Tecto–geochemical Features of Malage Ore Field, Gejiu Mining Area

SUN JIACONG(孙家骢), JIANG ZHUWEI(江祝伟) AND LEI YUESHI(雷跃时)
(Department of Geology, Kunming Institute of Technology)

Abstract

This paper deals with *R*–mode cluster analysis for more than 6000 analytical data from the samples of tectonite and mineralized rocks using the method of multivariate statistical analysis on the basis of division of the tectonic fault systems in the Malage Ore Field and *R*–mode factor analysis for the analytical data from tectonite samples collected along various directions of the faults according to fourteen variables related to the mineralizing elements which are selected in terms of *R*–mode cluster analysis from the chemical composition of tectonites. Thus the distribution characteristics of primary halo anomalies have been revealed with respect to the metallogenetic elements Sn, Cu, and Pb, Zn. The tecto–geochemical features are shown by the primary halo anomalies, thus providing the theoretical basis for metallogenetic forecast in the ore field.

The Malage Ore Field, one of the four major ore fields in the area, is located in the northern part of East Gejiu Mining District. Extensive and thoroughgoing studies were made by many authors of the geology, ore–forming mechanism and material source of this magnificent deposit and a detailed review of the previous results has been given in a recent report by the Southwest Geological Exploration Corporation, Ministry of Metallurgical Industry (1984)[1]. In this paper some characteristics of primary halo distribution are revealed from tecto–geochemical studies by using multiple factor statistics, providing the theoretical basis for mineral exploration in this area.

Classification and Evolution of Fault Tectonic Systems in the Ore Field

The structural features of various types, directions and magnitudes can be noticed in the Malage Ore Field (Fig. 1), and all of these features are characterized by multiple phases of activity[1)].

(1) Folds The Malage–Songshujiao anticline constitutes a first–order structure in the ore field. As indicated by the two types of scratch and cleavage on and between beddings, it is a composite fold system consisting of EW–striking compressive folds developed in the early stage and compressive–shear folds which are superimposed on its north limb. The late compresso–shear folds provide a favorable structure for mineralization.

1) Sun Jiacong et al. (1985), Ore–controlling characteristics of the tectonic system and metallogenetic forecast in the Malage Ore Field, Gejiu Tin–polymetallic Mining Area.

