	.04	0.00	0.00	0.00
CO2	3.40	3.51	4.39	.80	6.22	4.10	.15	.76	1.40	.51	.40	.22
BaO	.04	.08	.05	.34	.09	.01	.11	.07	.04	.10	.11	.01
SrO	.01	.02	.03	.01	.02	.01	.05	.01	.10	.02	.03	-
ZrO2	.03	.01	.02	.02	.03	.01	.03	.02	.02	.03	.02	.04
S	.27	.82	.04	.46	.44	.07	.03	.05	.03	.02	.03	.01
F	.39	.45	.43	.08	.14	.15	.17	.07	.11	.09	.07	0.00
H2O+	1.05	1.23	3.00	.26	1.98	.76	.32	.56	.27	.37	.39	.30
Total	100.10	96.84	101.37	98.31	98.12	97.89	100.36	98.64	100.30	99.87	100.28	97.74
(Minor)												
(ppm)												
Cr	19	130	105	0	1	17	0	4	122	7	1	1
Cu	6	29	54	29	4	53	4	4	33	4	4	4
Ni	8	70	76	4	4	4	4	4	75	4	4	4
Pb	1	24	9	804	98	447	9	6	1	9	10	43
Zn	54	271	51	1225	118	856	48	16	60	50	64	85
V	63	211	196	4	21	36	34	7	270	7	7	0
Co	6	36	31	6	4	16	18	16	40	17	13	24
Mo	0	0	0	2	0	32	0	0	0	0	0	2
Ag	4	10	16	4	5	14	4	4	17	4	4	4
Cd	2	12	3	9	9	31	0	0	3	0	0	1
Be	0	0	0	0	0	0	0	0	1	0	0	0
Appendix												
(ppm)												
Sr	88	195	340	92	220	119	403	135	1039	242	293	21
Zr	60	25	60	43	86	70	43	27	32	47	62	126
(wt%)												
LOI	4.63	5.78	7.69	1.43	9.81	5.05	.57	1.45	1.76	.93	.83	.59

Rock name: Serial No.5, Pale greenish mudstone; 6. Basalt; 7. Diabase dike; 8. Quartz porphyry; 9. Lapilli tuff; 10. Quartz porphyry; 11. Tuff breccia; 12. Quartz porphyry fragment; 13. Diabase "lava"; 14. Tuff breccia; 15. Welded tuff; 16. Felsite dike (see also the appendix for the details).

Table 2 Continued

Serial	17	18	19	20	21	22	23	24	25	26	27	28
No.	07-9-10	07-9-23	07-10-20	07-10-39	08-1	08-2	08-3	08-4	08-5	08-6	08-8	08-9
Code	CZWBDC.HWD	CZWBRYCFW.	CZWBLT.HW.	CZWBWT.FW.	CZWBLT.HW.	CZWBTB.HW.	CZWBTB.HW.	CZWBMS.HW.	CZWBMS.HW.	CZWBSS.HW.	CZWBMS.HW.	CZWBTB.HW.
(wt%)												
SiO2	68.33	79.48	73.71	74.12	50.88	67.90	44.55	63.60	56.87	61.75	60.33	56.46
TiO2	.36	.13	.25	.15	.96	.30	1.04	.51	.39	.44	.91	1.22
Al2O3	13.97	10.26	13.11	12.19	16.69	12.14	16.72	14.18	12.64	16.56	17.06	17.24
Fe2O3	2.08	.87	1.32	.85	4.66	1.68	5.91	4.31	2.77	3.21	5.87	4.00
FeO	.86	.11	.43	.54	4.18	.85	3.74	1.08	.10	.10	.65	2.97
MnO	1.28	.49	1.16	.20	.14	.07	.17	.11	.10	.06	.14	.77
MgO	.67	-	.45	.21	5.94	1.29	5.40	2.50	1.08	.99	1.67	2.66
CaO	1.62	.11	.15	.81	6.58	4.83	8.81	3.02	10.60	4.39	2.05	3.59
Na2O	2.71	5.45	.01	3.17	2.09	2.11	3.47	1.08	1.63	2.11	1.16	7.32
K2O	2.60	.47	5.38	4.68	2.13	2.44	2.55	4.03	3.62	4.31	7.46	.11
P2O5	.11	.05	.04	.05	.31	.07	.33	.11	.17	.15	.22	.42
C.	.02	0.00	.01	0.00	.10	.22	.20	.51	1.20	.37	.05	0.00
CO2	2.19	.60	2.10	.90	2.19	4.39	5.30	3.66	8.05	4.51	2.30	1.46
BaO	.02	.01	.05	.08	.10	.04	.16	.07	.11	.13	.09	.01
SrO	.01	.01	-	.02	.08	.01	.06	.02	.03	.04	.04	.04
ZrO2	.03	.02	.05	.02	.02	.02	.02	.02	.03	.03	.03	.02
S	.85	.63	.29	.05	.04	0.00	.01	0.00	0.00	.02	.01	.14
F	.04	.01	.06	.01	.04	.03	.04	.06	.04	.08	.15	.10
H2O+	.40	.11	.53	.17	1.83	.80	1.41	.50	.60	.61	.84	.90
Total	98.15	98.81	99.10	98.22	98.96	99.19	99.89	99.37	100.03	99.86	101.03	99.43
(Minor)												
(ppm)												
Cr	4	0	0	0	7	2	7	27	7	0	31	44
Cu	28	51	11	11	40	11	41	8	4	4	4	259
Ni	10	4	4	4	20	5	30	15	4	4	26	42
Pb	341	311	135	119	1	11	8	8	23	21	22	16
Zn	436	458	128	48	60	29	54	53	40	49	44	124
V	26	4	10	4	214	55	241	93	20	16	55	110
Co	8	30	13	6	31	8	32	13	6	5	17	24
Mo	0	4	0	0	0	0	0	0	0	0	0	0
Ag	4	4	4	4	12	4	12	4	4	4	4	4
Cd	11	7	5	1	2	0	3	0	1	1	0	5
Be	0	0	0	0	9	0	2	1	0	0	1	1
Appendix												
(ppm)												
Sr	188	142	27	184	899	173	579	258	344	429	412	475
Zr	69	89	72	47	80	47	82	59	36	59	73	45
(wt%)												
LOI	3.49	1.35	2.96	1.14	4.24	5.47	6.98	4.69	9.82	5.58	3.24	2.57

Rock name: Serial No. 17. Intrusive dacite; 18. Autoclastic dacite; 19. Lapilli tuff; 20. Welded tuff; 21. Lapilli tuff; 22. Andesitic tuff; 23. Basaltic tuff; 24–25. Reddish mudstone; 26. Fine-grained sandstone; 27. Reddish siltstone; 28. Tuff breccia (see also the appendix for the details).

