

PART F

BENCH TOP AND PORTABLE MINERAL ANALYSERS, BOREHOLE
CORE ANALYSERS, AND *IN SITU* BOREHOLE LOGGING

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1. INTRODUCTION

The general purpose techniques outlined in Part B of this series have been incorporated into a range of instruments for use in the mineral industry. Applications include analysis of samples in the laboratory and in the field, direct analysis at the rock face, analysis of bore cores, and *in situ* analysis in boreholes.

In many applications in the mineral industry, errors in analysis are due both to sampling and to inherent analytical errors. The sampling error is often far greater than the analytical error. Highly accurate analysis of a particular sample often requires the sample to be finely ground which is time consuming and labour intensive. It makes far more sense to analyse many samples with fair accuracy rather than to analyse with high accuracy fewer samples taking the same time and effort. Radioisotope X-ray techniques are well suited to rapid analysis of samples.

In applications where *in situ* measurements are made, e.g. at the rock face or in boreholes, and on samples which are not ground before analysis, e.g. borehole cores, X-ray analysis errors are often largely due to lack of homogeneity of the ore. A higher accuracy is achieved when analysis is averaged over larger sample volumes. K X-rays from higher atomic number (Z) elements are more penetrating than K X-rays from low Z elements, hence best prospects for accuracy of analysis are for higher Z elements. In practice, most successful applications have been to determine concentrations of elements of $Z \geq 50$.

2. BENCH TOP AND PORTABLE MINERAL ANALYSERS

2.1 Introduction

'Bench top' and portable mineral analysers are usually based on balanced filter techniques using scintillation detectors or low resolution proportional detectors. A recent development is the use of high resolution proportional detectors in these analysers. A bench top analyser is built for use in the laboratory. Portable mineral analysers (PMA) can be used in the laboratory, the field, and the mine.

The range of application of these instruments includes :

- . Mineral samples - for ore grade control in mining or process plant control.
- . Metal samples - alloy identification,
- production control of alloy manufacture, or
- scrap metal sorting.

- Thickness measurement - control of electroplating and hot dip galvanising.

2.2 Scintillation and (Low Resolution) Proportional Detectors

Rhodes [1971] has reviewed the techniques used with these instruments and given details of many applications. The usual practice is to determine the concentration of only one element although, by use of balanced filter pairs, analysis for more than one element is possible. A better approach to multi-element determination is to use the high resolution proportional detectors (section 2.3).

Donhoffer [1979] has recently published a survey of manufacturers of X-ray analytical instruments depending on scintillation and low resolution proportional detectors. Their price ranges from US\$10 000 to 20 000 and hence are relatively inexpensive compared with most conventional analytical instruments.

2.2.1 Examples of analysis in the laboratory

A typical analyser, manufactured by AMDEL, is shown in figure 1. The AMDEL analyser has been used in the mineral industry to determine concentrations of Ni, Cu, Zn, Sn, W, Pb and Bi, and in the steel industry to determine the thickness of coatings of zinc (galvanised iron) and copper plate.