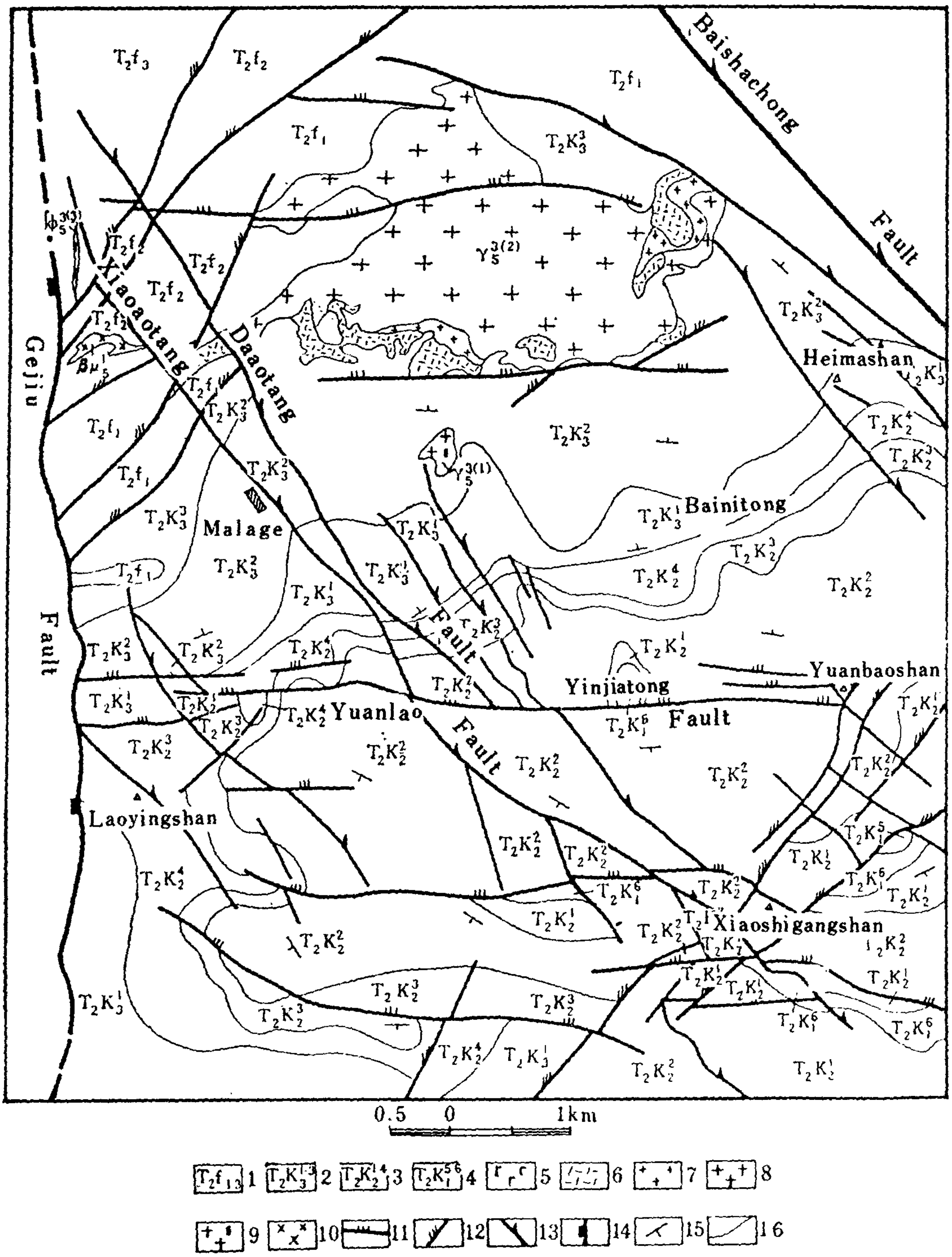

Fig. 1. Tectonic map of the Malage Ore Field.

1. Members 1—3 of the Middle Triassic Falang Formation; 2. beds 1—3 in the Bainidong member of the Middle Triassic Gejiu Formation; 3. beds 1—4 in the Malage member of the Middle Triassic Gejiu Formation; 4. beds 5—6 in the Kafang member of the Middle Triassic Gejiu Formation; 5. syenite porphyry dyke of the 3rd phase in Late Yenshanian; 6. aplite of the 2nd phase in Late Yenshanian; 7. medium–fine–grained biotite granite of the 2nd phase in Late Yenshanian. 8. medium–coarse–grained biotite granite of the 2nd phase in Late Yenshanian; 9. porphyritic biotite granite of the 1st phase in Late Yenshanian; 10. Indosinian diabase sill; 11. compressive fault in E–W structural zone; 12. compresso–shear fault in NE structural zone; 13. compresso–shear fault in NW structural zone; 14. compressive fault in SN structural zone; 15. attitude of strata; 16. geological boundary.

(2) Faults Faults of various directions and dimensions, most of them showing features of composite faults, are well developed in the ore field. As indicated by morphological and tectonic characters of the fault surfaces and by the characters of tectonites and lateral structures, faults stretching in all directions have been subjected to transformation in mechanical property. For example, the EW–striking group has undergone changes of compressive—shear (dextral) — shear (sinistral); the NE–striking group: shear (sinistral) — compresso–shear (sinistral) — shear (dextral); the NW–striking group: shear (dextral) — tenso–shear — compresso–shear (dextral) — shear–tensile (sinistral); the SN–striking group: shear (sinistral)—shear (dextral)—compression. Among these the NW–, EW– and NE–striking faults are of significant importance as a factor controlling mineralization.