Table 2 Continued

Serial	29	30	31	32	33	34	35	36	37	38
No.	08-10	08-11	08-12	08-14	08-15	08-16	08-18	08-21	08-22	08-23
Code	CZWBMS.FW.	CZWBMS.FW.	CZWBMS.FW.	CZWBAP.FW.	CZWBSS.FW.	CZWBCG.FW.	CZWBQP.FW.	CZWBWT.FW.	CZWBDB.FW.	CZWBDC.FW.
(wt%)										
SiO2	62.52	57.73	59.95	45.60	65.69	74.66	74.57	66.82	43.84	62.27
TiO2	.82	.99	1.08	1.78	.47	.14	.19	.48	2.00	.66
Al2O3	16.15	17.07	16.34	17.95	15.69	12.31	11.96	15.92	15.74	14.96
Fe2O3	6.00	6.59	7.05	9.01	3.62	.69	.66	1.78	9.52	2.42
FeO	.22	.66	.65	3.63	.54	.44	.42	1.32	2.31	1.31
MnO	.10	.12	.26	.15	.09	.07	1.39	.51	.76	1.11
MgO	1.86	1.96	2.48	5.35	1.56	1.32	.22	.78	2.72	1.34
CaO	1.62	1.98	1.23	10.28	1.77	2.82	.86	1.22	15.85	2.88
Na2O	.93	.17	.33	2.24	.19	.25	5.38	5.32	.75	3.81
K2O	5.06	6.57	5.14	1.25	4.79	3.36	1.06	3.42	.74	4.19
P2O5	.25	.44	.19	.55	.03	.01	.06	.15	.96	.27
C.	.04	.12	.10	.01	.24	.15	.01	0.00	0.00	.02
CO2	2.10	1.90	2.61	1.29	2.70	3.05	1.35	.56	2.00	2.22
BaO	.10	.07	.11	.06	.06	.04	.01	.07	.03	.12
SrO	.03	.02	.02	.13	.01	.01	.01	.02	.07	.03
ZrO2	.03	.03	.03	.01	.05	.02	.02	.04	.03	.03
S	.01	0.00	0.00	.04	0.00	.01	.03	.36	0.00	0.00
F	.21	.24	.08	.05	.08	.11	.03	.03	.21	.06
H2O+	1.31	1.68	1.10	.76	1.43	1.29	.57	.60	.99	1.16
Total	99.36	98.34	98.75	100.14	99.01	100.75	98.80	99.41	98.53	98.87
(Minor)										
(ppm)										
Cr	28	42	33	28	23	3	0	2	12	2
Cu	4	4	4	18	4	30	9	10	27	17
Ni	21	46	51	72	37	18	14	28	35	28
Pb	13	22	29	5	13	10	467	72	28	45
Zn	41	44	47	30	35	35	510	131	129	184
V	50	63	59	275	36	11	8	20	253	40
Co	12	15	16	37	8	6	8	6	22	8
Mo	0	0	2	0	0	0	3	3	0	0
Ag	4	4	4	17	4	4	4	8	19	8
Cd	0	1	0	3	1	0	11	3	8	3
Be	0	5	0	8	2	0	0	1	10	1
Appendix										
(ppm)										
Sr	287	270	133	1312	158	179	120	192	686	227
Zr	65	63	26	53	41	32	65	63	34	39
(wt%)										
LOI	3.47	3.76	3.85	2.18	4.44	4.55	2.03	1.52	3.07	3.43

Rock name: Serial Nos. 29–31. Reddish siltstone; 32. Basalt; 33. Granule conglomerate; 34. Pebbly conglomerate; 35. Quartz porphyry; 36. Welded tuff; 37. Diabase dike; 38. Dacite (see also the appendix for the details).

Table 3 Highly-correlated couples of elements selected from Table 2. The correlation ratios score more than 0.9.

CO_2: LOI	0.972	Fe_2O_3*: V	0.930
Pb: Zn	0.959	Total: MgO	0.910
MnO: Cd	0.953	Fe_2O_3*: SiO_2	−0.907
FeO: MgO	0.934	MgO: V	0.900

Number of samples=34
*Fe_2O_3: Total iron as Fe_2O_3

percent. Consequently, the rocks analysed are more or less altered with carbonate minerals, which is consistent with the observation under the optical microscope. The subsequent highest correlated couple is the ratio between lead and zinc which are the representative ore elements of the Wubu deposits. Several samples contain large amount of manganese (5.6% of No. 10, 2.1% of No. 6 and No. 9), which are related to manganocarbonate minerals. MnO content is highly correlated to cadmium content.

In Figures 5-9, the analysed results are shown in various diagrams with the notation of sedimentary (circle) and volcanic (cross) rocks. The volcanic rocks have a wide variation of SiO_2 content; the extremely high and low values may be partly due to hydrothermal alteration. Nevertheless, most of the rocks are plotted along the trend of calc-alkaline rock series with slightly high K_2O contents (Fig. 5). Low contents of FeO in the same diagram may be caused by the original oxidized character (magnetite series) and also by oxidation during the later alteration. Silica content of the sedimentary rocks are intermediate against the wide and bimodal variation in the volcanic rocks. This also indicates that the sedimentary rocks are volcaniclastics derived from nearby volcanic rocks.

Plots of the sedimentary rock in the Harker's diagram (Fig. 5) are more or less similar to those of the volcanic rocks. However, the sedimentary rocks are generally depleted in Na_2O, CaO and FeO. This indicates that the plagioclase has been decomposed and mafic silicates have been oxidized in these rocks through the original sedimentation processes and/or hydrothermal alteration during the mineralization. A few analyses with high K_2O contents are due to sericite contained in these rocks, which is consistent with the microscopic observation.

Among minor elements, those related to mafic major components (V, Cr, Co and Ni) are negatively correlated with SiO_2 content, except for zinc. The trace amount of lead and zinc are extremely high in some of the high silica rocks (Fig. 6), which may be suggestive for genetic link between rhyolitic rocks and lead-zinc mineralization.

Lead substitutes generally potassium in K-feldspar in rock-forming minerals, and Pb-K_2O relationship is shown in Figure 7. No correlation is observed in the rocks with a low range of lead (say below 100 ppm). Higher values than 100 ppm is definitely related to mineralization effect in referring to lead content in common unaltered volcanic rocks.

Figure 8 shows the correlation diagram between sulfur and other minor elements. Although the data scatter in a wide range, sulfur is positively correlated with lead and zinc, indicating these components often form sulfides, which are also observed under the optical microscope. In the low sulfur area, strontium and barium contents are relatively high, which may suggest the rare presence of sulfate sulfur. One sample having high contents of sulfur, lead, zinc and barium (No. 8) appears to contain both sulfate and sulfide species.

In order to delete the effect of carbonate alteration, the contents of some minor elements are plotted against ($CaO+MgO-CO_2$) (Figs. 9 and 10). With this calculation, strontium which is known to replace Ca position in plagioclase and other Ca-bearing silicates increases the correlation factors with CaO, ($CaO-CO_2$) and ($CaO+MgO-CO_2$) as 0.716, 0.8023 and 0.8677, respectively. Lead and zinc are strongly concentrated in the rocks with low content

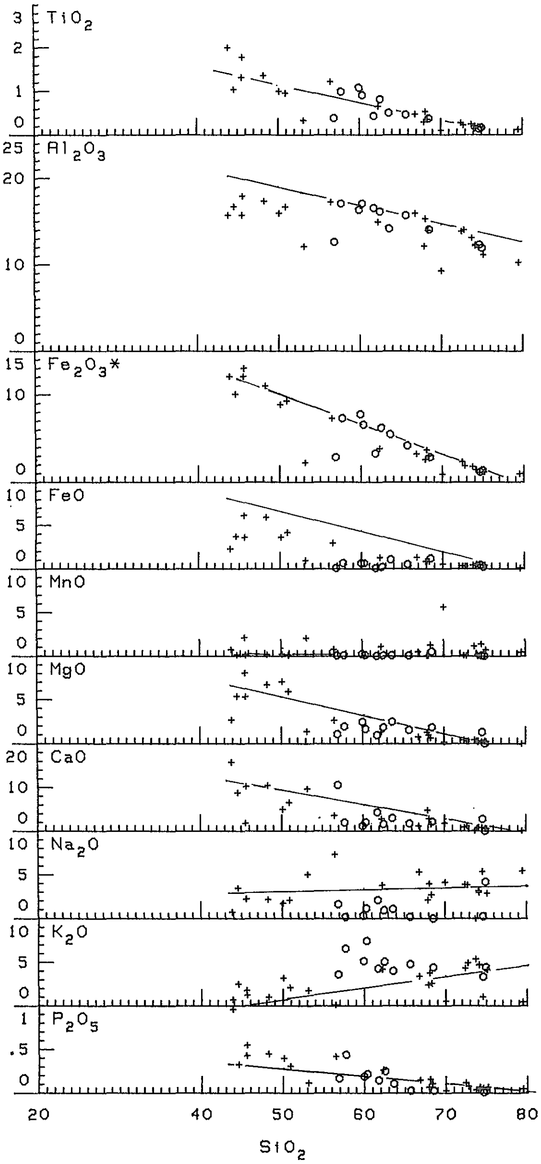

Fig. 5 Harker diagram for the major bulk rock chemical compositions. ○: clastic sediments, +: volcanics. Data are given in weight per cent. Note Fe_2O_3* is the total iron analysed by ICP method. Straight line is the average Japanese granitoids consisting of an equal amount of magnetite-series and ilmenite-series granitoids (ISHIHARA *et al.*, unpublished data).