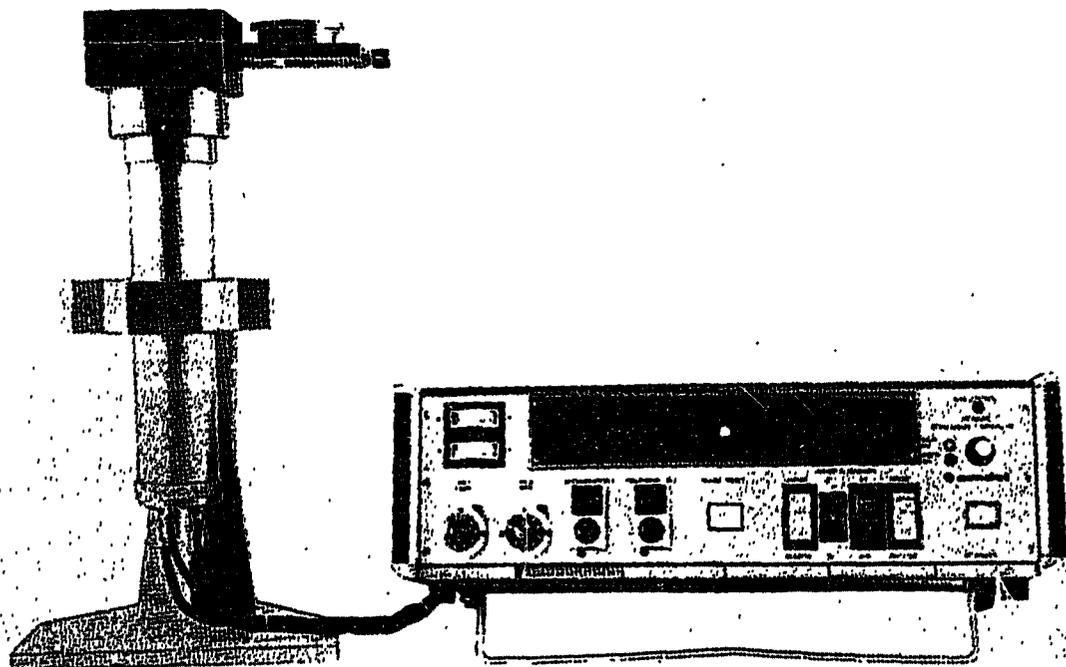


FIGURE 1
MINERAL ANALYSER WITH SCINTILLATION
DETECTOR

Three examples of applications of the AMDEL analyser using different X-ray techniques are given below; all are applied to the analysis of

samples from streams of mineral concentrators.

(a) Tin

Tin K X-rays are excited using ^{241}Am γ -rays. The instrument measures the intensities of X-rays in the tin K X-ray and backscattered γ -ray channels. In the absence of interfering elements, it is not necessary to use balanced filters to obtain accurate analysis.

(b) Nickel

Nickel samples are accurately analysed using the detector-radiator technique (see Part C of this series). Both nickel and iron K X-rays are excited using X-rays from ^{238}Pu , and the radiator suppresses the iron K X-ray component. This technique can determine nickel in the presence of high concentrations of iron, but is not successful when cobalt or copper is present in appreciable quantities.

(c) Tungsten

Preferential X-ray absorption gives good accuracy of analysis for tungsten if no lead is present. Separate measurements are made using γ -rays from ^{153}Gd (~100 keV) and ^{241}Am (60 keV).

Note that in the above examples the ore was finely pulverised in the grinding mills of the concentrator and no further preparation, beyond drying the sample, was carried out. This is possible in many cases where the 'natural grind' is $-150\ \mu\text{m}$.

2.2.2 Measurements at the rock face

The use of a portable mineral analyser to establish ore grades in a mine by measurements in a channel cut across a rock face [Clayton, 1977] is one example of the uses of a portable instrument. It enables a large number of measurements to be carried out rapidly, and gives immediate information to the mine management on the general changes in ore grade. In practice, the number of chemical analyses required is greatly reduced although regular calibration of the equipment is necessary.

Figure 2 shows a portable analyser being used to determine the concentration of zinc across a rock face. Figure 3 shows the difference count rates obtained across the face and also the assayed zinc content determined chemically from chippings taken across the channel. It is seen that relatively good correlation is achieved.

This technique for measuring at the rock face appears to be in only limited use. The main disadvantage is that accuracy of analysis may be very limited because of variations in grain size of the valuable mineral and other components of the ore. Frequent calibration may be necessary, hence many samples must be taken for the conventional assay required for this calibration.