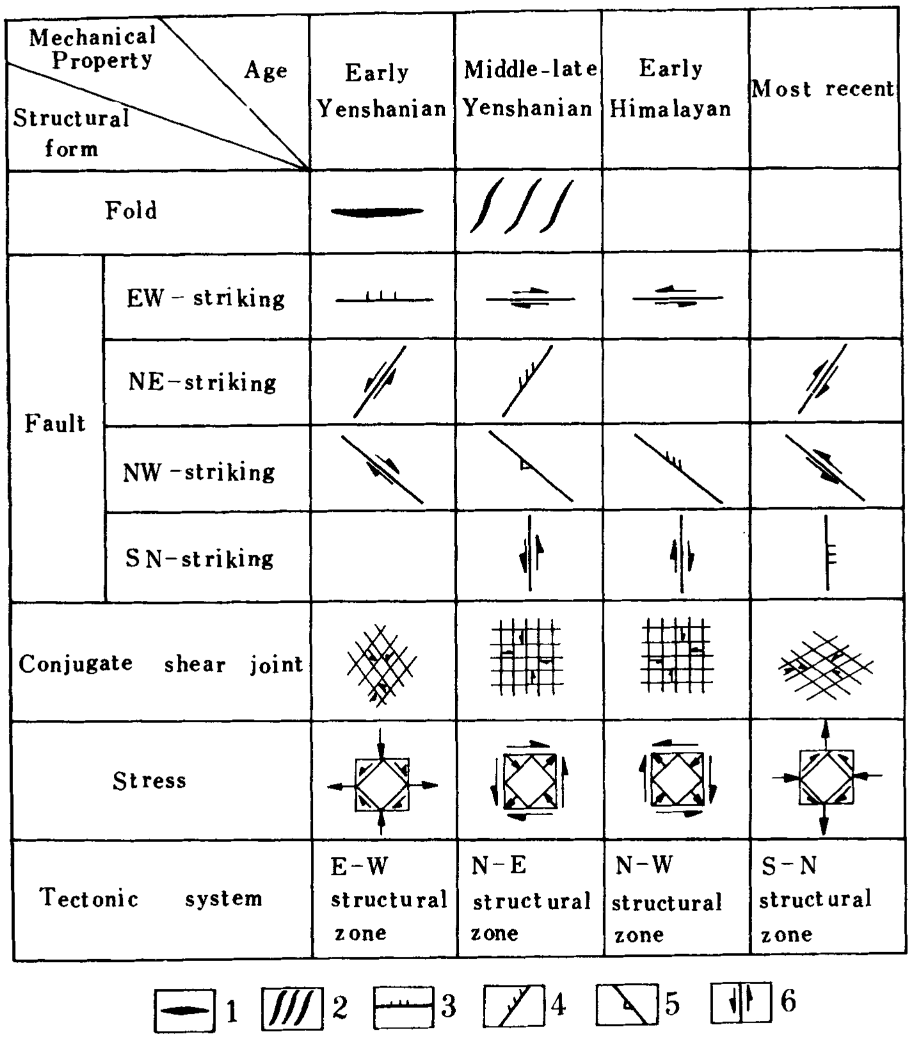

Fig. 2. Combination of structural features in different deformation epoches in the ore field.

1. Compressive fold; 2. compresso–shear fold;

3. compressive fault; 4. compresso–shear fault;

5. tensile fault; 6. shear fault.

(3) Joints Joints are well developed in the gently dipping strata of the ore field. Four groups of joints can be recognized based on statistics from 39 localities, indicating that the ore field has undergone four phases of tectonism: near SN–compression—NW to SE–compression—NE to SW–compression—near EW–compression.

(4) Microscopic structures Kink bands are commonly observed in calcite in various fault–tectonites. The direction of principal stress at a given point can be determined from these kink bands by using oriented thin sections. Petrofabric analysis of calcite clearly shows the influence of polyphase deformation and the directions of principal compressive stress obtained by this procedure for the various phases are in accord with the conclusion reached from macroscopic observations.

From the structural patterns on both microscopic and macroscopic bases as mentioned above, four groups of fault–structures can be recognized in the ore field, reflecting the development of four types of tectonic systems (Fig. 2).

