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# BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS.

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# APPLICATION OF A DIRECT READING OPTICAL SPECTROGRAPH TO GEOLOGICAL PROBLEMS

by

K.R. Walker

# APPLICATION OF A DIRECT READING OPTICAL SPECTROGRAPH TO GEOLOGICAL PROBLEMS

(Presented to the Fourth Australian Spectroscopy Conference, held in Canberra from 20th to 23rd August, 1963.)

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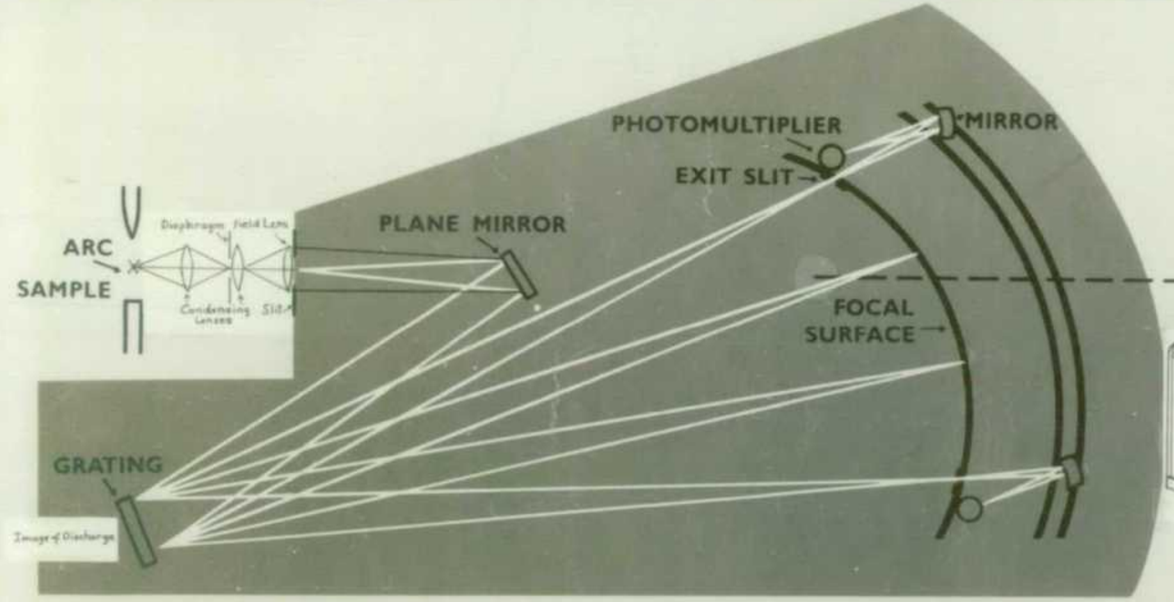
# AUTOMATIC SPECTROCHEMICAL ANALYSIS



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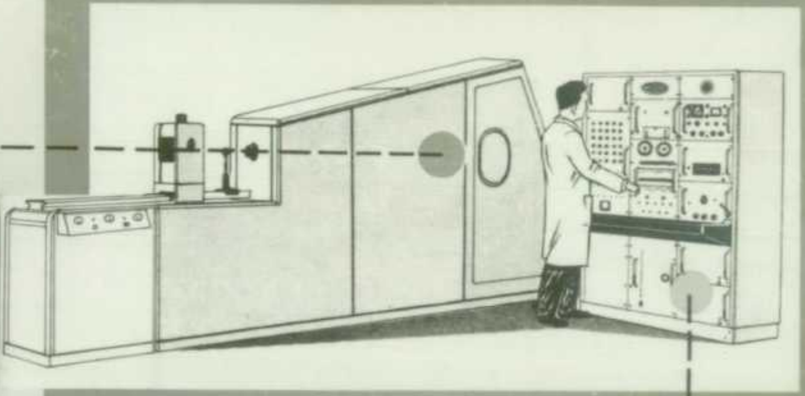