FIGURE 2

MEASUREMENT OF THE CONCENTRATION
OF ZINC ON THE ROCK FACE OF A MINE
USING A RADIOISOTOPE PORTABLE ANALYSER

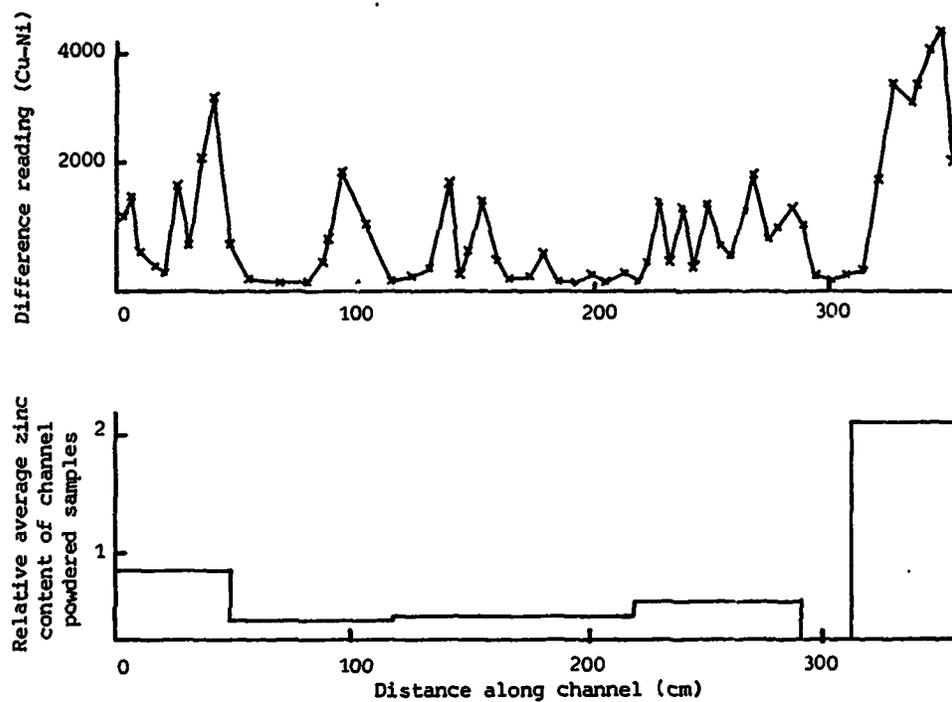


FIGURE 3

COMPARISON OF ZINC CONTENT ACROSS
A WORKING FACE DETERMINED BY
IN-SITU MEASUREMENT WITH A PORTABLE
RADIOISOTOPE ANALYSER AND ANALYSIS
OF A POWDERED CHANNEL SAMPLE

2.3 High Resolution Proportional Detectors

Simultaneous analysis for several elements in a narrow range of atomic number, e.g. $Z = 26$ to 30 can be achieved using the high resolution proportional detector (see Part B of this series). Outokumpu Oy of Finland manufacture the only instrument of this type (figure 4) which is available commercially [Rautala et al. 1979]. It contains a micro-processor to simplify the complex data processing required. The cost of this instrument is about US\$30 000. The robustness of the detector head units in harsh field conditions is not known.

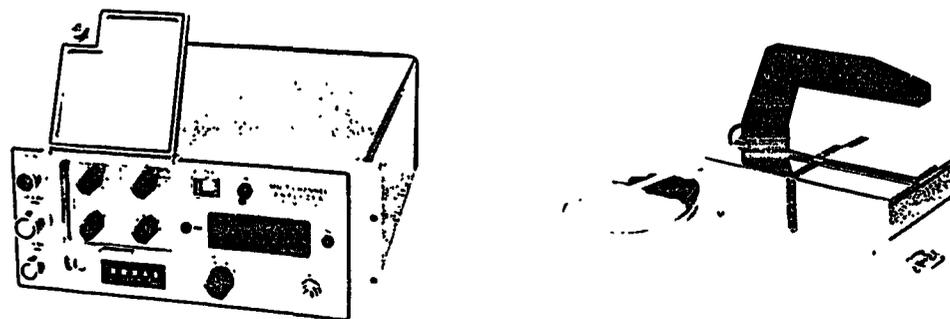


FIGURE 4

ANALYSER WITH HIGH RESOLUTION
PROPORTIONAL COUNTER

2.4 General Comments

Bench top and portable mineral analysers have now evolved to a high degree of complexity because of the advent of microprocessors, and there is no doubt that when properly matched to an application, they can perform a worthwhile function. In many circumstances they can replace even more elaborate equipment.