(1) The EW–striking structural zone is composed mainly of the EW–running Malage–Songshujiao anticline and a series of EW–striking compressive faults with two groups of NE– and NW–running shear faults associated. Formed approximately during Late Indosinian–Early Yenshanian, this zone is considered as the westward extension of the Nanling latitudinal tectonic system.

(2) The NE–striking structural zone includes three second–order structural zones. Its NW and SE parts are composed of NE–striking compresso–shear faults and the central part is represented by a series of NW–running tenso–shear faults in addition to the compresso–shear foldings superimposed on the north limb of the Malage–Songshujiao anticline. This zone, Middle–Late Yenshanian in age, is assigned by some other authors tc the Neocathaysian tectonic system in East Yunnan.

(3) Developed from the early fault system, the NW–striking structural zone is represented by some NW–running compresso–shear faults such as the Da'aotang and Xiao'aotang fault zones in the central part of the area and the Baishachong fault zone in the northeast. Formed during the Himalayan movement, it belongs to the Honghe–Ailaoshan structural belt as part of the Yunnan–Burma–Indonesia eta–type tectonic system.

(4) The SN–striking structural zone is recognized in the south section of the Xiaojiang fault belt, with the Gejiu fault as its backbone, accompanied by two sets of shear faults in the NE and NW directions. It was formed after the Eogene period and belongs to the Sichuan–Yunnan longitudinal tectonic system.

Statistic Analysis of Rock– and Ore–forming Elements in the Ore Field

One of the fundamental aspects of tecto–geochemistry is to trace regularities governing the transport, concentration and dispersion of ore–forming elements in relation to tectonic activity. For this purpose, 160 samples of tectonites were collected at approximately equal intervals along the strikes of fault systems of different orientations in addition to 73 samples of ores and mineralized rocks from deposits at Malage, Yinjiadong and Bainidong. Twenty–five elements including Cu, Sn, Pb, Zn, Ag, As, Cd, Bi, W, Mo, Sb, F, Mn, Fe, Li, Rb, Co, Ni, Ti, Si, Al, Na, K, Ca and Mg were quantitatively analyzed for tectonite samples and additional four elements, Be, In, B and Hg, were determined for samples from the deposits. A total of 6117 data are thus made available on which R–

mode cluster analysis[2] has been made. The elements which are most closely related to mineralization can therefore be detected based on a better understanding of the interrelationship between the deposits and the tectonites with respect to various chemical components.

