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IDENTIFICATION AND VOLUME PERCENTAGE DETERMINATION OF MIXED MINERALS BY USING DIGITAL IMAGE PROCESSING OF MICROANALYSIS PICTURES

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ABSTRACT

A technique based on digital image processing of X-ray microanalysis pictures taken from ground slices was used to identify mixed minerals and determine their volume percentages. It has been used to analyze some mixed minerals and the results agreed well with those obtained by chemical methods. This technique can also be used to other phase analysis which are based on micro-analysis.

I INTRODUCTION

The ground slices analysis are widely used for mineral measurements. Slices are usally prepared from particles obtained by smashing natural minerals,preseparating and condensing them in a proper processing routine. Referring to other information about the mixed minerals and the preprocessing routine,one can know what kinds of minerals are possibly contained in slices. The purpose of ground slice analysis is to determine what kinds of minerals really exist and how many volume percentages they are contained. The conventional procedures are carried out by observing the slices under a microscope. Minerals are identified by the naked eyes and their amounts are evaluated by counting the numbers of each kind of particles. This method is not suitable for those mixtures consisting of minerals with complex compositions or with similar optical properties.

In the present work,a technique based on digital image processing of X-ray microanalysis pictures taken from slices was proposed.

II WORKING PRINCIPLE AND OPERATION PROCEDURES

The flowchart used in the present work is shown in Fig.1,which include the steps 3 through 8 mentioned below. The whole procedure of analysis is as follows:

1. Referring to the relevant information about the mixed minerals analysed and the pre-processing routine of the slices,evaluate what kinds of minerals may exist. According to the composition of each possible mineral, make an element-combinations table for identification. As an example,the compositions of possible Nb-containing minerals in a particular slice and the element-combinations for identifying them are listed in Table 1. (The data for Nb-noncontaining minerals are not listed.) In this mixture, for example,a mineral which contains simulataneously Nb,Ti and Ce will be identified as Mineral C. In other words,in this example the combination Nb-Ti-Ce will correspond to Mineral C; combination Nb-Ti-Fe correspond to Mineral D, etc. The knowledge above is given by mineralogists.

Table 1. The compositions of possible Nb-containing minerals and the element-combinations used to identify them on a ground slice

Mineral	Composition								Element-Combination
	Nb_2O_5	BaO	MnO	Fe_2O_3	Ce_2O_3	CaO	TiO_2	SiO_2	
A	X			X					Nb-Fe
B	X		X	X					Nb-Fe-Mn
C	X				X		X		Nb-Ti-Ce
D	X			X			X		Nb-Ti-Fe
E	X				X				Nb-Ce
F	X					X		X	Nb-Ca
G	X	X					X	X	Nb-Ti-Si

2. Take pictures of electron image and X-ray images of elements for all the element-combinations on a fixed field of view by using microanalyzer (EMP or SEM with EDS). For the example shown in table 1,one picture of electron image and seven pictures of X-ray images should be taken; they are those for $NbL\alpha$,$CaK\alpha$,$SiK\alpha$,$MnK\alpha$,$FeK\alpha$,$TiK\alpha$ and $CeL\alpha$.

3. All the pictures are digitalized into binary images by image analyzer. A digitalized image consists of $3\text{-}4\times10^4$ picture elements. We call the picture element having value 1 'spot', for short in the following. Each digitalized X-ray image is 'registered' to electron one by a special

registration technique (here the word 'registration' has the similar meaning as it has in photography, see III-1). Then all the digital images(one electron image and several X-ray images) are stored in a disk.

4. A special 'particles reforming' program is used to reform contiguous spots in the digital electron image into particles and write the position and area of each particle into a table.

5. In order to obtain the volume percentage of a specific mineral, logic AND operations are applied to electron image and the related X-ray images for an element-combination corresponding to the mineral (for example, the NbLα, TiKα and CeLα images for Mineral C). Logic AND operation means comparing the relevant images spot by spot and reserving those spots appearing simulataneously in every image. After logic AND operations, an artificial image can be produced. Like in digital electron image, the contiguous spots in this image are then reformed into particles; a position-area table of this image is also obtained. It is clear that all particles on this image contain all the characteristic elements of the specific mineral. In other words, only the particles of the specific mineral can appear in this image. We call it the 'combined image' of the mineral. Combined images can be redisplayed on image analyzer for check if necessary.