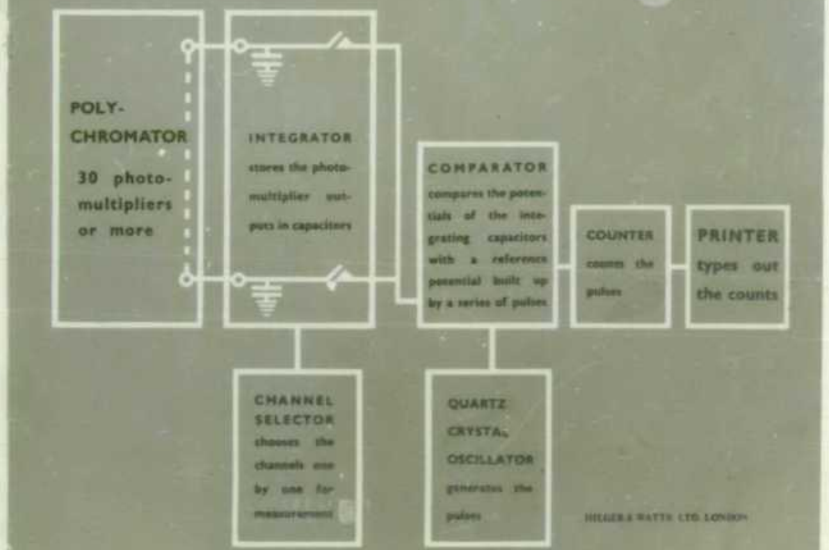

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# APPLICATION OF A DIRECT READING OPTICAL SPECTROGRAPH

# TO GEOLOGICAL PROBLEMS

(Presented to the Fourth Australian Spectroscopy Conference,
held in Canberra from 20th to 23rd August, 1963.)

## Introduction

Following the development of the direct reading optical spectrograph, and its successful application to production control in the metallurgical industry, geological organizations have been encouraged to instal and develop them for their own use. When compared with many present analytical procedures used by these organizations, the main attraction of the direct reader is the possibility for increased analytical speed for a wide element coverage without sacrificing accuracy.

To date in the western world there are about 20 direct readers used for silicate analysis, but only 15 are wholly employed in this application. The remaining ones are used in the chemical industry, and in agricultural research organizations for plant tissue and soil analysis; in each of these applications only part of their use is for silicate analysis. Table 1 lists present users of direct readers for silicate analysis and summarizes the analytical methods employed by them.

First attempts to use direct readers for silicate analysis were made during the last decade, and the first installations were in the glass and aluminium industries. Soon after an oil and a mining company, and a research organization, installed them for routine rock analysis for major and minor elements. It is only in the last couple of years that geological surveys have commenced installing them for routine analysis of geological samples and for their research requirements. About 6 instruments to date are used, or are being set up, for trace element analysis of silicates.

Few papers have been published so far on the analysis of silicate materials by direct reading optical spectrograph. All known references are in the bibliography.

## Proposed application of a direct reader in the B.M.R.

The direct reader in the Bureau of Mineral Resources will be used to analyse rocks, minerals and soils for major, minor and trace elements, and its main application will be in the analysis of samples for geochemical surveys. It will also have an application in fundamental research, and will contribute to the solution of many geological problems, especially petrological ones, which frequently arise in the course of Bureau work. Most of this work requires an instrument with high sensitivity for trace elements, a wide element coverage, and a potential for rapid analysis of samples.

## Factors limiting the application of direct readers to geological problems.

We know that when using a photographic instrument the spectrographer analysing geological materials is continually confronted in each group of analyses with analytical problems that show up during analysis and computation. Part of his solution to these problems is achieved by exploiting the operational versatility of his instrument. With these facts in mind, let us consider the direct reader in the light of the Bureau's application.

The instrument being installed will analyse 33 elements in a sample. Because of the accuracy of the recording and read-out equipment, for efficient operation, the analytical methods used must also be accurate, i.e. capable of achieving good semiquantitative or quantitative results. Hence, if a universal quantitative analytical method was possible, the 33 elements could be determined simultaneously. However, for analytical reasons it is more appropriate to divide the elements of the programme into volatile and involatile elements, and analyse each group separately under suitably controlled conditions for the group. The analytical methods employed must be compromised with invariant element lines in the programme and with fixed slit sizes which cannot conveniently be altered between analytical runs.

Matrix and interelement effects so common in silicate analysis where physical methods of analysis are employed, are also a major problem in the use of a direct reader. The complexity of spectra of silicates presents a challenge in instrument design and construction if the spectra are to be recorded satisfactorily, and especially if sensitive but faint element lines are to be recorded without excessive background. By eleminating the photographic procedure in analysis, background, line interference, self absorption etc., could go unnoticed or under estimated in their effect and distort the results, especially as the samples to be analysed are of unknown chemical composition, and include a diversity of matrix types and a wide range of element concentrations.

To select a programme of element lines which is universally applicable under all analytical conditions is almost impossible, and invariably to meet the analytical and instrumental structural requirements one has to effect a compromise in some element line selections. Thus, after installation of the instrument, exit slit changes may be necessary from time to time, or at least desirable, for the satisfactory analysis of different groups of rocks.