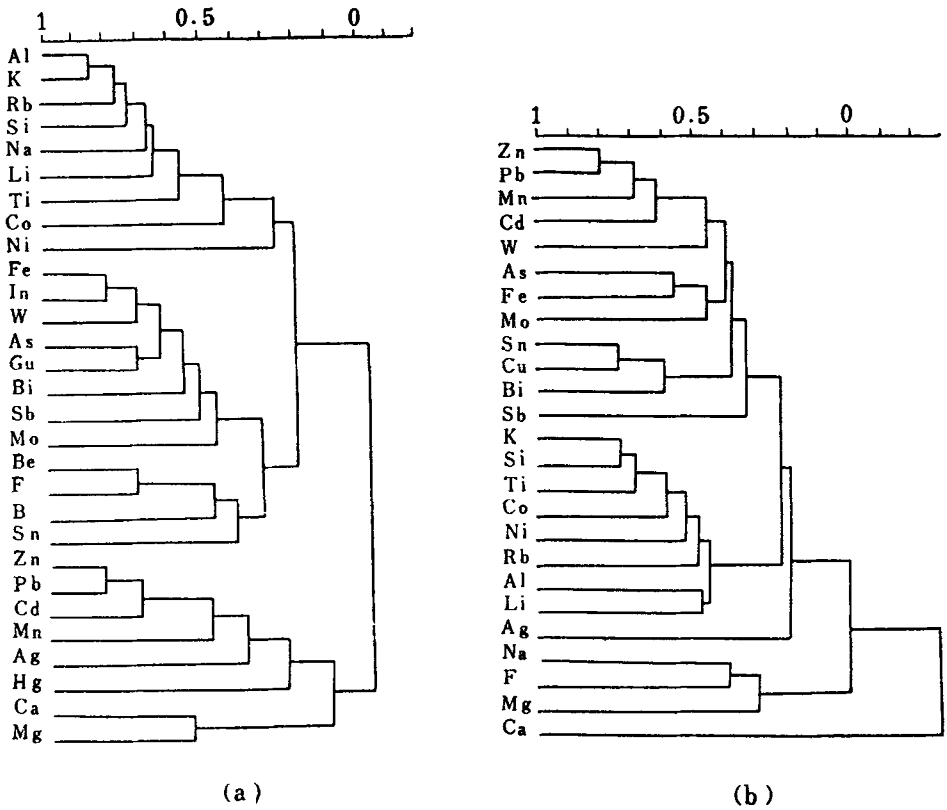

Fig. 3. Results of *R*–mode cluster analyses for samples collected from fault–tectonites and ore deposits in the Malage Ore Field.

a. 73 deposit samples (29 variables);

b. 160 fault–tectonite samples (25 variables).

R–mode cluster analysis on deposit samples

Some relationships can be established among the 29 elements based on *R*–mode cluster analyses of 73 samples collected from ore deposits. As shown in Fig. 3A, these elements can be divided into four groups at a correlation coefficient level $r = 0.24$: (1) those related to the rock–forming process (Al, K, Rb, Si, Na, Li, Ti, Co and Ni); (2) those to hypo– and mesothermal Sn–Cu mineralization (Fe, In, W, As, Cu, Bi, Sb, Mo, Be, F, B and Sn); (3) those to meso– and epithermal Pb–Zn mineralization (Zn, Pb, Cd, Mn, Ag and Hg); and (4) those to carbonate wall rocks (Ca and Mg). It is obvious that the 18 elements in groups (2) and (3) are of first importance as indicators of mineralization. Further distinctions can be made among them at $r = 0.4$ level: those responsible for Cu mineralization in contact zones at high temperatures (Fe, In, W, As, Cu, Bi, Sb and Mo); those in association with Sn mineralization at high–intermediate temperatures (Be, F, B and Sn) and those closely related to meso– and epithermal Pb–Zn mineralization (Zn, Pb, Cd and Mn).

R–mode cluster analysis on fault–tectonite samples

The relationships among the 25 elements based on *R*–mode cluster analyses of 160 samples of fault tectonite are shown in Fig. 3B. As can be seen, six groups are distinctive at $r = 0.33$: (1) those bearing a close relation to mineralization (Zn, Pb, Mn, Cd, W, As, Fe, Mo, Sn, Cu, Bi and Sb); (2) those related to rock–forming process (K, Si, Ti, Co, Ni, Rb, Al and Li); groups 3 (Ag) and 4(Na and F) are of unclear implication; and groups 5 (Mg) and 6 (Ca) have relevance to carbonate wall rocks. Although the various elements in tectonites are not correlated as closely as in ore deposits, two sets of samples are very similar in element assemblages indicative of rock–forming process, mineralization and wall–rock environment. More close relations can be revealed at $r = 0.59$ between the group of Zn, Pb, Mn and Cd and the group of Sn, Cu and Bi, indicating that the faults serve as channelways for ore–forming hydrothermal solutions.

Combining the results of deposit and tectonite analyses, the 14 elements displaying most close relations to mineralizations are Cu, Sn, Pb, Zn, Ag, As, Cd, Bi, W, Mo, Sb, F, Mn and Fe, which can be used as major indicators in primary halo studies along the fault system.

Table 1. Loading matrix of the varimax rotation factor by the *R*–mode factor analysis for the ore potential of faults in the Malage Ore Field

