Mixed Population Screening for Sulfur Isotopes

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Abstract Quantitative research of the origin of sulfur isotopes is a difficult problem that has puzzled geochemists all along. In the study of the middle and lower reaches of the Yangtze River and the Dongpo orefield in Hunan Province, the authors successfully applied the mathematical model of mixed population screening to quantitatively resolving the problem on the origin of sulfur isotopes, which is significant in finding out the source of mineralizing matter and metallogenic mechanisms.

Key words: sulfur isotope, mixed population, screening

1 Mathematical Model of Mixed Population Screening

Research of modern economic geology indicates that the formation of most ore deposits is characterized by multiple origins, multiple stages and multiple geneses, therefore the formation process of an ore deposit can be taken as a mixture or superposition of multiple populations, which can be described by a mathematical model of mixed population screening.

The following mathematical model can be used to express a mixed population that is composed of several populations:

$$P(A+B+\cdots) = f_A P_A + f_B P_B + \ldots$$

where $P(A+B+\cdots)$ represents the mixed population, P_A and P_B represent different populations, f_A and f_B represent the percentages of different populations. $f_A + f_B + \cdots = 1$. By means of graphic interpretation, not only the average of different populations composing the mixed population, but also the percentage of each population can be obtained. Applying the model to researching sulfur isotopes we can find out the sulfur origin of an ore deposit according to the average and at the same time we can get the percentage of each original sulfur. This provides an important approach to quantitative research of sulfur isotopes.

2 Basic Features and Mixed Population Screening of Sulfur Isotopes in the Dongpo Orefield

The Dongpo orefield is an important polymetal mineralizing area in China. In this research, totally 132 data of sulfur isotopes were obtained, including 116 from predecessors. Bar charts of the sulfur isotope distribution (Fig. 1) were completed separately since the sulfur isotopes of sulfides are different by themselves. It can be seen from the charts that the sulfur isotopes in the orefield have a discrete distribution, and that the $\delta^{34}S$ values vary from $-11\permil$ to $+14\permil$ with a standard deviation of $4.6\permil$. The distribution has multiple peaks, which indicate multiple sulfur origins. Firstly, the $\delta^{34}S$ values are mainly distributed near 0, standing for magmatic sulfur, which is one origin of all kinds of sulfides sulfurs in this area. Secondly, the negative values stand for biogenic stratigraphic sulfur, which is one origin of acerilla and sphalerite sulfur in this area. Thirdly, the high positive values stand for stratigraphic sulfur formed by reducing action, which is one of the main origins of all kinds of sulfides sulfurs in this area. The typical case is the Jinshiling pyrite deposit.