Speed of analysis is not only determined by the ability of the spectrographer to recognize and minimize analytical hazards associated with a particular sample, but also by his ability to select prior to exposure the appropriate instrument sensitivity settings to satisfactorily record line intensity on his working curves, without repeating the exposure with other settings. These factors do not arise where a direct reading instrument is employed on production control analysis, because programmes are usually simpler and element lines can be duplicated, and because matrix and concentration levels of elements to be analysed are approximately known before analysis, with the result that the appropriate sensitivity settings can be made at the first attempt. Also analysis is for major and minor elements where the analytical method employed is not designed to achieve high sensitivity, but rather good precision.

When compared with the photographic instrument the direct reader has other limitations in silicate analysis. The usable spectrum of the direct reader is 2000 to 7000 A°. Though, preferably, the upper limit is 6500 A°, which is the limit to which commercially available red sensitive photomultipliers will operate satisfactorily. Thus the alkali metals, whose most sensitive spectral lines are above the wavelength range of the instrument, e.g. Li 6706, K 6939, Rb 7800, and Cs 8521 etc. can only be determined by less satisfactory lines.

Because of the factors mentioned, one has to be extremely selective in ones choice of analytical lines for a programme, details of which are given in Table 2. This has not always been the case where manufacturers have set up direct readers for silicate analysis, as can be seen in the line selections in programmes of some instruments already in operation. In our own case, after selecting our programme with great care, the manufacturer chose to record B 2498, Be 2348, Rb 4202, Pb 3683 and Li 3232 in the 2nd order, and Zn 2138 in the 3rd order, where there appears no structural reason why these lines could not have been observed in the 1st order. It is possible however, that the manufacturer's choice was influenced by the blaze of the grating employed, and that he anticipated that greater benefit would result by exploiting this rather than the higher sensitivity of lines observed in the 1st order. Dr. Astbury, of the British Ceramic Research Association, claims that photomultiplier receptors are at least 10 times as fast as the fastest photographic plate used in photographic instruments.

In their application, direct readers are complimentary to photographic instruments, in that they are faster and cheaper to operate for quantitative or good semiquantitative analysis, whereas the photographic instrument is better for rapid, less accurate work.

## Modifications for the proposed B.M.R. installation.

In order to meet the requirements of our application we have had the standard direct reader used for production control in the metallurgical industry modified. We have aimed at maximum flexibility for operator control of the instrument. Figure 1 is a diagram of the instrument with modifications.

The instrument being installed is the Hilger 3-metre Polychromator. The optical bench, which is of the conventional style used in large photographic instruments, will accommodate an optical arrangement shown by photographic instruments to be suitable for D.C. arc analytical methods. The optical system employed will focus light representative of the complete arc column, or any part of it selected by means of a diaphragm, into the instrument, but will exclude the light from the electrodes. The D.C. arc source unit will form an extension from the instrument's optical bench, and the top of it will support one end of the 6 foot optical bar. The sloping instrument panel of the source unit is located centrally beneath the arc box, and contains a voltmeter to record the voltage across the electrodes, an ammeter, switches and controls. It is a triggered, constant current unit and has a continuously variable amperage range between 2 and 15 amps.

As a result of Pilkington Bros'. experience in England with a Polychromator used for silicate analysis, we have requested that the entrance slits be reduced from 35 to 15 μ and the exit slits from 85 to 50 μ. These are fixed and their reduction in size calls for more stringent temperature control in the laboratory. Hot air from the source unit and arc box will be exhausted from the laboratory, and air conditioning will be installed to control temperature to ±1° F and humidity to between 35 and 50 percent. Pilkington Bros. found that these operating conditions improved the slope and stability of working curves.

One minute timing clocks in the recording electronic console will be replaced by 5 minute clocks with facilities to prearc up to 30 seconds.

Facilities for coupling a paper feed chart recorder will be provided, and this will enable line profiling during arcing, and hence the study of element excitation characteristics. This facility will aid setting lines on peak, and we hope may provide a means, by scanning the line or by running standard blanks, of evoluting background and detecting line interference. It will be especially useful for examining how chosen lines react in various matrix types at different element concentration levels. Other forms of read-out will be by meter, dekatron tubes and typewriter, all of whose readings will have to be corrected by means of working curves, compiled from standard samples, to determine the concentrations of elements present.