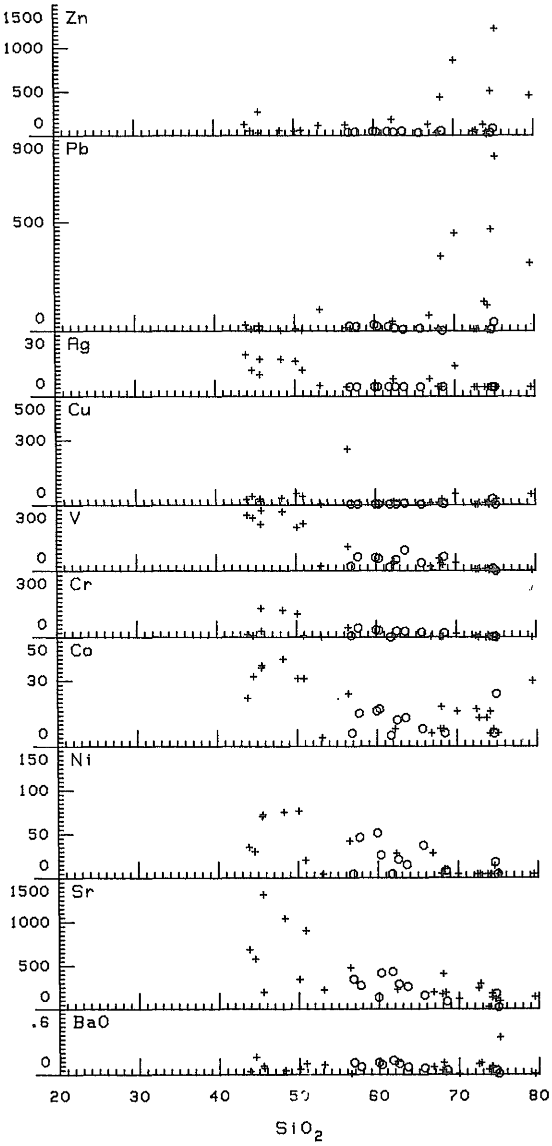

Fig. 6 Harker diagram for the minor bulk rock chemical compositions. ○: volcanics, +: clastic sediments. Silica is in weight per cent. Other values are given in ppm.

of ($CaO+MgO-CO_2$). Silver content with the carbonate-subtracted index gives quite different patterns from the lead and zinc contents. Cobalt, chromium, nickel and vanadium show the same feature as silver against the index and also against silica (Figs. 6 and 10).

Mode of Occurrence of the Wubu Deposit

The Wubu deposit occurs just in the Wubu

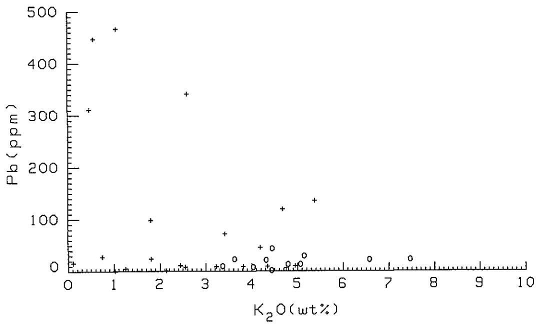

Fig. 7 Cross plot of K_2O(%) and Pb (ppm) content. ○: clastic sediments, +: volcanics.

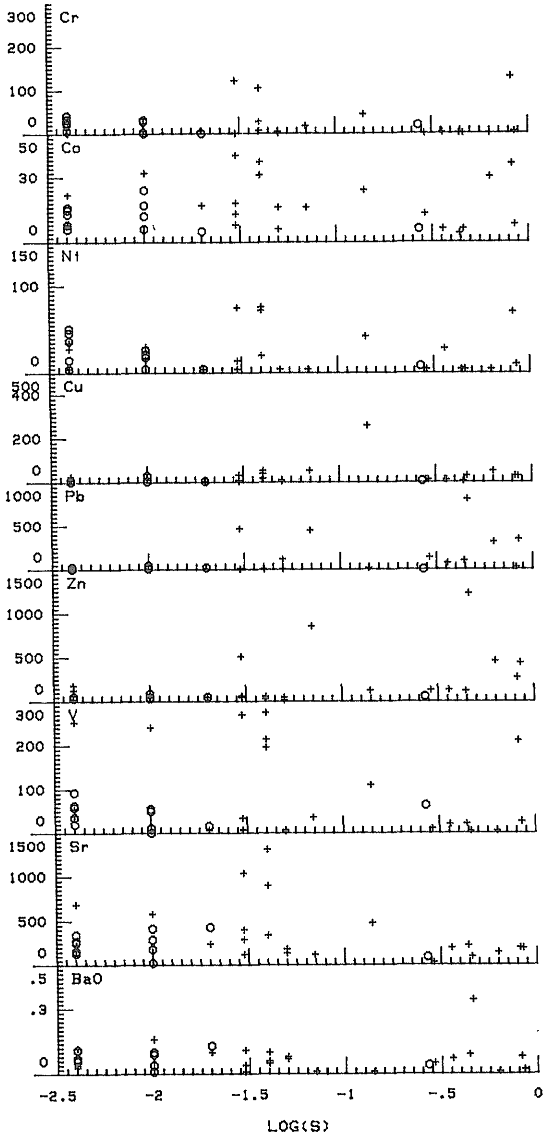

Fig. 8 Cross plots of sulfur (logarithmic of weight per cent) and minor elements (ppm). ○: volcanics, +: clastic sediments.

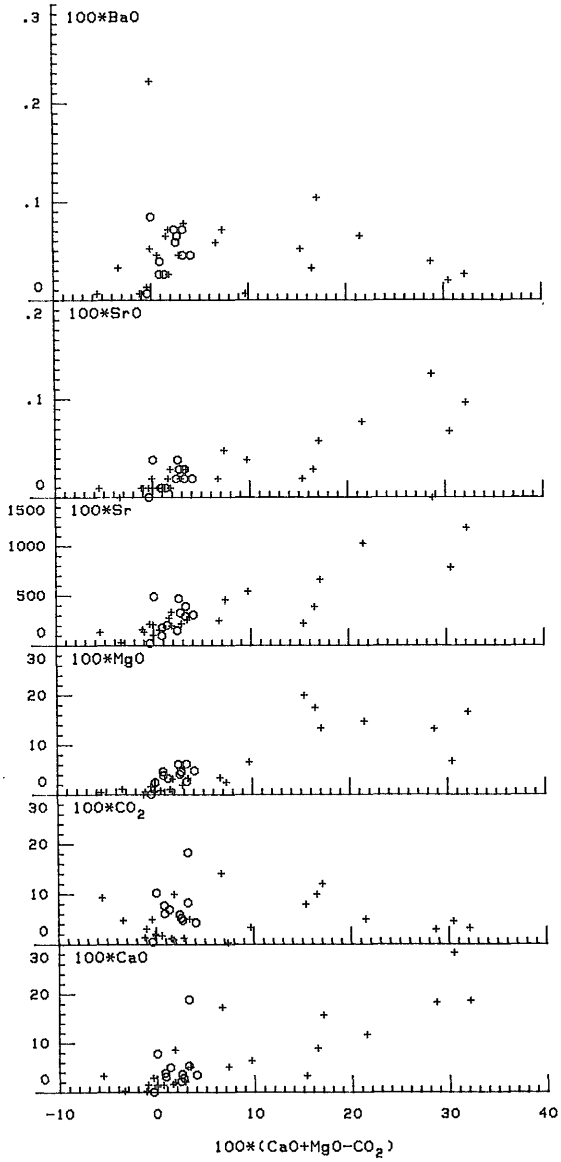

Fig. 9 Cross plots of ($CaO+MgO-CO_2$) and some elements (molecular ratio). ○: volcanics, +: clastic sediments.

fault zone which is not only the boundary between Jurassic and Cretaceous, but also a part of the peripheral ring fracture of the Wubu volcanic depression. The mineralization area, however, disperses into both the footwall Jurassic volcanics and hanging wall Cretaceous volcanics with clastic sediments. This widely distributed mineralization area does not contain a high grade content of metals.