Factor / Variable	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Variance of common factors
Ag	0.1563	0.1567	0.0075	0.9662	0.0235	0.1086	0.0719	0.0035	1.0001
As	0.2361	0.1610	0.9304	−0.0437	0.0900	0.1452	0.1117	0.0956	1.0000
Bi	0.0532	0.9860	0.0402	−0.0237	0.1382	−0.0319	−0.0236	0.0471	1.0001
Cd	0.8747	0.3847	−0.1387	0.0511	0.0166	−0.0661	0.1300	0.2085	1.0000
Sb	0.1550	0.1853	0.1186	0.0261	0.9427	0.0288	0.1566	0.1137	1.0001
Mn	0.8395	−0.0692	0.4128	0.1913	0.0457	−0.0478	0.1466	0.2400	1.0000
Mo	0.2391	0.1612	0.1571	0.0678	0.1496	0.0769	0.9240	0.0734	1.0000
F	−0.0018	−0.0240	0.1141	0.1010	0.0262	0.9838	0.0653	0.0577	0.9999
W	0.3350	0.2252	0.1629	−0.0127	0.1170	0.0766	0.0844	0.8853	1.0001
Fe	0.2755	0.1551	0.5893	0.1809	0.2647	0.0556	0.4788	0.4665	1.0000
Zn	0.9499	0.1406	0.1460	0.0839	0.1483	0.0617	0.1017	0.1161	1.0001
Pb	0.9275	0.1539	0.2576	0.0684	0.1057	0.0434	0.1591	0.0814	1.0000
Sn	0.3594	0.7863	0.0922	0.3128	0.1509	0.0266	0.2851	0.2305	1.0000
Cu	0.2946	0.7388	0.4216	0.2409	0.0231	0.0033	0.2801	0.2295	1.0001
Variance contribution	3.8007	2.5187	1.7563	1.1912	1.0821	1.0306	1.3709	1.2489	
Accumulated percentage	27.15%	45.14%	57.68%	66.19%	73.92%	81.28%	91.08%	100%	