All sensitivity controls are designed to cover the complete useful range of chosen spectral lines in the programme. Fine sensitivity controls provide parallel and angular movement of working curves, where ambient working conditions (such as slight temperature variations) cause a shift.

Matrix corrector and sum corrector facilities are also incorporated.

## Programme Selection.

For our application a comprehensive programme is necessary to meet the requirements of geochemical surveys and research. Table 2 shows the programme and the order of tabulated read-out. Instrumental space usually permits only one line per element in a large programme. From the elements of interest with respect to our application we have selected those which can be satisfactorily analysed by optical emission spectroscopy, and from these, those elements whose sensitive lines can be accommodated in the 1st or 2nd order by the instrument. The instrument design limits exit slit positions so that in the 1st order they can be no closer than 24 A° to each other and in the 2nd order no closer than 12 A°. Up to 50 exit slits can be accommodated at the focal plane. We chose well recognized sensitive element lines which have no apparent interfering lines within 0.25 A° of them.

The elements were then divided into 2 groups (1) volatile and (ii) involatile elements. This uses the electronic console arrangement and exposure timing facilities of the instrument to the best advantage. There are 4 banks of 10 channels, divided into 2 groups of 20 channels each, and the exposure of each group can be terminated by time or by the concentration level of a chosen internal standard in the group. Each group is independent of the other with regard to exposure termination. Each group has 6 of its channels for internal standard use, and patchboard facilities enable any element of the group to be plugged into any of that group's standard channel positions, which are those that can be profiled. Spare channels in each group can be used for duplication or triplication of any element channel in the group, and hence for slight extension of working curves for an element when required.

## Analytical Method proposed.

As the most important aspect of our application is to analyse for trace elements, we plan to use a D.C. arc technique, anode excitation of rock powder with a Pd. - graphite mix to determine involatile elements, and an In -$K_2SO_4$ mix to determine volatiles, Pd and In being the internal standards. Most spark or interrupted arc methods using pelletized samples have good precision but poor sensitivity for trace elements, though it may be worthwhile experimenting in the future with fusion or solution techniques incorporating ion exchange procedure for trace analysis. Both these techniques have the advantage of minimizing matrix effects by reducing the sample to a common chemical and structural state, and hence, with the aid of a tape machine, lead to excellent precision though possibly with some sacrifice of accuracy. However, some spectrographers using fusion techniques have experienced difficulty in obtaining satisfactory line to background ratio for faint element lines, i.e. for low element concentrations. As sensitivity, accuracy and speed of analysis are important requirements in our application we will initially use D.C. arc methods. By using these we estimate that with sample preparation time, up to 33 elements in a sample can be determined in about 20 minutes with an accuracy within 10 percent of the element present. Spectrographers experienced in both photographic and direct reading instruments find that methods developed for the photographic instruments can in most cases be used with little modification for the direct readers.

## Results of trial runs.

Eight working curves compiled from results of initial trial runs made on the instrument by the manufacturer in London have been selected for comment, and are shown in Figure 2. They are Na 5688, Mg 2780, Al 2575, Ca 4425, Cu 3274, Mn 4034, Pb 3683 and Li 3232. The slope of the curves ranges from 50 to 56°. The result for Mg shows that provided a line is set on peak and background minimized, the analytical method employed will produce good results with the instrument. Scatter of points in some curves is not a matter for concern; it probably reflects only the manufacturer's lack of experience with the analytical method. In the case of Ca, the working curve indicates a possible matrix effect. The shift in the working curve occurs for rocks with high silica and low alumina contents.

The main point for concern, however, shown by the working curves is the strong indications that background significantly affects the line intensities of elements present in low concentrations, e.g. Mn, Pb and Na. In fact, many of the results obtained in the trial runs for trace elements, not shown in the diagram, were recordings of background only. This probably indicates that lines for these elements were not set on peak, for in each case there were only low element concentrations in the standard samples analysed. It could, of course, also mean that the instrument lacks sensitivity, and for low element concentrations gives poor line to background ratios. Further trial runs are at present in progress to check exit slit settings, and experiment with masking and filtering, to improve this ratio.