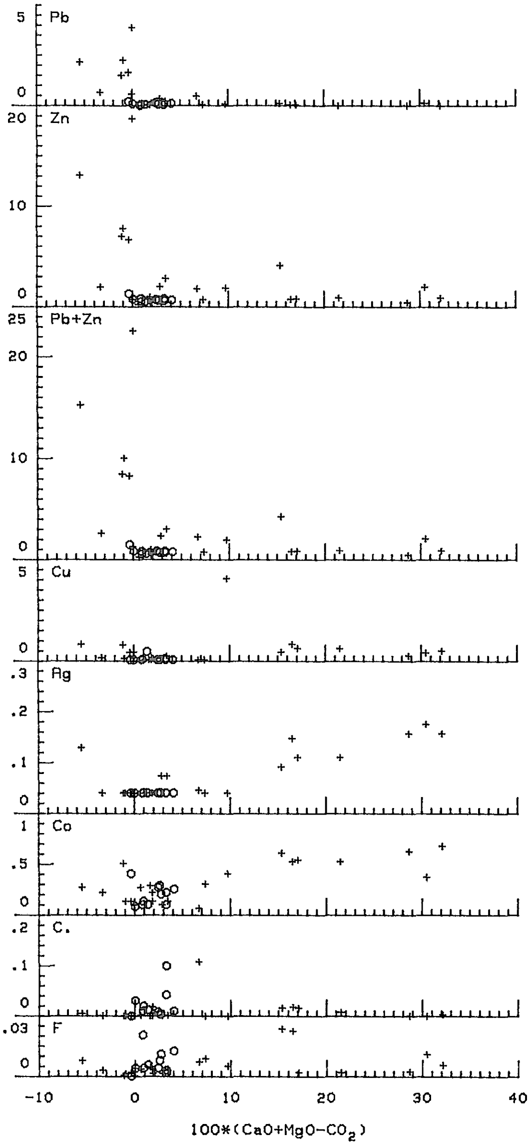

Fig. 10 Cross plots of ($CaO+MgO-CO_2$) and metal elements, carbon (C), and fluorine (F) (molecular weight ratio). ○: volcanics, +: clastic sediments.

The extent of the low grade mineralization area is in the direction normal to the fault for about 3 to 4 kilometers in width.

The shape of ore zone in the Wubu fault is very similar to the shape of stratabound or stratiform ore deposits partly because the fault zone forms just the boundary between Jurassic and Cretaceous rocks. Thickness of the ore zone ranges up to 20 meters. The occurrence of ore is divided into several modes as vein, network vein, massive and compact, disseminated, banded, and brecciated ores within the ore zone vertically in ascending order. The structure or arrangement of ores is peculiarly asymmetric, not symmetrically zonal as the common veins show. The veins and network veins continue into the footwall to the distance of more than 200 meters. In the hanging wall, however, there are scarce of lead-zinc veins nor veinlets. Carbonate veins and disseminations are abundant in both the footwall and the hanging wall as well as in the ore body.

There are six minable ore bodies in the ore zone along the Wubu fault, among which the largest in size is called number 1 ore body. The ore bodies are generally arranged along north-northwest strike and steeply dip to west-southwest direction. The ore bodies are stratiform or lenticular in shape; they pinch out or swell up irregularly along the fault zone (Fig. 11). The size of each ore body ranges from several hundred meters to two thousand meters in length. The thickness ranges from one to 30 meters but 4 to 10 meters in their averages. The depth from the ground surface to the bottom of ore is about 850 meters in maximum and 400 meters in common along the dip-plane. The ore bodies sharply cut the footwall rocks but gently do the hanging wall rocks.

Sulfide minerals of sphalerite, galena, chalcopyrite, and pyrite replace the silicate phenocrysts of volcanics, clastic fragments and fossils in the sediments. Magnetite, hematite, and goethite also replace the larger crystals in altered rocks. Each ore mineral is described as follows.

Sphalerite

Sphalerites in the low grade lead-zinc area appear in the form of fine-grained crystals. They show transparent or opaque in color under the optical microscope. Some grains of sphalerite contain much amount of very fine-

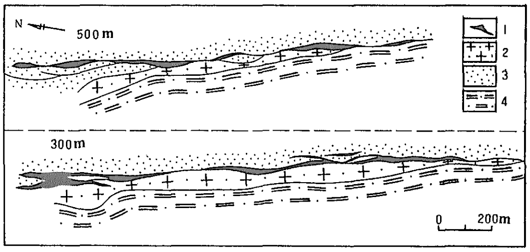

Fig. 11 Schematic map of number 1 ore body (after Zhejiang Geol. Prospecting Team No.5, 1983: unpublished). Plan of 500 and 300 meters levels; 1: ore body, 2: quartz porphyry, 3: welded tuff, 4: tuff, sediments, and basic lava.

grained crystals of chalcopyrite bleb (or chalcopyrite "desease" by BARTON Jr., 1978). Some blebs of chalcopyrite in sphalerite are more than 10 micrometers in diameter, but most of them are less than 2 micrometers in diameter. The bleb-concentrated part in sphalerite displays the dark bluish to blackish in color under the transmitted optical microscope. Sphalerite which occurs in the massive or brecciated ores show a very good transparency with very few chalcopyrite blebs. Each grain of sphalerite is separated or neighboured together.

Sphalerite in the veins includes much amount of chalcopyrite blebs in the grain rim or cracked boundary, but not so much in the interior. Chalcopyrite blebs are larger in size in the interior of sphalerite grain than in the rim. Fibrous twinned texture is observed in the sphalerite grains, which have chalcopyrite blebs, chalcopyrite bleb-free zone, or optical anomaly detected by the internal reflection with the crossed Nicol under transmitted light. Sphalerite replacing silicate phenocrysts sometimes shows the relict of the replaced minerals which are quartz, feldspar, and hornblende in many cases. This sphalerite is often accompanied by pyrite and carbonate which may have formed slightly earlier than the sphalerite.

The iron content of sphalerite was reported as low as several per cent (HUANG *et al.*, 1983) which is reconfirmed by the present study. The reported decrepitation and filling temperatures of fluid inclusions ranged 170 to 181°C in the averages. The sulfur isotope ratios ranged +1.5 to +4.5 per mil in delta values of ^{34}S (HUANG *et al.*, 1983).

Galena

Galena occurs mostly with sphalerite in the ore zone. The occurrence of galena in the country rocks is more frequently found in veinlets in the footwall than in the hanging wall where the mineral occurs commonly replacing phenocrysts. One such example of galena veins hosted in the middle part of the footwall welded tuff was taken by the drill hole, ZK46. Larger crystals of galena is common in the massive and brecciated ores in the ore zone.

Galena in the veins frequently fills the cracks of sphalerite, chalcopyrite, and pyrite. It also cuts the larger crystals of chlorite in some cases, but is in turn cut by the radial needle-like aggregate of chlorite.

Delta values of ^{34}S of galena were measured to range from −3.3 to +2.1 per mil. The sulfur isotope fractionation between sphalerite and galena give the isotopic formation temperature of 127 to 301°C (HUANG *et al.*, 1983). The decrepitation temperatures of fluid inclusions in galena range from 162 to 290°C and the average is 207°C (HUANG *et al.*, 1983).

Chalcopyrite

The mode of occurrence of chalcopyrite is divided into two main types. One is the chalcopyrite blebs mentioned before, while the other is automorphic and allotriomorphic crystals occurring in the replaced phenocryst, vein, and other lead-zinc ores. The first type is usually present in the sphalerite grains, especially of finer-grained crystals. The blebs are also present in and around the crack in sphalerite, which is already filled by secondary sphalerite overgrowth and chalcopyrite blebs of possibly an earlier stage. Multiple striations of rows of blebs are occasionally seen from the rim to the core. The form of such rows show a radial or paralle manner in a sphalerite grain (Plates 1 and 2).

The second type mainly occurs in the high-grade ore body, while it is few in the low-grade and wide-spread mineralization area. Some chalcopyrites of the second type are cut by sphalerite. Others with galena fill the crack of sphalerite.

Pyrite

Pyrite is a common mineral in the mineralization area. Most of the pyrite grains are in the form of automorphic in the ore zone, while it occurs in irregular shape replacing phenocrysts and fossils of the host rocks in the low-grade and wide-spread mineralized zone. Automorphic crystals of pyrite are frequently covered by a thin layer of sericite film on the part of outer surface of pyrite. Pyrite occasionally includes small grains of sphalerite or chalcopyrite. It is common that a part of pyrite crystals is replaced by other sulfide minerals. The decrepitation temperatures of fluid inclusions ranged from 138 to 212°C with the average of 186°C (HUANG *et al.*, 1983).