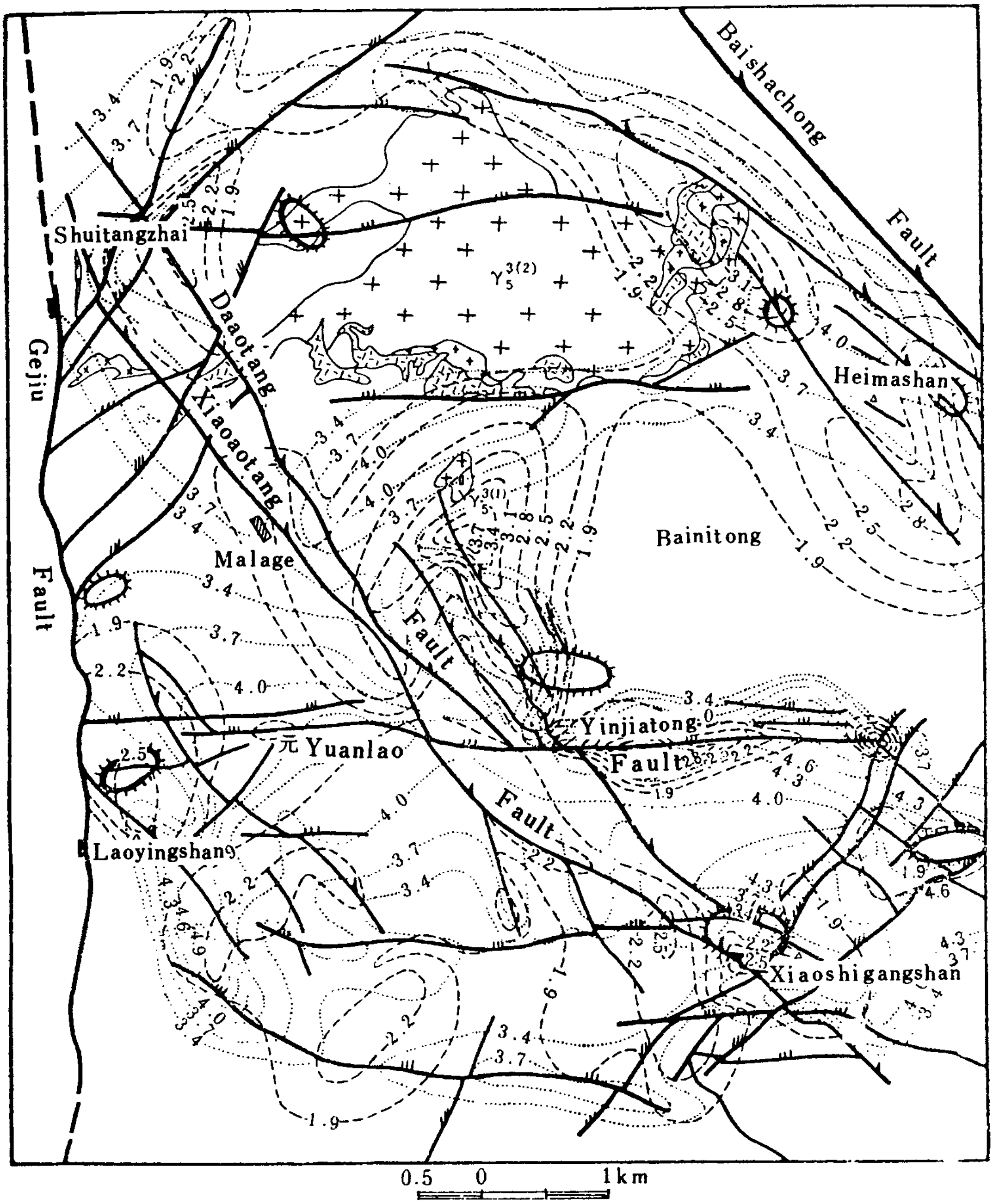

Fig. 4 The distribution of primary fault-halos in the Malage Ore Field.

1. Factor 2(Sn, Cu, Bi; contours at 1.9—2.2—2.5—2.8—3.1—3.4—3.7);
2. factor 1(Pb, Zn, Cd, Mn; contours at 3.4—3.7—4.0—4.3—4.6—4.9);
3. syenite porphyry dyke; 4. aplite; 5. medium-fine-grained granite;
6. medium-coarse-grained granite; 7. porphyritic granite; 8. diabase sill;
9. crest of granite stock; 10. EW-striking compresso-shear fault;
11. NE-striking shear-compresso-shear fault; 12. NW-striking tenso-shear-compresso-shear fault; 13. SN- striking shear-compressive fault.

Tecto–geochemical Characteristics of the Fault System in the Ore Field

As a channelway for ore–forming solutions, the fault system in the Malage Ore Field exerts a critical control over the transport, concentration and dispersion of ore–forming elements. In some cases, fault–related primary halos are often clearly recognizable where no halo anomaly is indicative on the surface. Therefore, the study of ore–forming element distribution in relation to the fault system should be an essential aspect in attempting to reveal the features of an ore field within the framework of tecto–geochemistry. Additionally, primary halos in association with the fault system can also be used as a simple but effective guide in searching for new ore bodies.

R–mode factor analysis[3] was conducted on 160 fault–tectonite samples with the 14 elements most closely related to minearalization given in the previous section as variables. As a result, orthogonal factor solutions are obtained (Table 1), and three sets of association can be established with loading ⩾ 0.5, i.e., A_1: Zn, Pb, Cd and Mn; A_2: Bi, Sn and Cu and A_3: As and Fe. Among these A_1 and A_2 are of primary importance, with the variance of their corresponding factors F_1 and F_2 contributing 45.14% of the total. A_1 is the reflection of the primary halos of meso–epithermal Pb–Zn mineralization and A_2 the primary halos of hypo–mesothermal Sn–Cu mineralization. Based on the factor scores of A_1 and A_2, a map showing the distribution of primary halos (Fig. 4) is prepared and the following generalizations can be given concerning fault–primary halos in this area:

(1) Primary halo anomalies are distributed in most cases along faults, in other words, the concentrations of ore–forming elements in fault–brecciation zones of various directions are higher than their background abundances. Not only the similarities are prominent in correlation patterns between fault–tectonites and orebodies or mineralized wall rocks (Fig. 3), but also the agreement is general good between the mineralization characters of fault–tectonites and the type and distribution of primary halos on the surface. For example, sections in fault–tectonites with high concentrations of Sn and Cu correspond with Sn–Cu anomaly areas and, on the other hand, faults in Pb–Zn anomaly areas always contain higher concentrations of these elements. This indicates that active faults during mineralization must have channeled ore–bearing hydrothermal solutions and thus may have been responsible for the extensive mineralization of these elements as well as for the localization of primary halos on the surface.