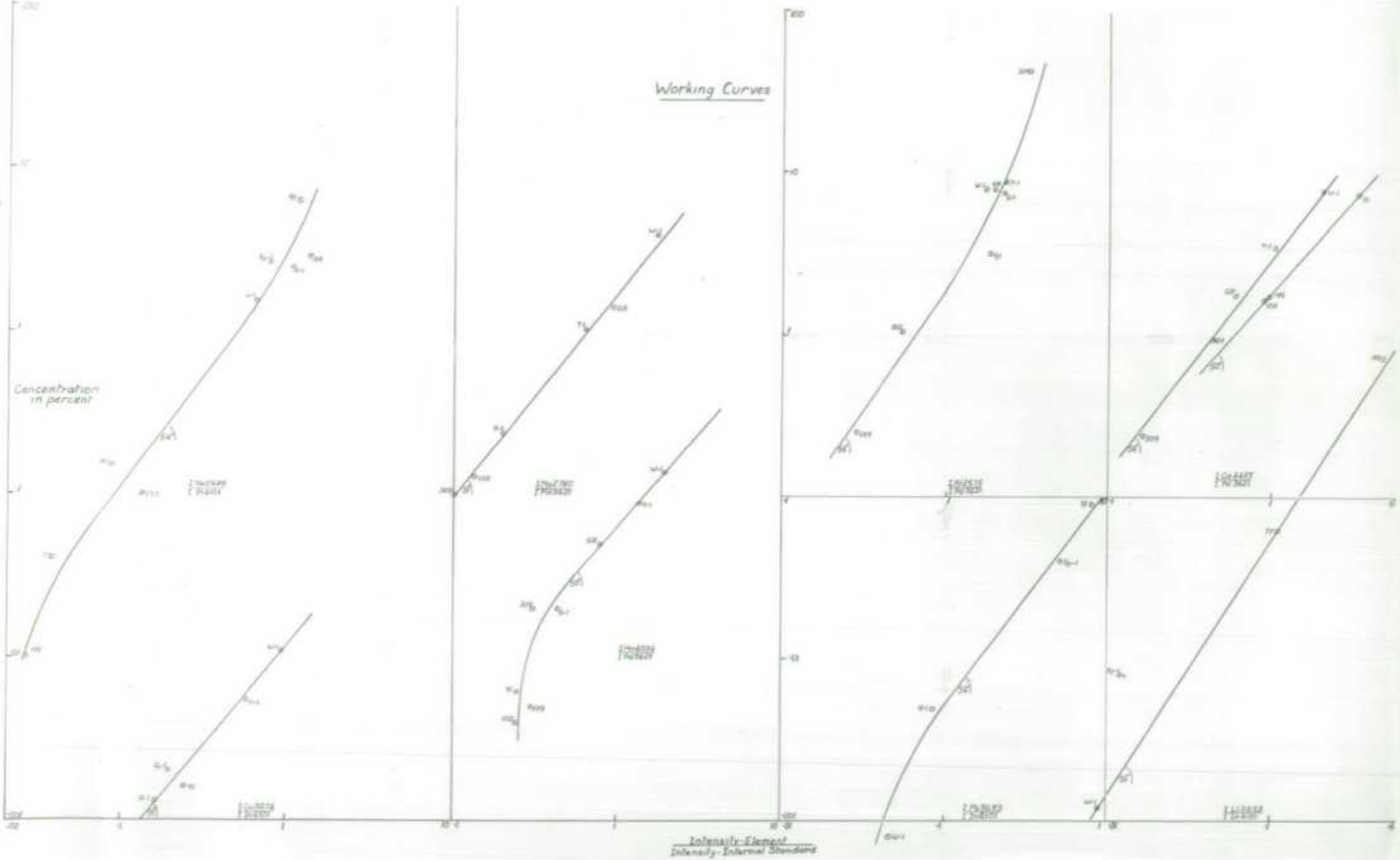
## Possible solutions for problems already apparent.

As the trial runs have shown, the main problem to be overcome is background. The problem of overcoming background next to faint lines has been commented on by all operators of these instruments to date where they have been interested in trace element determinations (Hildebrand, Churchill, Astbury etc. - see Table 1). The answer to the problem, I think, lies partly in the choice of analytical method, for example the selective use of fluxes, buffers, electrode sizes etc, and possibly the use of a Stallwood jet for volatile runs, and partly in controlling (i) exit slit sizes or masking, (ii) appropriate filtering at exit slits, e.g. a glass filter in front of the Sr 4607 exit slit would remove 2nd order UV interference, (iii) the amount of unwanted light entering the entrance slit, e.g. employing a rotating adjustable aperture disc, and (iv) background by directly correcting for it, e.g. employing, as mentioned, the paper feed recorder and profiling facilities to measure it.