Others

There are very few occurrences of argentite and barite. The occurrence of several silver minerals was reported by ZHENG and XIE (1984). Carbonate minerals of calcite, dolomite, and rhodochrosite are very common in the groundmass, phenocrysts, and fragments, as well as in the fractures of the host rocks. Alteration products of sericite, chlorite, and quartz are seen in the groundmass of the host volcanic rocks. It is characteristic that the clay minerals of chlorite and sericite grow often to large crystals, more than 50 micrometers in diameter, which appear in and around the ore body.

Discussions

Host Rocks

The volcanic rock types do not largely change between the footwall Jurassic and hanging wall Cretaceous rocks as being suggested by the bulk rock chemical compositions though the rocks are more or less altered. Alkali-silica plots of the least altered rocks, though not shown here, indicate that most of them fall in the field of calc-alkaline series, though some do in the edge region of alkaline series. Altered one like No.23 (Table 2) falls as if in the field of alkaline basalt. There occur also extremely sodic rocks such as Nos. 9, 18, 28, and 36 in the studied area. Microscopic observations indicate that many albite phenocrysts are clastic origin so that the high sodium content is original for the rocks of the studied area. The cross plot of the values of lead and potassium content shows no correlation (Fig. 7), which supports the presence of sulfide mineralization in them.

Clastic sediments are more or less tuffaceous because they are frequently alternated by tuff and because they contain altered relict of glass. Their clastic fragments of plagioclase, K-feldspar, and hornblende are considered to be originated from the volcanic rocks in this area. Clastic sediments also contain a certain amount of carbonate which shows clastic origin or veinlets. The higher amount of Fe_2O_3 in the fresh and clastic sedimentary rocks indicates that they were originally in the oxidized condition. Microscopic observation also indicates the presence of large amount of hematite which suggests the oxidized state under terestrial condition.

Wide-Spread but Low-Grade Mineralization

Suppose the ore vein were eroded on the subaerial surface after the Cretaceous age, a certain record may persist within terrestrial sediments, such as placers of clastic sulfide, oxidized sulfide, sulfate, gold, or silver. Such a record has never been discovered around the Wubu depression and in the Quaternary area. Tertiary sediments are, indeed, very scarce in this region. The sulfides in the Cretaceous sediments should be brought about by the movement of metal-bearing fluid in the underground not by the reworked sedimentary process. An example is the relict feature of fossils replaced by pyrite and sphalerite.

HUANG *et al.* (1983) supposed that the low lead-zinc content less than 100 ppm was brought about by the leaching of metals from silicates by circulating hydrothermal solutions. The high lead-zinc content of rocks far from the leaching zone and ore zone was considered that it was an incomplete result of leaching.

Rocks of the hanging wall include sulfide minerals. Sulfate minerals are scarce in them. The lead and zinc contents of the rocks are high in value when the samples contain a certain amount of sulfide minerals. Sulfide sulfur is more or less correlated with lead, zinc, and cadmium. The lead-zinc contents of some rocks are, however, less than 100 ppm in the sites very close to the ore body or within ore body itself. This is the unmineralized zone left in the ore zone. The sulfide sulfur is also low values at this place. There is a small amount of sulfide minerals, too. Some other rocks take low values of less than 100 ppm of lead-zinc content in the bulk rock chemical compositions though they are far from ore body. The higher lead-zinc contents of rocks near the ore body is caused by sulfide mineralization.

The type of the mineralization is fissure-filling. The replacemental type is accompanied by the fissure-filling one so that there remain unmineralized zone where the solution can not reach nor react. The high content of lead-zinc of the rocks occurring far from the ore body does not indicate the residue of a leaching process of silicates but suggests a weak sulfide mineralization.

Stages of Main Mineralization

There are some stages of metal sulfide mineralization in the Wubu deposit. The sequence of mineralization stages is summarized in the Figure 12. Before the mineralization, the minerals of the original rocks in the ore zone is replaced by silica, chlorite, sericite and carbonate minerals. Different rocks show different mode of alteration. The dikes of quartz porphyry and diabase are slightly less altered than welded tuff and felsic volcanics. The latters are most altered rocks along the Wubu fault zone. This may be caused by the difference of fluid movement through the different porous systems, or by the different age of intrusion during the alteration and mineralization.

A scenario of the main mineralization is described as follows. The first stage of sulfide mineralization is characterized by pyrite with less amount of chalcopyrite. The second stage is represented by sphalerite with galena replacing the pre-existing minerals and filling fissures. The third is the stage of the formation of chalcopyrite blebs in sphalerite. A copper-bearing fluid may easily combine the iron of sphalerite to form chalcopyrite (BARTON Jr., 1978). It may explain the low content of iron in sphalerite. The occurrence of the chalcopyrite blebs in this Wubu vein type deposits is similar to the case of Japanese kuroko deposits though the kuroko deposits consist of bedded sedimentary and networked vein type ores. Mineralization of galena occurs in fourth stage with subsequent mineralization of copper and zinc. Carbonate and silica appear again after the fourth stage. Clay minerals, especially iron chlorite appear also after the sulfide stages and enclose the needle-like small grains of hematite and goethite in them. Silver may deposited during the final stage. The behavior of silver is different from that of lead and zinc (Figs. 6 and 10). We do not have chemical relations that precipitated silver with lead and zinc concurrently in the sulfidic environment. It is suggested that their mineralizations took place in different stages.

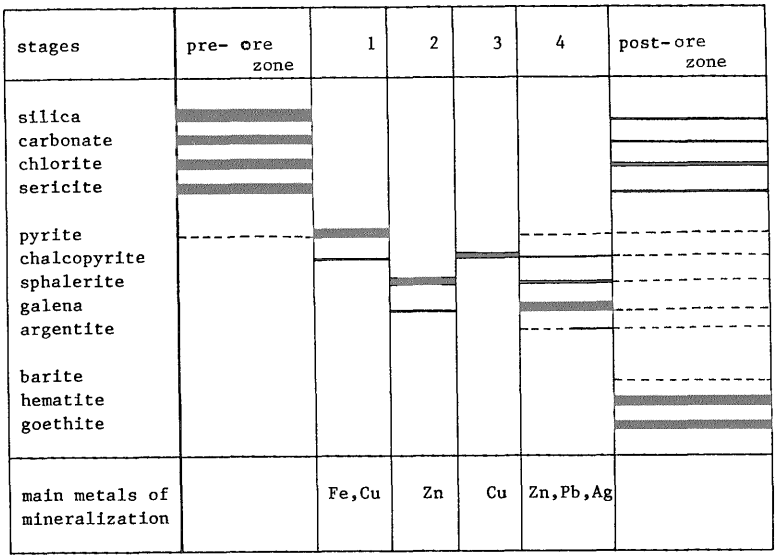

Fig. 12 Mineralization sequence of the ore zone.

The area of the silver mineralizations may have shifted from the area of the other sulfide mineralizations.

Most of the temperatures of sulfide formation was reported around 200°C regardless of the difference of minerals. This suggests that the type of mineralization for each stage is due to the changing chemical composition or partial pressure of fluid, not by the temperature difference. The metal-bearing fluids may alter the silicate minerals significantly because of the existence of gigantism of clay crystals in the ore zone and of the presence of replacement by clay minerals during sulfide stages. Consequently, the secondary porosity occurs by dissolution and extincts around the time of the mineralization, which changes the tendency of the movement of fluid in the porous system.

Fluid Movement after the Main Mineralization Stages

The immersing fluid in the ore zone can remain after the sulfide stages. At this time, the oxygen fugacity rose up, because of the presence of oxide minerals like hematite and goethite. Such preserving fluid can dissolve the sulfide minerals again. If it occurs, the oxygen fugacity of fluid decrease again and the solution contains a little bit higher amount of metal ions. The gigantism of clay minerals excludes or drainages the metal-bearing solutions into more porous part. Moreover, there occurs intrusive activity after the mineralization which supplies heat energy to remove the solution away from the ore zone. Where does the solution move with metal ions?