Primary halo anomalies are often found around the protruding parts of a granite stock, a phenomenon in agreement with the distribution of major ore deposits in this area. Meanwhile, the type of primary halo above the ore deposit is consistent with the mineralization below. As has been revealed, the distributions of granite stocks and ore deposits are controlled by the NE–striking structural zone, arranging in three NE–running structural belts. The same pattern is observable with respect to primary halos which also occur in three parallel NE–striking fault zones, i.e., the Shuitangzhai anomaly zone in the northwest, the Heimashan–Malage–Laoyinshan anomaly zone in the middle and the Yuanbaoshan–Xiaoshigangshan anomaly zone in the southeast, making up three second–order tecto–magmatic mineralization zones, strongly reflecting the control of NE–striking structures.

(2) Within each tecto–magmatic mineralization zone, the shape and distribution of primary halos are apparently controlled by active faults during mineralization, and therefore these halos may run discordantly with respect to the general trend of the mineralization zone. For example, in the middle Heimashan–Malage–Laoyinshan zone in the ore field, a series of NW–striking tenso–shear faults were developed in the Malage deposit. These faults have played a major role in the circulation

of ore–forming solutions, causing the primary halos above them to extend also in the NW direction. Similarly, the NW–trending faults from Laoyinshan to Xiaodapo and at Heimashan are also responsible for their NW–stretching primary halos as observed on the surface. For this reason, three NW–running primary halos of subsequent order, separated at about equal distances, were developed in the middle mineralization zone in the ore field. As a further example, primary halos at the Yinjiadong deposit are controlled to a great extent by the Yuanlao fault, resulting in a narrow EW–running primay halo anomaly zone.

On the other hand, although similar in mineralizing element assemblage, faults of different orientations are quite different in intensity of mineralization. For example, the NW–trending tenso–shear faults are generally in association with well–developed mineralization, containing comparatively high concentrations of ore–forming elements; most of the EW–trending shear faults, with the exception of the Yuanlao fault, are poorly mineralized and the NE–running faults served only as channelways for ore–forming solutions, leaving little signs of mineralization. Such differences in mineralization intensity between fault–brecciation zones of different orientations can be explained by their different mechanical properties and by the different depths they have reached in the crust.

(3) Another striking tecto–geochemical feature of the ore field is that Pb–Zn halo anomalies do not coincide with Sn–Cu. For example, at Malage and Laoyinshan Sn–Cu anomalies lie to the northwest, while Pb–Zn anomalies to the southeast. Taking Yinjiadong as another example, Sn–Cu anomalies are found at the west end of the area, while Pb–Zn anomalies at the east end. Generally speaking, Sr–Cu anomalies appear in the immediate vicinity of a granite stock but Pb–Zn anomalies occur far away. Such a distribution pattern reflects the zonal character from hypothermal to meso–epithermal deposition and also the direction in which the ore–forming solutions flowed, i.e., from northwest to southeast or from west to east, which provides a plausible explanation for the fact that ore deposits always occur southeast of the crest of the ore–bearing granite stocks.

Conclusions

(1) In the Malage Ore Field, the general trend of primary halo anomalies is controlled by the NE–running tectonic system, while the shape and distribution of individual anomalies are dependent on fault structures of subsequent order. As has been demonstrated, by controlling the concentration and dispersion of ore–forming elements, the NE–striking tectonic system is responsible for mineralizations in the ore field.

(2) Judging from the distribution pattern of primary fault–halos, the four anomaly areas at Xiaoshigangshan, Heimashan, Xiaodopo and Shuitangzhai should be the favorable loci of ore deposition. However, in comparison to known deposits, these anomalies are relatively small in extent and low in intensity, indicating that the predicted deposits may be of medium to small size or may be deeply buried.

(3) Through systematic sampling of fault–tectonites, anomalies can be delineated in areas where no data on normal soil geochemistry are available. As has been proved, geochemical approach based on fault–structural halos may be very effective and economically rewarding.

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