Self absorption can be avoided by careful line selection for the programme or by duplicating lines for an element to cover different concentration ranges e.g. we have used Cu 3274 for 1 to 500 p.p.m. Cu, and Cu 2824 for more than 500 p.p.m. The use of the Stallwood jet should also help minimize self absorption where volatile elements are affected.

Line interference is something best checked out thoroughly by a photographic instrument, and again is a problem of line selection. Lines for elements universally suitable under all matrix conditions and for all element concentrations are hard to find. For example I find that Ca 4289.36 interferes with Cr 4289 in basic igneous rocks, and Y with Ti 3982 in syenites etc.

Matrix effects, as for self absorption, fortunately show up in the working curves and are readily detected. For example, in the working curves of the trial runs there was a shift in the curve for Ca in high silica - low alumina rocks. This is a problem of standardization. Dr. Astbury of The British Ceramic Research Association, also found a similar effect using Ca 3968 (1 - 11%) and Ca 3179 (0 - 55%) in rocks with low Al content. In


Working Curves
Concentration in percent
Intensity-Element / Intensity-Internal Standard

his semiquantitative work the most serious deviation for Ca results were in magnesite which contains little or no Al. Even quite small Al content, he found, suffices to make observed intensities lie close to the common working curve.

Availability of standards is a problem faced by spectrographical laboratories everywhere, and especially where the analytical method employed requires control of matrix effects, such as in our case where trace elements will be determined using D.C. arc techniques. A number of rocks and ore standards are in circulation, but these do not give a complete coverage of concentrations for each element in various matrices.

This paper is but a brief review of the problems to date which we are aware will confront us with this instrumentation in its fairly new application to the analysis of geological materials.

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## TABLE 1

## DIRECT READING OPTICAL SPECTROGRAPHS EMPLOYED ON SILICATE ANALYSIS

| Instrument | Location | Application | Analytical Method | Analytical Speed |
|---|---|---|---|---|
| A.R.L. Quantometer | California Research Corporation, La Habra, California.<br>(Dr. Hildebrand) | Geochemistry of sedimentary rocks. | Low voltage "interupted arc" discharge to rotated pelletized sample comprising rock powder, graphite, internal standard-alkali flux mix. Obtained reasonable freedom from matrix effects, good precision but poor sensitivity for trace elements, and inability to read background adjacent to faint lines. | |
| " " | Alcoa Research Laboratories New Kensington, Pennsylvania.<br>(Dr. Churchill) | Mineral and rock analyses for major and minor elements. Geological survey work. | Low inductance spark discharge to pelletized sample. Weighed powder sample mixed with flux, then fused and ground. To this, a salt standard and graphite added before briquetting. Proved to be universal method for miscellaneous materials, because interelement effects, structural effects and rock standard requirements largely eliminated by fusion technique. Method based on Tingle and Matocha (1958), but found too insensitive for trace analysis, for which a conventional D.C. arc method is used. | With sample preparation time, 6 elements determined within 1 to 2% concentration present, in 40 minutes. |
| " " | National Centre of Scientific Research, Nancy, France.<br>(Dr. Govindaraju) | Rock analyses for 10 major elements - analyses for trace elements planned.<br>Programmed for 24 trace elements, - 10 simultaneously. | Controlled arc and spark excitation of pelletized samples. The ground sample first fused with fluxes added, then ground and the product mixed with graphite and Ni internal standard before briquetting. Synthetic standards, approximating composition of rocks for analysis, used to determine best analytical conditions and control instrument's operation. | |
| " " | Aluminium Laboratories Ltd, Arvida, Quebec, Canada.<br>(Dr. Lemieux) | Analysis of bauxite, carbon materials and rock minerals. Also used for analytical control of materials required for aluminium production. Analysis for 13 major and minor elements.<br>29 analytical lines set. | D.C. arc technique on powdered samples, anode excitation using graphite - sample mix and Cu as internal standard for bauxite analysis. For analysis of other elements, a graphite - sample mix and buffer used, with Al as internal standard. Used synthetic standards to determine calibration curves, optical backgrounds, reproducibility and limits of detection. Precision for individual arcings within 5%, and accuracy within 5% of element present. | Quadruplicate analysis of sample in 15 minutes. Does not include sample preparation time. |
| " " | Corning Glass Works, Corning, New York.<br>(Mr. Close) | | | |
| 3 m. Hilger Polychromator. | Pilkington Bros Ltd, St. Helens, England.<br>(Mr. Ward) | Study of raw materials required for glass manufacture, and of glasses, sands and alumino-silicate refractories. | D.C. arc technique, cathode layer excitation. Obtained good sensitivity and fair reproducibility, and, provided strict control of slit widths and instrument temperature maintained, proven photographic methods can be applied directly to direct reader. Method based on Innes (1958). | With sample preparation time, 10 major and minor elements determined within 2% of amount present in 40 minutes. |
| " "<br>(Installation planned) | Australian Glass Manufacturers, Sydney.<br>(Dr. Draycott) | | | |
| " "<br>(Recently installed) | British Ceramic Research Association, Stoke-on-Trent, England.<br>(Dr. Astbury) | Analysis of high silica materials, alumino-silicates, high alumina materials, chrome bearing ores, refractories and pottery glazes. | Spark excitation of solutions or briquetted fusions, using a semiquantitative method (based on Tingle and Matocha, 1958); suitable for wide variety of materials. Found sensitivity of instrument to be 10 times greater than that of the fastest photographic plate. | |