The wide-spread mineralization area is an possible answer. After the time of cauldron depression in the lower Cretaceous age, the sedimentary basin of middle to upper Cretaceous age developed in the collapsed area and a part of the fractured zone along the caldera wall could have been mineralized by metal-bearing fluids to form the present ore zone. During and after the time of sedimentation in the middle to upper Cretaceous age, the metal-bearing fluid moved to wider area apart from the ore zone. The sedimentary rocks of the wider area contain a certain amount of organic matter which can reduce the solution to precipitate sulfide and/or sulfate as the buffer that replaced the phenocrysts and fill the pore spaces. These different processes can explain the difference in occurrence of the mineralization between the footwall and the hanging wall rocks. The sulfide veinlets in the footwall rocks is mostly a product of mineralization of four stages as well. The mineralization of hanging wall rocks gives rise to the concentration of lead and zinc with carbonate after the time of main sulfide mineralization (Fig. 10).

Remaining Problems of the Genesis

We briefly consider the three genetic hypotheses for the Wubu deposit here; sedimentary and/or diagenetic deposition, precipitation from circulated hot water, and magmatic hydrothermal origins.

1) Sedimentary and/or diagenetic deposition;

The mining geologists of the Wubu deposits suggested the possibility of some lead-zinc deposits around the Wubu volcanic depression in the same stratigraphic horizon which may not yet be confirmed. Ores show the asymmetric arrangement. These might indicate that the Wubu deposit is a primarily sedimentary deposit, but not of vein type. If the lead-zinc deposit was originally deposited on the bottom of the water, the deposit is a very rare example of the terrestrial sedimentary sulfide deposits associated with volcanic rocks. The subaqueous volcaniclastic shale and sandstone are the major country rocks of the Wubu deposit as well as the subaerial welded tuff. The mineralization should occur in a subaqueous environment because it must be preserved the reduced environment. The vein feature at present may be formed by the post-sedimentary hydrothermal alteration after the sulfide deposited. However, if the age determination reported by HUANG *et al.* (1983) is true, it is difficult to explain the age of lead which is older than the contemporaneous igneous activity of the Cretaceous age. We consider that the asymmetric structure of ore zone can be constructed by the slip movement of the Wubu fault in the shallow subsurface.

2) Precipitation from Circulated Hot Water;

HUANG *et al.* (1983) indicated that there was a system of water circulation through the Mesozoic volcanic rocks. Circulated water leached metals from the volcanic rocks of Cretaceous age occurring in the area within ca. 2 kilometers in width from the deposit and to precipitate ores in the Wubu fault, so that the lead and zinc contents should decrease in the country rocks by the leaching process. Present study clarifies the wide-spread weak mineralization area which is unlikely in their model. The location of leached zone may be hidden in the underground or eroded out in some where. HUANG *et al.* (1983) also suggested that the lead metals might come from deeper source such as pre-Cretaceous carbonate rocks. In this case, the system of circulated water spreads as wide as, or more than, the size of the whole Wubu volcanic depression centered by a possible heat source of the Banshang quartz monzonite.

The major lead-zinc mineralizations in China are in the mode of stratabound sedimentary or replacemental deposits hosted in dolomite rocks. If we can estimate the deep-seated lead-zinc sedimentary beds or lead-zinc-rich connate water associated with the carbonaceous sediments in the deeper part of the Wubu area, circulated water system can remobilize them to form lead-zinc deposits in the Wubu fault. Around the Mesozoic volcanic field of the south-eastern China, we have several huge lead-zinc deposits in the Paleozoic dolomites like the Fankou deposits. The basement rocks of the pre-Cretaceous age may continue to the Wubu volcanic region. It will be worth while confirming the presence of preceded lead-zinc concentration in basemental sediments in future studies.

3) Hydrothermal origin from magmatic source;

An evidence of deep-seated granitic rocks is found in the breccia dike near the Wubu fault, though the scale of this igneous rock is unknown. Instead of remobilization of metals, the granitic magma can concentrate heavy metals from itself and from the country rocks when it intrudes them. If we have some evaporite zone under the Wubu area, granitic magmatism can easily concentrate heavy metals into the differentiated hydrothermal solution as pointed out by ISHIHARA *et al.* (1986, in this volume). Before the Mesozoic age, there occurred shallow marine environments in the southeastern China which might have formed evaporite deposits in this area.

We do not have clear evidence of the presence of the stratigraphic ore horizon, the deep-seated lead-zinc-bearing sediments, the enough scale of the associated granitic rocks, nor the evaporite. Consequently, we hold a simple hypothesis of the hot water model with the possible heat and materials source of many volcanic or subvolcanic activity during the development of the Wubu cauldron which also supplied many fractures as the possible fluid passage.

Conclusions

1) Clastic sedimentary rocks are mostly of volcanic origin judging from the microscopic occurrence and chemical compositions.
2) The country rocks of the Wubu deposit contain a certain amount of carborate as well as excess silica which are brought in through the mineralization process.
3) The K_2O content of rocks does not correlate with lead content in the bulk rock chemical composition. Lead-zinc content of the country rocks is rather correlated to the content of sulfur, suggesting the presence of the sulfide phases.
4) The country rocks contain silicate phenocrysts replaced by sulfide which clarify the presence of a wide-spread area of sulfide mineralization.
5) The sulfide mineralization in the ore zone can be divided into four stages with different mineral occurrences; (1) pyrite with chalopyrite, (2) sphalerite with galena, (3) chalcopyrite blebs in sphalerite, and (4) galena and sphalerite. Lead and zinc precipitated with carbonate in the main mineralization stages, while silver mineralization took place in a different stage from the main sulfidation stages and may be associated with the nickel, chromium, cobalt, and vanadium.
6) It is suggested that the movements of fluid excluded from the ore zone give rise to the presence of the replacemental sulfide of silicate phenocrysts and other elements with carbonate in the hanging wall.
7) Although the asymmetric structure of ore zone is peculier, we hold the genetic hypothesis of the Wubu deposits is of fissure-filling vein type deposit in the Wubu fault caused by the hot water associated with the cauldron subsidence and its igneous activity.

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References

BARTON Jr., P. B. (1978) Some ore textures involving sphalerite from the Furutobe Mine, Akita prefecture, Japan. *Mining Geol.*, vol. 28, p. 293-300.

BUREAU OF MINES (1980) Minerals facts and problems (1980 edition). *U.S. Department of the*

Interior, Bur. Mines Bull. 671, 1060p.

CHIN, E. (1980) The mineral industry of China. In Bureau of Mines: *Minerals yearbook 1978-79*, vol.4, Area reports: international. U.S. Department of the Interior, Bur. Mines, p. 251-252.

Fuji Journal (1980) *China's mining industries review*. (In Japanese). Fuji Journal Inc., Tokyo.

Geological Survey of Japan ed (1985) Research on Mineral Resources Associated with Volcanic and Plutonic Rocks. *Rept. ITIT Project*, no. 8113, 191p.

GUO, W., LIU, L. and YU, Z. (1982) The foundamental features of metallogenic megaprovince and epochs of eastern China. (In Chinese). *Mineral Deposits* (China), vol. 1, p. 1-14.

HUANG, B., ZHENG, R., YOU, Y., XU, Z., LI, Q., TIAN, D., WANG, Y. and GAO, J. (1983) On geological characteristics and mineralization mechanisms of Wubu Pb-Zn deposits, Zhejiang. (In Chinese). *Bull. Nanjing Institute of Geology and Mineral Resources*, vol. 4, p. 85-104.

ISHIHARA, S., SASAKI, A., SHIBATA, K. TERASHIMA, S. and MATSUHISA, Y. (1986) Characteristics of Cretaceous magmatism and related mineralization of the Lower Yangte area, eastern China. *Bull. Geol. Surv. Japan*, vol. 37, (in press).

LIU, Y. and LU, F. (1983) Genetic classification and time-spatial distribution of lead-zinc deposits in China. (In Chinese). *Bull. Nanjing Institute of Geology and Mineral Resources*, vol. 4, p. 73-83.

LU, Z. (1982) The petrochemistry of Mesozoic volcanic rocks of East China and its geological significance. (Translated to Japanese by SATO, T. and ISHIHARA, S.). *Bull. Geol. Surv. Japan*, vol. 33, p. 409-415.