The operating 'factor' for an analytical device in a particular situation is

$$[\text{function performance}] \times [\text{availability}] / [\text{cost}] .$$

The best equipment, in a functional sense, may not be the best overall because of excessive difficulties in maintenance or because of excessive costs.

We know of several circumstances in which simple mineral analysers have replaced the more complex and expensive X-ray tube machines because the mineral analysers perform *adequately for the application* and are far more reliable (more available) and less expensive to operate (less intricate sample preparation, and use of semi-skilled operators).

Emphasising again the proper matching of an analyser to an application, we expect to see a continuing increase in the use of mineral analysers.

3. MEASUREMENTS ON BOREHOLE CORES

An enormous number of cores are generally taken during exploration and mine control operations. These are normally analysed by chemical assay with significant time delays and at high cost. Equipment capable of giving rapid analytical data has a strong appeal.

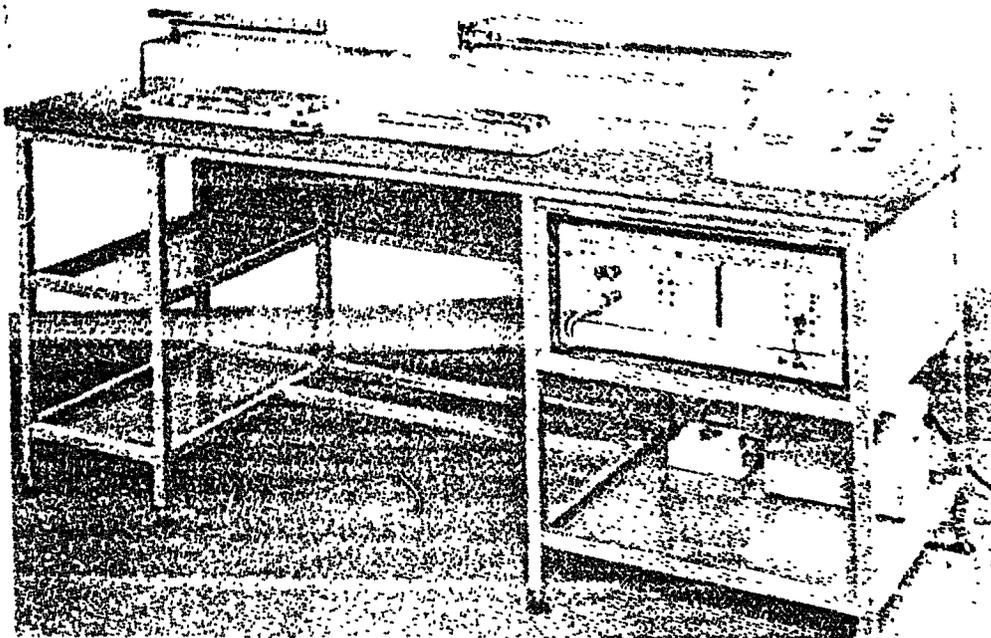


FIGURE 5

X-RAY FLUORESCENCE BOREHOLE CORE ANALYSER

Figure 5 shows a borehole core analyser developed to determine the concentrations of tin [Clayton 1977]. In this equipment, characteristic Sn K X-rays are excited by ^{241}Am radioisotope sources, and detected on a proportional counter incorporating balanced filters of palladium and silver. The difference between the two readings is automatically indicated. In addition, the intensity of scattered γ -rays is also measured simultaneously and, by adjusting the measurement time so as to acquire a constant number of scattered X-rays, the difference reading obtained is directly proportional to tin concentration and independent of matrix variations.

4. IN SITU BOREHOLE LOGGING

Borehole logging equipment based on XRF techniques is finding increasing application in grade control. However, the relatively low excitation and fluorescent radiation energies associated with the XRF analysis, especially for elements of low and medium atomic number ($Z \lesssim 40$), result in a low penetration (generally < 1 cm) into the rock and this restricts application to virtually dry and shallow boreholes.