TABLE 1 (Continued) DIRECT READING OPTICAL SPECTROGRAPHS EMPLOYED ON SILICATE ANALYSIS

| Instrument | Location | Application | Analytical Method | Analytical Speed |
|---|---|---|---|---|
| A.R.L. Quantometer | Bolidens Gruvaktiebolag, Skelleftehamn, Sweden. (Dr. Danielsson) i.e. Bolidens Mining Company. | Analysis of ore dressing products, concentrates, ores, rocks and slag and also of geochemical samples, soils and peats. Used also in production control of mining plant processes. Determinations are for 12 major, minor and trace elements. At least 16 analytical lines set. | Spark excitation employing tape machine. Methods involve (1) homogenization of samples with buffer <u>or</u> (2) solution procedure with internal standard added using ion exchange procedure to reduce sample to common chemical and structural state before final powdering and homogenization <u>or</u> (3) fusion technique with buffer and internal standard added, quenching and homogenization. Precision excellent, accuracy good, though accuracy not crucial consideration. | Complete analysis of slags by fusion technique in about 10 minutes. |
| Hilger & Watts 3.4 m. Ebert (with D.R. attachment) (Recently installed) | Anglo-American Corporation, Central Metallurgical Laboratory, Johannesburg, South Africa. | Geological prospecting samples, especially heavy mineral concentrates from panned soil samples, analysed for trace elements. Lines set for 15 trace and 3 major elements. | D.C. arc method, anode excitation for set time, of weighed powdered rock sample - graphite mix after homogenizing. | |
| R.C.I. Air Optical Spectrometer (Recently installed)<br>Jarrell-Ash 3.4 m. Ebert (with D.R. attachment). | United States Geological Survey, Denver, Colorado. (Mr. Myers)<br>Washington, D.C. | Mineral and rock analyses for minor and trace elements. Currently programmed for 22 elements, expand to 40 elements in 12 months and add computer stage. | D.C. arc method, anode excitation employing Stallwood jet (A/O mixture) and magnetic rotation of arc. Methods described in USGS Bull. 1084 - I indicate rock powder mixes with graphite and silica used, but with carbon lines for internal standard. | |
| A.R.L. Quantometer (Recently installed) | Geological Survey of Canada, Ottawa, Ontario. (Dr. Cameron) | Analysis of materials for geochemical problems. Employed on analysis for major elements but propose to develop techniques for trace element analysis. | Spark excitation of pelletized sample. Obtain good precision. | With sample preparation time, complete 100 samples per man week. |
| 3 m. Hilger Polychromator (Installation planned) | Bureau of Mineral Resources, Canberra. (Dr. Walker) | Rock, mineral and soil analyses for major, minor and trace elements. Programmed for 33 elements. 34 analytical lines set. | Plan to use a D.C. arc method, anode excitation of rock powder mixes with In as internal standard for analysis of volatile elements and Pd the internal standard for involatile elements. | With sample preparation time, estimate that a sample can be analysed for 33 elements within 10% of concentrations present in about 20 mins. |
| A.R.L. Quantometer | State Raw Materials Laboratory, Trondheim, Norway. (Dr. Kvalheim) | | | |
| A.R.L. Quantometer | Michigan State University, East Lansing, Michigan. (Dr. Bass) | Analysis of plant materials and plant ash solution for 10 major, minor and trace elements. | Interrupted arc, producing spark-like condition, of solutions with buffer and internal standard added. | Duplicate analysis of sample in 20 minutes for 10 element determination. Does not include sample preparation time. |
| Hilger Poly Spek (Medium quartz spectrograph) | Macaulay Institute for Soil Research, Aberdeen, Scotland. (Dr. Mitchell) | Analysis for trace elements in soils and plants.<br>Determine up to 11 minor and trace elements. | 1. Porous cup spark excitation of solutions with internal standard added. Analytical conditions controlled by synthetic standards.<br>2. Rotating disc triggered A.C. arc excitation of pelletized sample with graphite - buffer mixture and internal standard added. | |
| A.R.L. Quantometer | Union Carbide Nuclear Co., Oak Ridge, Tennessee. (Mr. King) | | | |
| " " | Mallinckrodt Chemical Works, Uranium Division, Saint Charles, Missouri. (Mr. Vogel) | | | |