RUI, X., WU, Y., FENG, Y., WU, H., CHANG, C., QI, J. and CHU, S. (1983) Problems on subaerial volcanic lead-zinc deposits of Mesozoic age in southeast Chine. (In Chinese). *Bull. Nanjing Institute of Geology and Mineral Resources*, vol. 4, p. 45-58.

SHUI, T. (1981) Researches on Mesozoic volcanic structure in Zhejiang Province. (In Chinese). *Scientia Geologica Sinica*, 1981-2, p. 113-120.

YOSHII, M. and SATO, T. (1983) An outline of GEOCAPS, a geochemical data analysis program system in BASIC. *Geol. Data Processing*, no. 8, p. 21-40.

WANG, W. (1983) The relationship between dolomite and stratabound lead-zinc deposits. (In Chinese). *Bull. Nanjing Institute of Geology and Mineral Resources*, vol. 4, p. 59-72.

WANG, Y. (1983) A tentative discussion on types and main characteritics of lead-zinc ore deposits in China. (In Chinese). *Mineral Deposits* (China), vol. 2, p. 21-29.

WU, L., QI, J., WANG, T., ZHANG, X. and XU, Y. (1982) Mesozoic volcanic rocks in the eastern part of China. (In Chinese). *Acta Geologica Sinica*, vol. 56, p. 223-234.

ZHANG, F. (1980) Brief introduction of metal mines in the Peoples Republic of China. A paper presented at 4th Joint Meeting MMIJ-AIME, Tokyo.

ZHENG, R. and XIE, C. (1984) A preliminary study of the distribution of silver in the Wubu Pb-Zn deposit, Zhejiang Province. (In Chinese). *Mineral Deposits* (Chine), vol. 3, p. 19-26.

Appendix List of the analysed samples No.5 - No.38 in Table 2.

Sample No.	Location	Rock type	Description
820906 −2:42	490 mL	Mudstone (HW)	Pale greenish, massive, with quartz and carbonate vein (whitish, larger than 1 mm in width).
−2:43	*do.*	Basalt (HW)	Massive dark greenish, fine-grained with pyrite disseminations.
−2:48	490 mL No. 7	Diabase dike	Dark green-grayish with green patch and fragment of shale. K=10.0-12.0 ($\times 10^{-3}$ SI unit).
−3:01	*do.*	Quartz porphyry (FW)	Pinkish, with less than 5 mm in diameter of quartz and feldspar phenocryst.
−3:15	*do.*	Lapilli tuff (FW) with basaltic fragments	Whitish clayey feldspar, banded glass, quartz, chlorite and pyrite patch.
−4:26	*do.*	Quartz porphyry (HW)	Pink and green siliceous rock with less than 1 mm in diameter of pyrite and quartz.
820907 −2:34	Surface near the Mining office	Tuff breccia (FW)	Blackish, with white plagioclase, pink, yellow, green epidote, black shale, reddish quartz fragment.
−3:00	Surface	Fragments in breccia dike (FW)	Mega K-feldspar-(larger than 3 cm in diameter), chlorite-bearing quartz porphyry.
−3:45	*do.*	Diabase "lava" (FW)	Massive, finer-grained, less altered, lava (?).
−4:14	*do.*	Tuff breccia (HW)	Siliceous tuff with reddish fragments larger than 2 cm in diameter.
−4:30	*do.*	Welded tuff (HW)	Blackish compact, with 1-2 mm in diameter of plagioclase phenocrysts
820907 −4:51	Surface	Felsite dike (HW)	Pinky gray, with 1-5 mm pinkish elipsoidal and lath feldspar.
−9:10	490 mL No. 8	Dacite intrusion (HW)	Light-grayish, massive compact with quartz phenocryst and quartz or chlorite vein.
−9:23	*do.*	Dacite autoclastite	Pinkish, silicified, with larger than 1 cm in diameter of mega-quartz crystals and (pyrite)-quartz veins.
−10:20	*do.*	Lapilli tuff (HW)	Whitish patch larger than 3 mm in diameter in pale grayish siliceous matrix with sericite and pyrite.
−10:39	490 mL No. 13	"welded tuff" (FW)	Hard and compact, massive, lapilli tuff (silicified) with quartz phenocrysts larger than 5 mm in diameter (pink, transparent).
820908-1	Dill Hole: ZK46 3 m	Lapilli tuff (HW) (tuff breccia)	Pale greenish, andesitic.
-2	ZK46 7.8 m	Andesitic tuff breccia (HW)	Andesitic, with greenish subangular fragments, reddish brown siliceous fragments.
-3	ZK46 29.2 m	Basaltic tuff (HW)	Dark greenish, with subangular fragments of basaltic breccia.
-4	ZK46 52.4 m	Reddish mudstone (HW)	Massive compact fine-grained.
-5	ZK46 55 m	Reddish mudstone (HW)	Laminated with large quartz fragment.
-6	ZK46 56.45 m	Sandstone (HW)	Finer-grained.
-8	ZK46 98.5 m	Reddish siltstone (HW)	Massive compact.
820908-9	ZK46 105 m	Tuff breccia (HW)	Basaltic fragment (pale greenish) with pale reddish quartz porphyritic fragment, matrix filled by epidote and quartz.
-10	ZK46 112 m	Reddish siltstone (FW)	Massive compact.
-11	ZK46 122.5 m	Raddish siltstone (FW)	*do.*
-12	ZK46 138 m	Reddish siltstone (FW)	*do.* just above the mineralization zone.
-14	ZK46 161.3 m	Basalt (FW)	Dark grayish, massive, fine-grained and compact with thin quartz vein.

Appendix (Continued)

Sample No.	Location	Rock type	Description
-15	ZK46 217 m	Granule conglomerate (FW)	Gray-greenish at the bottom of sandstone.
-16	ZK46 218 m	Conglomerate (FW)	Pale greenish siliceous, pebbly conglomerate.
-18	XK46 282 m	Quartz porphyry (FW)	Like as "autoclastite".
-21	ZK46 375.1 m	Welded tuff (FW)	Dark grayish, with hematite veinlets.
-22	ZK46 386.2 m	Diabase dike (FW)	Massive blackish green, finergrained with spotty alteration of epidote.
-23	ZK46 404.6 m	Dacite (FW)	Strongly silicified, dark-gray and pale-gray with dark green patch.

五部鉱床，中国における代表的火山性鉛・亜鉛鉱化作用

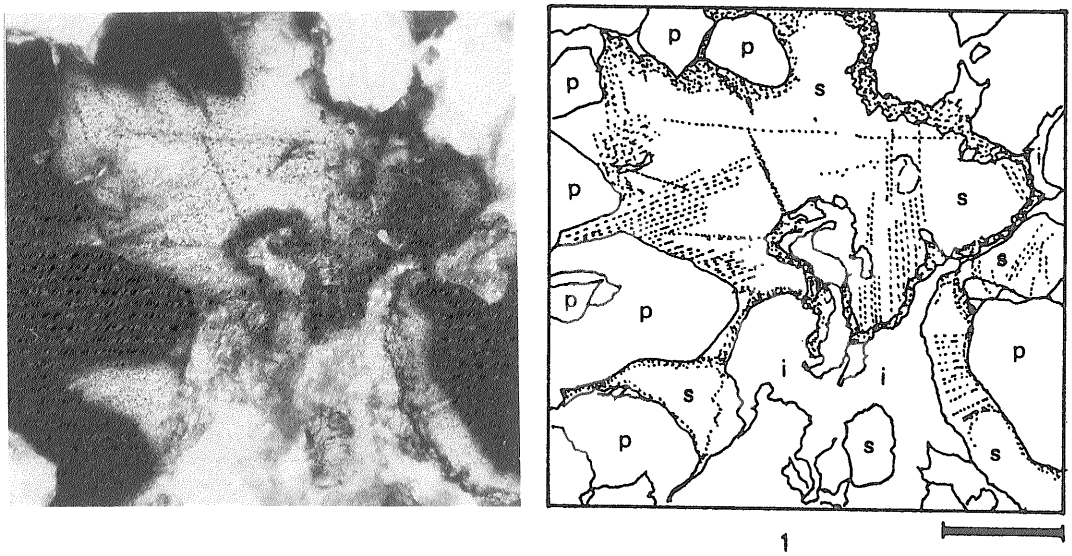
古宇田亮一・倪　若水

要　旨

中国の鉛・亜鉛鉱床は主な母岩によって5つの主要な型に分けられる。それは，規模の大きな順に，堆積岩型，深成岩型，火山岩型，変成岩型，第四紀堆積物型である．五部鉱床は，中国南部の沿岸火山岩域に位置する代表的な火山性鉛・亜鉛鉱床である．五部鉱床は五部断層の一部に存在し，五部火山性陥没構造の北東端に位置する．鉱床の上盤は下部白亜系に属し，下盤は上部ジュラ系に属する．上盤の岩石は，主に熔結凝灰岩，赤色砂岩・シルト岩，凝灰角礫岩からなる．下盤の岩石は，珪長質熔岩，凝灰岩，火山角礫岩，熔結凝灰岩及び砕屑岩からなる．これらから代表的岩石試料の全岩化学分析を実施した．