Most applications are therefore in open-pit mines, and in underground mines where sufficiently dry conditions prevail. For measurement of tin and elements of higher atomic number, operation in partially or fully water-filled boreholes is possible.

By allowing percussion or rotary drilling to be used, the high cost of diamond core drilling is avoided, the cost of analysing a core is eliminated and analytical results are immediate. Because of the reduced cost, additional borehole logging can be contemplated and a more complete picture of the spatial distribution of mineralisation can be obtained.

4.1 Balanced Filter Techniques

Borehole logging equipment designed to measure the concentration of tin is shown in figure 6. It consists of a probe incorporating three 5-mCi americium-241 sources and a scintillation counter with balanced filters of Ag and Pd which are driven by an electric motor also mounted within the probe casing [Clayton 1976]. The axial length of borehole 'sampled' at each measurement is about 5 cm. The probe is attached to a reversible scaler, mounted on a trolley or on one of the two back-packs by a cable which is normally 30 m long. However, the equipment itself

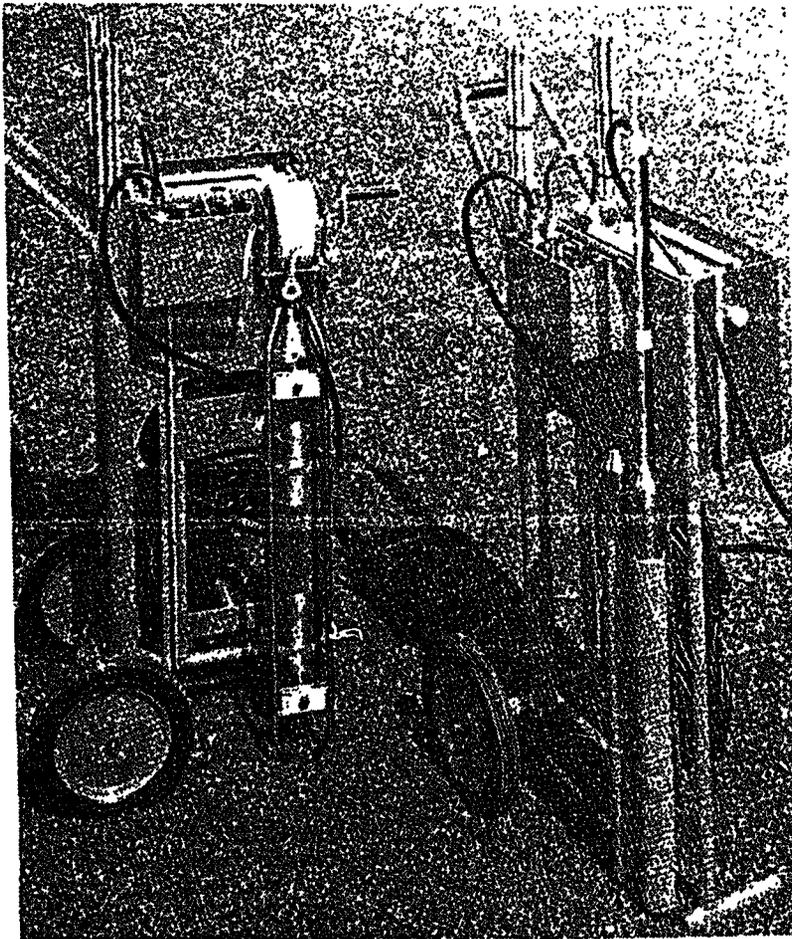


FIGURE 6

BOREHOLE LOGGING EQUIPMENT

The trolley on the left is designed to measure the concentration of copper in "blast-holes" in open-pit mines. The trolley on the right is designed to measure tin concentrations in open-pit and in underground mines.

is designed to operate to a depth of 300 m. All controls are on or adjacent to the scaler and the whole equipment is battery operated. The limit of detection for tin is about 0.1 per cent (95 per cent confidence level due to counting statistics); this accuracy is achieved in a total measurement time of about 30 s (10 s with each filter).