6. Profiles of particles on a combined image are not distinct enough for measuring area. This should be done on a digital electron image. So, a so-called 'particles position coincidence' program is used to compare the position-area tables of both electron image and combined image. The program finds out the coinciding particles on the electron image for each particle in combined image and calculates the volume percentage of the mineral based on the sum of these coinciding particle's areas.

7. The percentages of other minerals can be obtained by repeating the procedures 5 and 6 for their corresponding element-combinations. The program is so arranged, that the processings for complex element-combinations are done sooner than those for simpler combinations. In this way, each particle can only be counted once. For example, if a particle has been counted as Mineral C (element-combination Nb-Ce-Ti), it will no longer be counted as a particle of Mineral E(element-combination Nb-Ce).

8. Repeat steps 2 to 7 for sufficient fields of view in order to obtain reliable results with satisfactory statistical accuracy.

III SOME SPECIAL TECHNIQUES AND THEIR IMPORTANCE

1. 'Registration' of digitalized images. If there is no interface between a microanalyzer and a image analyzer, the signals of electron and X-ray images for a fixed field of view can only be input into image analyzer through pictures. In this case registration among images is most important, because after logic AND, particles on the resultant combined image are always diminished. The worse the registration among pictures, the more the diminution will be. Though the technique mentioned in section II-6 (calculating volume percentage of a mineral based on electron image) can decrease the error caused by this effect, when mineral particles are fine, the particles on combined images may be so small, that they will be rejected as noise. (See the next point in this section.) Our image analyzer is equipped with some means to register pictures, but the registration is not good enough to give satisfactory results. So, our program must have a fine registration function before logic AND operations. In the present work, all X-ray images are 'registered' to electron one. The procedures are as follows. A digital X-ray image is sequentially made a small displacement in four directions: right and left, back and forth. (In fact, it is the coordinates of spots on the image that are changed by the same amount in the same directions.) Each time a displacement is made, the overlapped area between electron and X-ray image is calculated. The optimal displacement should be the one by which a maximum overlapped area is obtained; it is then selected as the first displacement. Based on this displacement, the second one is obtained by trying the further displacements in three other directions (the one in which the image is replaced to its last position need not be tried). Repeat this procedure, a digital X-ray image which has a maximum overlapped area with electron one can finally be obtained. We call this image 'registered' image.

2. Reduction of noise. Generally, the signal/noise ratio of X-ray images is poor. It is important to reduce the noise level on images in order to use them as described above. This was carried out by several steps:

(1) The logic AND operations among digital electron image and X-ray images can effeciently reduce noise, because the signal/noise ratio in the former is much better than that in the latter. Furthermore, noise spots always distribute randomly. The probability of appearing

of noise spots on two images in a distinct position is very small. So, logic AND operations among X-ray images can also reduce the random noise.

(2) Reforming the contiguous spots on digital images into particles is not only a means to count the particle's number and calculate their areas, as mentioned above, but also a step to reduce noise. It was observed that noise spots residual after logic AND operations appear mainly in two forms: like small worms or hollow circles; or gather as small spot-groups. After reformed into particles, the noise spots in the first form can be rejected as particles with area/perimeter ratio smaller than a given value; and those in the second form can be rejected by setting an area threshold for particles.

IV THE RESULTS

The present technique has been used to process about 700 pictures taken from three kinds of mixed minerals. As an example, Table 2 shows the analysis results obtained by processing 136 pictures taken from slices described in table 1. The results of classifying and volume percentage determining of minerals agree well with those obtained by chemical methods, which involve complicated reversion calculations. Some of our results have been quoted in engineering. Minerals with particles not bigger than 0.02mm can be quantitatively analyzed. A set of pictures for a field of view (8 pictures for the Nb-containing minerals shown in Table 1) takes computer time about 15 min. This technique can also be used for other phase analysis (identification and volume percentage determination) based on X-ray images.