## TABLE 2.

### BUREAU OF MINERAL RESOURCES - POLYCHROMATOR PROGRAMME

| Volatile Group A. | | | | Involatile Group B. | | | |
|---|---|---|---|---|---|---|---|
| Element | Line | Order | Concentration range | Element | Line | Order | Concentration range |
| In | 4101 | 1st | | Pd | 4321 | 1st | |
| Bi | 3067 | 2nd | 1 - 1,000 p.p.m. | Fe | 3048 | 1st | 2,000 - 250,000 p.p.m. |
| Ag | 3382 | 1st | 1 - 1,000 p.p.m. | Al | 2575 | 1st | 5,000 - 200,000 p.p.m. |
| Li | 3232 | 2nd | 1 - 5,000 p.p.m. | Be | 2348 | 2nd | 1 - 500 p.p.m. |
| | 6706 | 1st | | La | 4333 | 1st | 1 - 500 p.p.m. |
| Ga | 2943 | 1st | 1 - 500 p.p.m. | Sr | 4607 | 1st | 1 - 5,000 p.p.m. |
| Pb | 3683 | 2nd | 5 - 10,000 p.p.m. | Mg | 2780 | 1st | 500 - 250,000 p.p.m. |
| Na | 5688 | 1st | 500 - 50,000 p.p.m. | Cr | 4254 | 2nd | 1 - 10,000 p.p.m. |
| Zn | 2138 | 1st | 25 - 10,000 p.p.m. | Co | 3453 | 1st | 1 - 5,000 p.p.m. |
| Tl | 3775 | 1st | 1 - 500 p.p.m. | Ni | 3414 | 2nd | 1 - 10,000 p.p.m. |
| P | 2534 | 1st | 500 - 300,000 p.p.m. | V | 4379 | 1st | 1 - 5,000 p.p.m. |
| Ge | 2651 | 1st | 1 - 1,000 p.p.m. | Mn | 4034 | 1st | 100 - 50,000 p.p.m. |
| K | 4044 | 2nd | 100 - 50,000 p.p.m. | Mo | 3170 | 1st | 1 - 500 p.p.m. |
| | 6939 | 1st | | Ca | 4425 | 1st | 500 - 300,000 p.p.m. |
| Rb | 4202 | 2nd | 1 - 5,000 p.p.m. | Ba | 4934 | 1st | 1 - 5,000 p.p.m. |
| | 7800 | 1st | | Ti | 3242 | 1st | 100 - 50,000 p.p.m. |
| Cs | 4555 | 1st | 1 - 500 p.p.m. | B | 2498 | 2nd | 1 - 1,000 p.p.m. |
| | 8521 | 1st | | Sc | 4246 | 1st | 1 - 500 p.p.m. |
| Cu | 3274 | 1st | 1 - 500 p.p.m. | Zr | 3438 | 2nd | 1 - 1,000 p.p.m. |
| | 2824 | 2nd | 500 - 10,000 p.p.m. | | | | |
| Sn | 2840 | 1st | 5 - 10,000 p.p.m. | | | | |

| Channel Bank. | Volatile Group A. | | Involatile Group B. | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Standard Channels | In | Li | Pd | Be |
| | Bi | Ga | Fe | La |
| | Ag | Na | Al | Sr |
| Element Channels | Pb | K | Mg | Ca |
| | Zn | Rb | Cr | Ba |
| | Tl | Cs | Co | Ti |
| | P | Cu | Ni | B |
| | Ge | Cu | V | Sc |
| | * | Sn | Mn | Zr |
| | * | * | Mo | x |

* Spare channels for duplicating or triplicating any channel within the volatile group.

x Spare channel for duplicating any channel within the involatile group.

| | | | |
|---|---|---|---|
| Exit slits set | 21 | Exit slits set | 19 |
| Photomultipliers set | 18 | Photomultipliers set | 19 |
| Channels | 20 | Channels | 20 |