Figure 7a shows a typical log which gives the variations in radioisotope logging signal along a borehole. For comparison, figure 7b gives the chemical analysis of core along the borehole. The correlation between radioisotope log and chemical assay is good, particularly at the higher tin concentrations. There seems to be some discrepancy at lower tin concentrations, the radioisotope log appearing to overestimate the tin concentration.

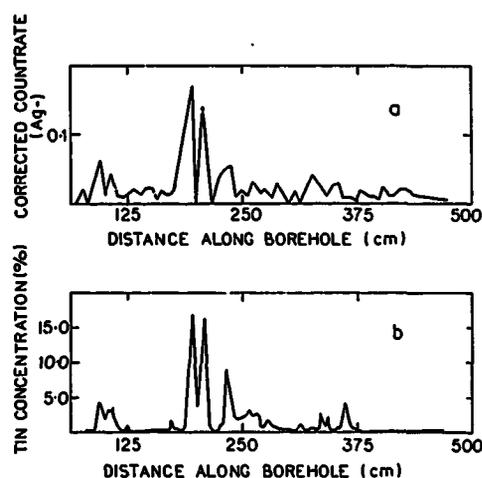


FIGURE 7

COMPARISON BETWEEN BOREHOLE LOG AND
CHEMICAL ANALYSIS OF CORE REMOVED
FROM THE BOREHOLE

The main limitation to use of this type of probe is that, because of the sequential measurements with the balanced filters, continuous scanning of the borehole is not possible.

4.2 Spectral Analysis Techniques

Example 1

Christell et al. [1976] have reported on the logging of boreholes for lead and barium using spectral analysis techniques. The advantage of these techniques is that the hole can be continuously logged. The following discussion is based on their paper.

The lead ore in the Laisvall mine in Sweden occurs as galena impregnations in quartzitic sandstone belonging to an autochthonous series of Eocambrian and Cambrian sedimentary rocks. Direct assay of lead in the production boreholes in the mine would assist significantly in ore calculations and in locating ore boundaries. Preliminary investigations showed that gamma back-scattering techniques could not be used

for unambiguous lead determination because of the occurrence of barium. Therefore a method based on X-ray fluorescence was explored.

The K X-rays of lead at 75 keV are excited by means of a γ -radiation source. The corresponding radiation energy for barium is 32 keV. It was decided to register the X-radiation by means of a γ -ray spectrometer in such a way that each line would fall in its individual energy channel.