鉱床は裂か充塡熱水性，鉱石は，黄銅鉱粒を含む閃亜鉛鉱，方鉛鉱，黄銅鉱，黄鉄鉱，重晶石，及び少量の含銀鉱物からなる．炭酸塩鉱物も多量に含まれる．主要変質鉱物は絹雲母と緑泥石であり珪酸塩斑晶や石基を交代し，ほかに針鉄鉱，炭酸塩鉱物，及び硫化鉱物も認められる．銀は，鉱床生成の後期に炭酸塩変質とは逆に相関して濃集したと考えられる．硫化鉱物は狭小な鉱床帯の中だけではなく，五部断層に沿う長さ 10 km の鉱床帯を中心に，幅 2 km 程度の地域に広がって存在している．この弱鉱化帯を検出することは，この型に属する他の鉱床の探査にも役立つと考えられる．

（受付：1985年10月23日；受理：1986年4月8日）



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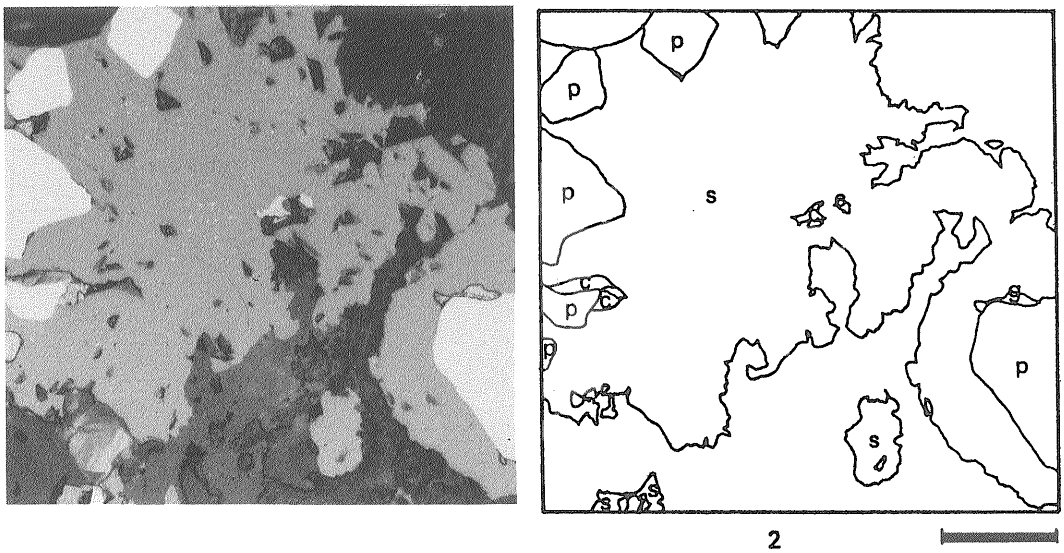
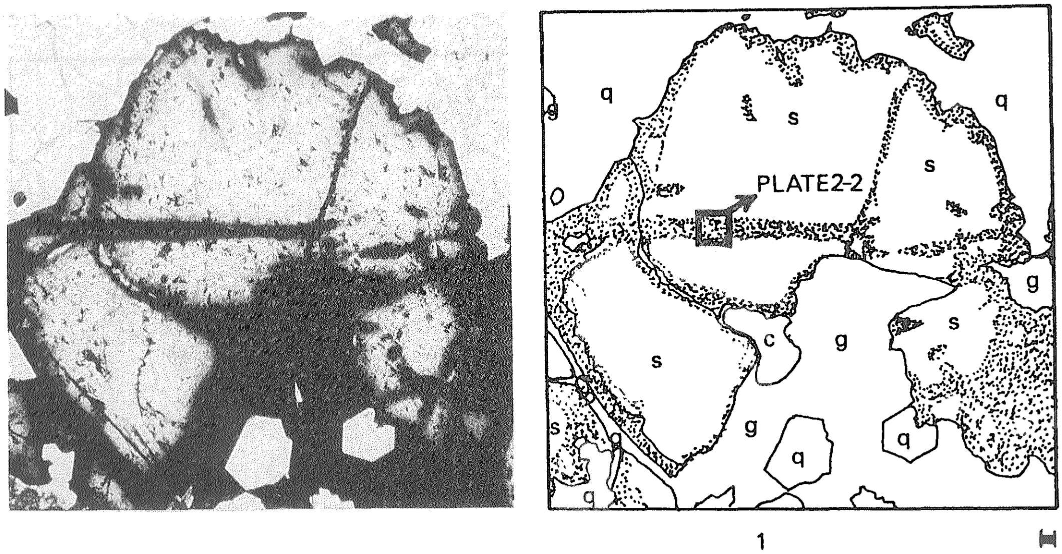
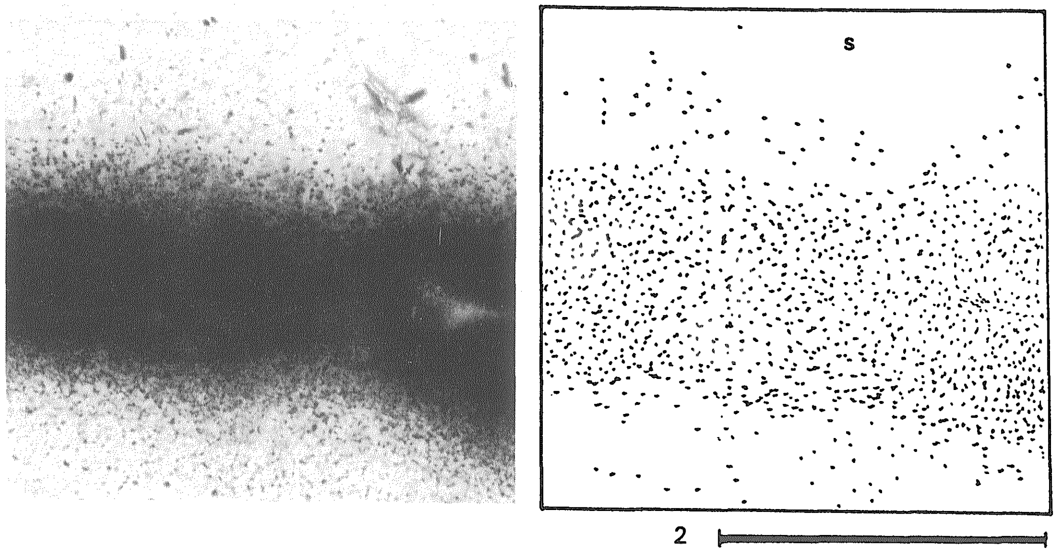


2

Sphalerite overgrowth on pyrite (lower left side in the plates) and striations of chalcopyrite blebs in sphalerite. Sample 820906-3: 52 from small veinlet of the ore zone. 1: open nicol, 2: reflected light, bar: 50 micronmeters, s: sphalerite, c: chalcopyrite, p: pyrite, g: galena, i: sericite, dots: blebs of chalcopyrite.





Chalcopyrite blebs dope sphalerite. Sample 820907-10: 15 from vein part of the ore zone. 1: open nicol, 2: enlargement of 1, bar: 50 micronmeters, s: sphalerite, c: chalcopyrite, g: galena, q: quartz, dots: blebs of chalcopyrite. Note chalcopyrite blebs occur along the internal crack of sphalerite which is filled by the overgrowth itself and the blebs.