Mixed population screening was carried out for sphalerite in the field to quantitatively find out the function of sulfurs from various origins in mineralization. The result is showed in Tables 1 and 2. Table 1 shows that 57.2% of the sulfur in sphalerite came from reduced stratigraphic sulfur from sulfate (Population A) and the estimated average of $\delta^{34}S$ is $+8.38\permil$, which is approximate to the composition of sulfur isotopes in the Jinshiling stratabound pyrite deposit; 21.4% of the sulfur came from magmatic sulfur (Population B) and the estimated average of $\delta^{34}S$ is $+2.00\permil$, which is close to the composition of sulfur isotope in the pyrite from the Qianlishan pluton; 21.4% of the sulfur came from biogenic stratigraphic sulfur (Population C) and the estimated average of $\delta^{34}S$ is $-3.00\permil$, which is close to the composition of sulfur isotope of pyrite in carbonate strata. Moreover, the superposition of sulfurs of different origins shows a spatial regularity, appearing as semicircles centered around the Qianlishan pluton and Jinshiling stratabound pyrite deposit respectively (Fig. 3). The semicircles in the former case represent magmatic sulfur, while those for the latter case
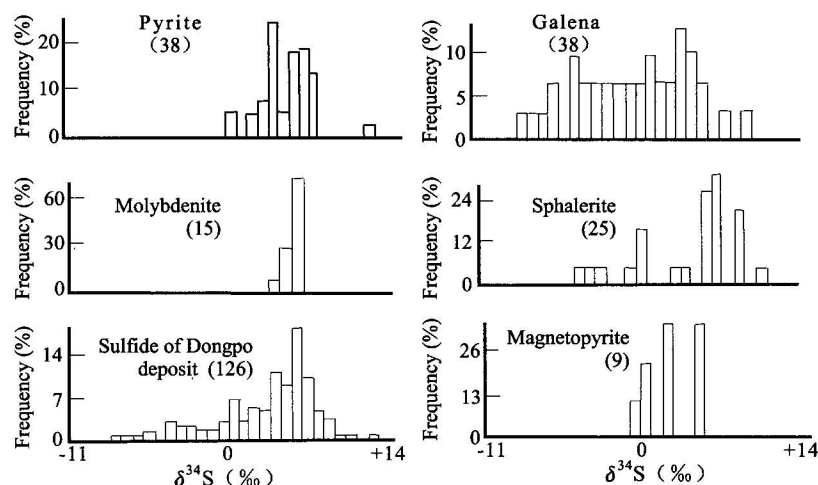
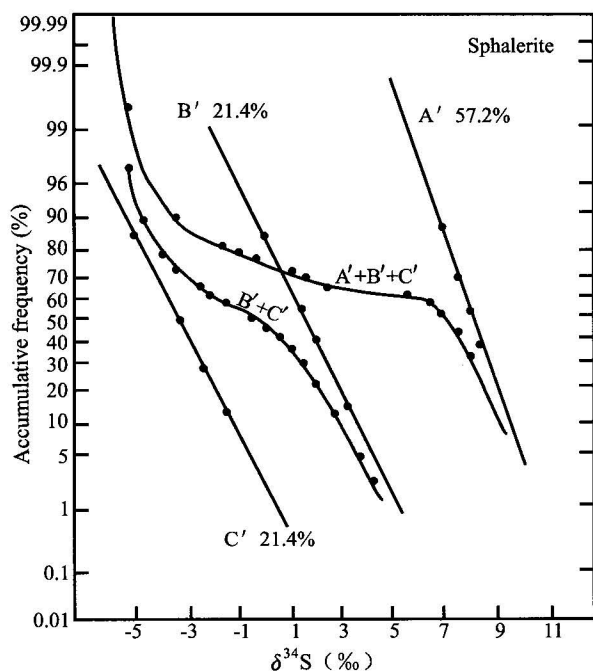Fig. 1. Distribution of sulfur isotopes from sulfades in the Dongpo orefield.

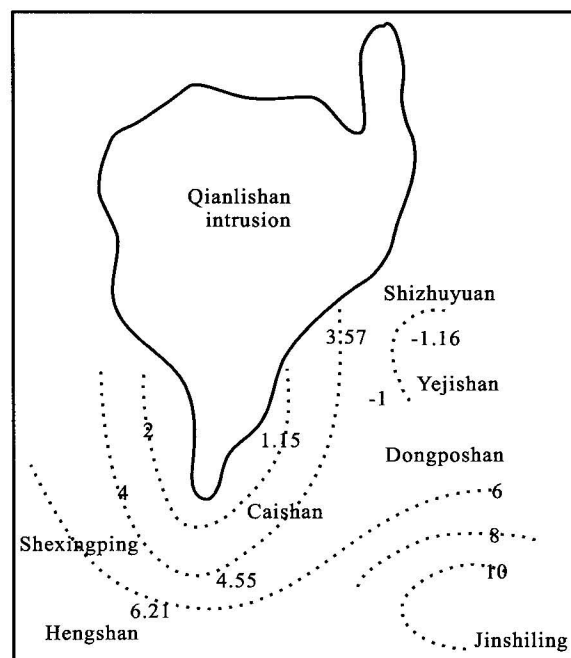Fig. 2. Population screening of the $\delta^{34}S$ values of sphalerite in the Dongpo orefield.

Fig. 3. Contour map of the $\delta^{34}S$ values in the Dongpo orefield.