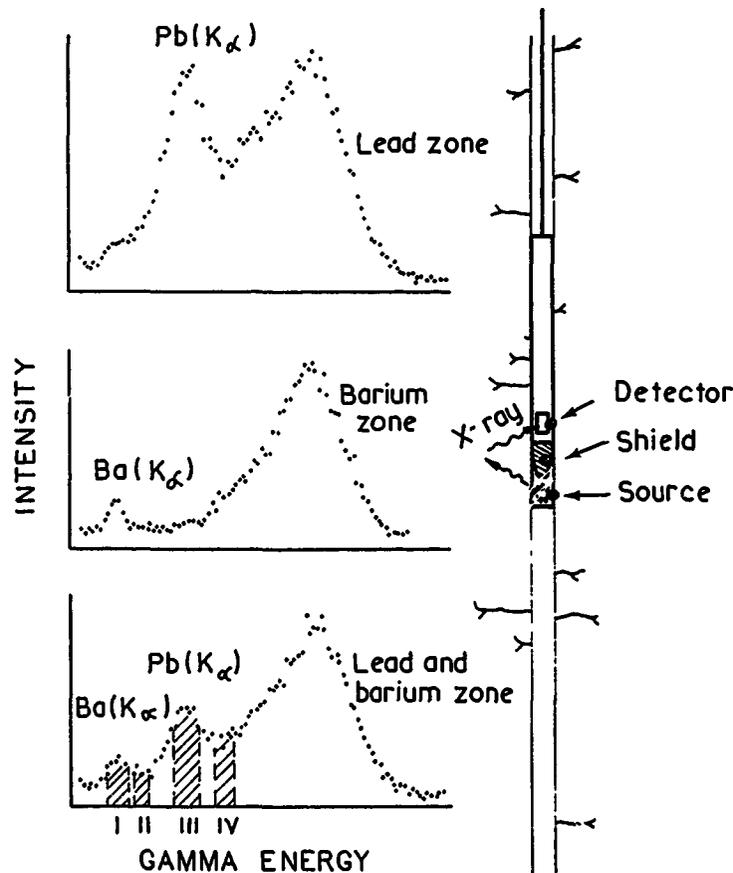


FIGURE 8

SOURCE DETECTOR CONFIGURATION AND
TYPICAL SPECTRA FROM X-RAY FLUORESCENT
LOGGING (XRF)

Two more recording channels were adjusted to register the radiation intensity just above each peak and permit matrix corrections to be made by using the ratio of peak channel to adjacent channel count. The principle is demonstrated in figure 8. The intensity ratios (called lead and barium ratio, respectively), which are independent of counting periods and source decay, are used as a preliminary measure of the concentration of the metal concerned.

When barium occurs together with lead in the rock matrix, the preliminary, approximate concentration value for lead will have to be corrected for the interference from barium, which attenuates the lead

X-radiation. This is particularly important for low lead and high barium contents. By means of measurements in borehole models and core-analysed holes, it has been possible to determine a correction factor for the lead content for varying barium contents.

Calibration of the logging equipment involves fundamental difficulties since the *in situ* measurement and the core analyses cannot be performed on the same volume of material. The difficulty is further increased by the heterogeneous composition of the rock material. An attempt to overcome this problem was made by drilling a number of calibration holes in the mine, arranged as in figure 9. Boreholes with and without cores (diamond drill-holes and percussion boreholes) were used. A calibration diagram for the diamond drill-holes is given for lead in figure 10. The calibration is somewhat uncertain at high lead concentrations mainly because of the insufficient number of comparison values. However, this is not very important since an approximate value for the lead concentration is adequate at high concentrations. For low concentrations, e.g. when determining mining boundaries, the values must be as accurate as possible. The standard deviation of an individual observation, as defined by the least-squares deviation from the best straight line, corresponds to a change in lead concentration of 2.5% Pb.

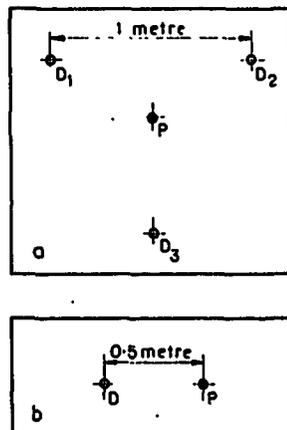


FIGURE 9

GEOMETRIC PATTERN OF (a) THE LEAD-BARIUM CALIBRATION BOREHOLES AND (b) THE HOLES FOR THE ACCURACY TEST
 D = Diamond (core) drilled 56-mm holes
 P = Coreless 51-mm holes

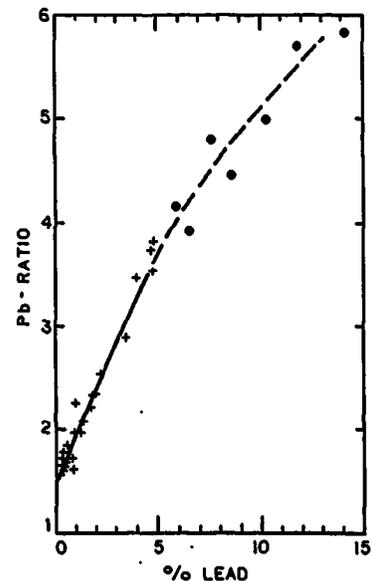


FIGURE 10

CALIBRATION CURVE FOR LEAD IN DIAMOND-DRILLED BOREHOLES

On the assumption that the calibration curves for the diamond drill-holes also apply for the coreless production holes, a number of holes of each kind were logged and the lead concentrations calculated. These concentrations were then compared with the corresponding results from core analyses. A list of some of these measurements and analyses is given in table 1. The discrepancies noted are not greater than can be explained by the heterogeneous-mineralisation. From this it can be concluded that the concentration values for lead obtained by the radio-isotope X-ray fluorescence method are as reliable as those obtained by core-drilling and analysis. Furthermore, the logging technique is much quicker and it enables a very detailed investigation of the borehole profile to be made, even in coreless holes.

