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MINERALOGICAL MODAL ANALYSIS WITH THE ELECTRON MICROPROBE *X*-RAY ANALYZER

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One problem frequently encountered in mineralogical planimetric integration analysis is the correct microscopical identification of the mineral grains in the point counting process. When thin sections are integrated in transmitted light, the minerals can be identified according to their optical properties. Often, however, it is difficult to identify properly very fine-grained minerals and complex mineral intergrowths, thus introducing errors into the modal analysis. Furthermore, opaque minerals in thin sections cannot be properly identified and are simply referred to as "ore." Optical identification of certain minerals, particularly of the various silicates, in polished sections is even more difficult and limits considerably the planimetric integration of such sections.

These difficulties can be largely overcome by combining the point counting with the electron microprobe technique (for details on the latter, compare Birks, 1963). Thus, in addition to the optical mineral identification as provided by the microscope of the electron probe, the minerals are simultaneously identified according to their chemical compositions and their occasionally characteristic luminescence properties under electron bombardment (*e.g.* enstatite—blue and/or red; feldspar—blue; oldhamite—yellow; quartz—orange, gray; sinoite, Si_2N_2O—green).[1] Thus, misidentification of minerals, which is a common source of error in conventional point counting techniques, is largely eliminated.

In practice the measurements are carried out in the following manner. The quantitative compositions of the minerals constituting the sections are determined with the electron microprobe, and their luminescence properties are noted. One characteristic element for each mineral is selected and the spectrometers of the electron probe are set to the respective Kα wavelengths of each element. In the case of an electron microprobe with three dispersive channels, three minerals can thus be readily identified by the presence or absence of a given element. In addition, characteristic luminescence may serve to identify one or two more minerals. Thus, planimetric integration of four to five different minerals can

[1] It is necessary, however, to study carefully the correlation between color of luminescence and mineral species in each case before the luminescence can be used as a reliable means of identifying minerals.

be carried out in one run. The electron beam of the electron microprobe is centered at the intersection of the ocular cross hairs. The sample is then stepped in preselected steps under the static electron beam. After each step the nature of the mineral is recorded and together with the total number of steps as a reference the measurements are evaluated in the same manner as in conventional point counting (Chayes, 1956). In complicated systems, manually triggered stepping motors and manually operated laboratory counters may be employed to move the sample and to count the number of steps and the number of intersections of the electron beam with the respective minerals. However, the procedure can also be made largely automatic. Automatic stepping motors may be used to drive the sections and to record the simple yes-no answers from the spectrometers (presence or absence of preselected characteristic elements) on chart paper or on punch tape for computer evaluation. In any case, the method is fast and very reliable, since errors due to mineral misidentifications are largely excluded.

The method has been used successfully in semiautomatic planimetric integration of polished meteorite sections. One example may serve to illustrate its usefulness. The Odessa iron meteorite contains certain nodules consisting of a variety of minerals, among them olivine, rhombic pyroxene, Ca-rich Cr clinopyroxene, plagioclase, and chlorapatite (Marshall and Keil, 1965). Seven polished sections of seven different nodules were integrated semiautomatically in reflected light to obtain

TABLE 1. REPRODUCIBILITY OF THE PLANIMETRIC INTEGRATION ANALYSES OBTAINED SEMIAUTOMATICALLY WITH THE ELECTRON MICROPROBE. POLISHED SECTION NUMBER 1

Run number	Total number of counts	Olivine		Rhombic pyroxene		Ca-rich Cr clinopyroxene		Plagioclase	
		Number of counts	Volume per cent	Number of counts	Volume per cent	Number of counts	Volume per cent	Number of counts	Volume per cent
1	410	291	71.0	1	0.3	58	14.2	60	14.6
2	611	420	68.8	1	.2	105	17.2	85	13.9
3	308	209	68.0	2	.7	55	17.9	42	13.6
4	560	389	69.5	1	.2	101	18.0	69	12.3
5	374	254	67.9	1	.3	58	15.5	61	16.3
6	417	276	66.2	1	.2	74	17.7	66	15.8
7	392	259	66.1	0	.0	71	18.1	62	15.8
8	250	173	69.2	0	.0	40	16.0	37	14.8
9	351	240	68.4	1	.3	56	16.0	54	15.4
10	413	284	68.7	0	.0	68	16.5	61	14.8
Averages and standard deviations	4086	2795	68.4±1.5	8	0.2±0.2	686	16.8±1.1	597	14.6±1.2

TABLE 2. RESULTS OF PLANIMETRIC INTEGRATION OF THE SILICATES AND OF CHLORAPATITE FROM NODULES IN THE ODESSA IRON METEORITE

Section number	Total number of counts	Olivine		Rhombic pyroxene		Ca-rich Cr clinopyroxene		Plagioclase		Chlorapatite	
		Volume per cent	Weight per cent	Volume per cent	Weight per cent	Volume per cent	Weight per cent	Volume per cent	Weight per cent	Volume per cent	Weight per cent
1	4086	68.4	70.6	0.2	0.2	16.8	17.3	14.6	11.9	0.0	0.0
2	3285	32.6	34.8	17.1	17.1	25.4	27.1	24.8	20.9	.0	.0
3	2280	49.7	51.8	9.0	8.8	24.2	25.3	17.1	14.1	.0	.0
4	2802	38.4	40.3	27.5	27.1	19.5	20.5	14.6	12.1	.0	.0
5	2342	55.0	56.7	9.8	9.5	22.2	22.9	11.0	8.9	2.0	2.0
6	627	19.0	20.5	39.2	39.8	11.0	11.9	22.8	19.4	8.0	8.4
7	1232	36.2	38.9	5.2	5.2	27.2	29.3	31.4	26.6	.0	.0
Average		47.6	49.8	13.2	13.0	22.0	23.0	15.9	13.1	1.1	1.1

quantitative numbers on the relative proportions of the aforementioned minerals. The spectrometers of the microprobe were set to the $K\alpha$ wavelengths of Ca, Mg and P. Olivine is then recognized by its high Mg but negligible Ca content. Rhombic pyroxene has high Mg and small but measurable Ca content. Ca-rich Cr clinopyroxene is characterized by its high Ca, and chlorapatite by its high P content. Plagioclase is easily recognized by its bright blue luminescence. In Table 1 the results of the repeated measurements of section 1 are presented to establish a measure of the reproducibility of the method. The variations in the total number of counts in different runs are due to the different stepping distances used each time (20–100 microns). In Table 2 the results of the integration of seven sections of different nodules are summarized. The average of the seven sections was calculated taking into account the size of each section. The weight percentages were calculated from the volume percentages by means of the following density values: olivine 3.3, rhombic pyroxene 3.1, Ca-rich Cr clinopyroxene 3.3, plagioclase 2.6, chlorapatite 3.2. It is apparent that the relative proportions of the silicates and of chlorapatite are quite different from nodule to nodule.

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AN IMPROVED HOLDER FOR GRINDING THIN SECTIONS[1]

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A new holder for grinding thin sections using diamonds for wear points has been found to be highly satisfactory and a distinct improvement over a previously described holder using boron carbide strips.[2] This holder is made of two blocks of brass, joined by a pair of $\frac{1}{4}$ inch stainless steel pins

[1] Publication authorized by the Director, U. S. Geological Survey.

[2] Cochran, M. C., and A. G. King (1957) Two new types of holders used for grinding thin sections. *Am. Mineral.* **42**, 422–424.