Table 1 Screening analysis of sphalerite in the Dongpo orefield

Population	Percentage (%)	Estimated average of $\delta^{34}S$ (‰)	Average of $\delta^{34}S$ of terrain (‰)
A	57.2	+8.38	8.00
B	21.4	+2.00	3.05
C	21.4	−3.00	−1.08

represent reduced stratigraphic sulfur. Outwards from the pluton, heavy sulfur is increased gradually and transformed into reduced stratigraphic sulfur from sulfate, which strongly proves that the sulfurs in the study area is of mixed origin.
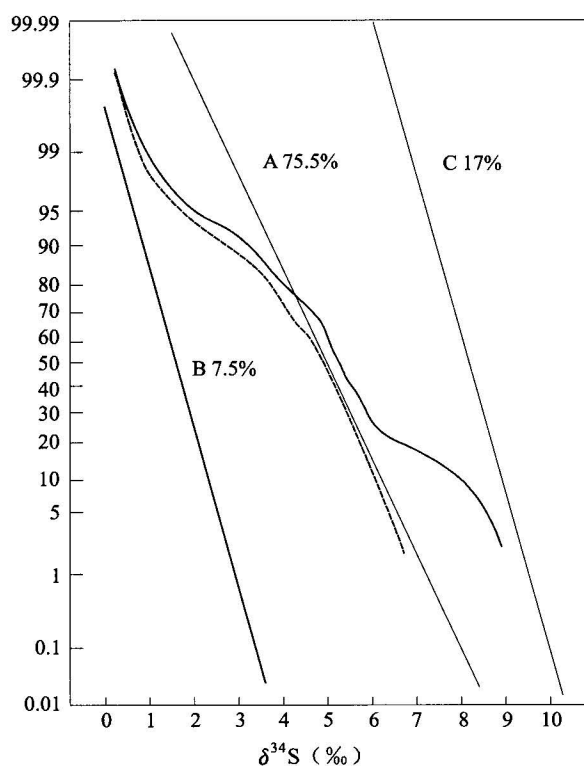
3 Mixed Population Screening of Sulfur Isotopes in the Tongguanshan Copper Deposit

The Tongguanshan copper deposit is one of the important copper ore deposits in China. For the purpose of quantitative study of the percentages of sulfurs from different origins in this area, mathematical statistics of sulfur isotope contents was carried out for 134 sulphide samples collected at Tongguanshan (Table 2).

According to Table 2, mixed population curves were drawn with the accumulative frequency and the content being the coordinates (Fig. 4), and mixed population

Table 2 Statistics of sulfur isotope content of sulphide in Tongguanshan

$\delta^{34}S$ (‰)	0.25	0.4	1.25	1.75	2.25	2.75	3.25	3.75	4.25
Grouping frequency (%)	1.49	0.75	1.49	2.24	1.49	3.73	5.97	9.7	9.7
Accumulative frequency (%)	99.97	98.48	97.3	96.2	94	92.5	88.8	82.8	73.1
$\delta^{34}S$ (‰)	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75
Grouping frequency (%)	17.91	13.41	9.7	5.97		3.73	5.22	5.22	2.24
Accumulative frequency (%)	63.4	0	45.5	32.7	22.4	16.4	12.7	7.5	2.2

Fig. 4. Normal probability chart of sulfide isotope screening of the Tongguanshan orefield.

Table 3 Results of mixed total screening for sulfur isotope of sulphide in Tongguanshan

Population	Percentage %）	Estimated average (‰)	Average $\delta^{34}S$ in terrains (‰)
A	75.5	4.95	
B	7.5	1.60	4.2
C	17.0	8.15	2.35

screening was performed. Populations A+B and C were screened out first (dot-dashed line) with the fitting inflection point being 17%. Since A+B is mixed by two populations, A and B were screened out then with the inflection point being 91%. Therefore, in the mixed population, A and B account for 75.5% ((100–17)×91%) and 7.5% ((100–17)×(100–91)%) respectively. The results for the three populations are showed in Table 3.

The following facts can be seen from Table 3. For Population A, the estimated average of $\delta^{34}S$ is 4.95‰, approaching to the average of $\delta^{34}S$ from sedimentary gelpyrite (4.2‰), which shows that 75.5% of the sulfur in the Tongguanshan copper deposit came from sedimentary strata. For Population B, the estimated average of $\delta^{34}S$ is

1.60‰, approaching to the average of $\delta^{34}S$ from pyrite of the Tongguanshan deposit (42.35‰), which shows that 7.5% of the sulfur came from plutons. The remainder 17% might be relevant to the sulfate in the study area.

From the above one can see that the sulfur of the Tongguanshan copper deposit has multiple origins and mainly came from sedimentary strata related to sedimentary gelpyrite.

In a word, the mathematic model of mixed population screening has been applied to quantitatively finding out the origins of sulfur and this is of great significance for the study of metallogeny.

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