TABLE 1

CALCULATED MEAN LEAD CONCENTRATION IN AN ANALYSED ZONE IN THE LAISVALL MINE
(Comparison between core and *in situ* analyses)

Borehole	Analysed Zone (m)	Calculated Mean Concentration of Lead (%) in the Analysed Zone from:		
		Core Analysis	<i>in situ</i> Analysis Diamond-drilled Hole	<i>in situ</i> Analysis Percussion-drilled Hole
1435	0.00 - 11.48	2.56	2.44	2.10
1436	7.10 - 9.86	2.52	2.31	
	0.00 - 11.54	1.20		1.29
1437	0.00 - 4.79	1.78	1.93	
	0.00 - 6.07	2.16		2.31
1438	0.00 - 11.01	7.18	6.76	6.03
1439	0.00 - 11.04	0.45	0.46	0.46
1440	0.00 - 8.91	0.36	0.42	
	0.00 - 12.07	1.12		1.33

Example 2

Preliminary tests have been made with borehole probes based on high resolution proportional detectors. This probe, manufactured by Outokumpu Oy of Finland, can be pushed into boreholes of diameter ≥ 45 mm. Good agreement has been shown between *in situ* borehole measurements and chemical analysis of the bore core (figure 11).

5. CONCLUSION

Bench top and portable mineral analysers have become well established in the mineral industry, and have in some cases replaced more complicated and expensive X-ray tube/Bragg crystal analysers. There is limited but increasing use of radioisotope X-ray techniques of analysis for scanning of bore cores, especially for tin at concentrations greater than 0.1 wt %. The application of radioisotope X-ray techniques to *in situ* borehole logging is increasing, and is particularly suited for logging for tin ($Z = 50$) and higher atomic number elements.

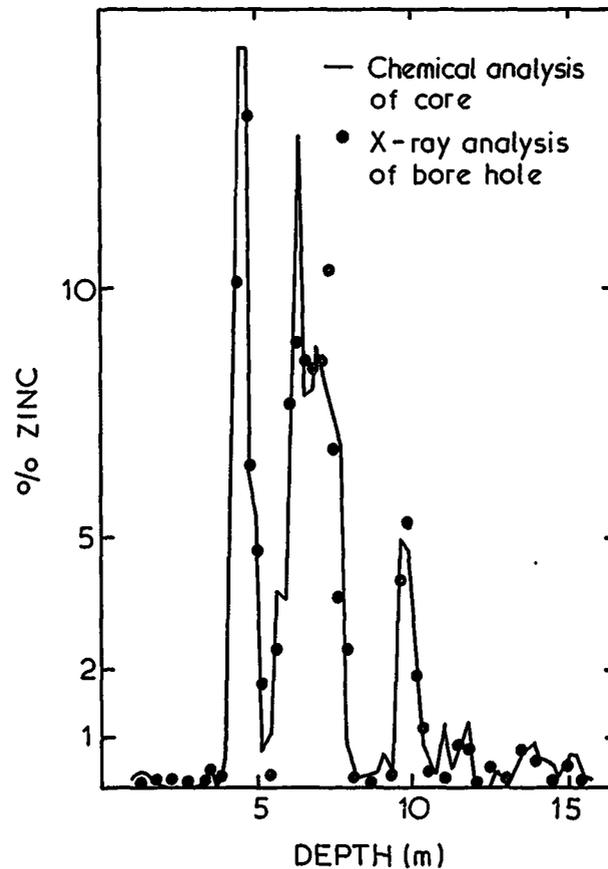


FIGURE 11

COMPARISON OF BOREHOLE EDXRF
AND CHEMICAL ANALYSIS

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