Table 2. The analysis results for slices described in table 1

Mineral	A	B	C	D	E	F	G
Particle's number	91	48	7	8	9	2	0
Particle's area ($100\mu^2$)	1686	1323	215	209	136	78	0
Volume percentage (%)	40	32	5	5	3	2	0

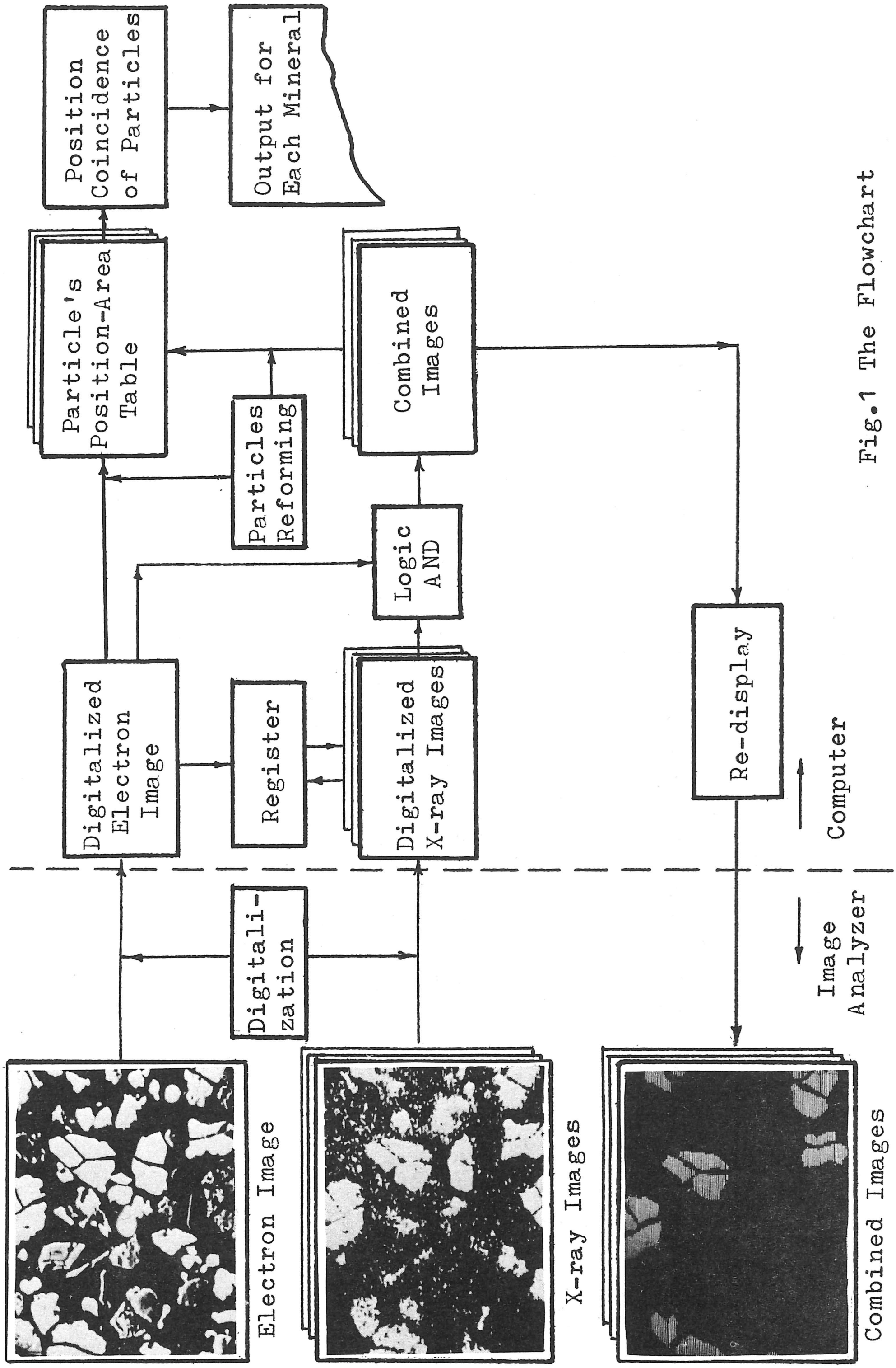

Fig.1 The Flowchart