Introduction

Analysis of geological materials has traditionally been very slow in conventional analytical laboratories, which can lead to additional costs being incurred in mining excessively off-reef or processing plants performing below specification because of the delay in getting data back on which operational decisions have to be made. Recent developments in the automation of analytical laboratories now allow for very rapid turnaround times for analytical and quantitative mineralogical data, which can help reduce such costs as well as reduce the unit costs of the analyses themselves.

Many aspects of automation have been around for some time. What is relatively new is their application to the analytical laboratory and the development and invention of the necessary additional components to allow turnkey automated analytical processes to become a reality. A sample is logged in at one end and a final result comes out at the other within minutes. Even the cleaning of all equipment is automated.

A survey of heavy mineral laboratories shows that many of the available automated systems have been incorporated in these laboratories. These include moving samples by air-tube systems and the use of a robot to carry out sample preparation and analysis of sand samples involving milling, pressed powder pellets preparation and XRFS.

However, many other completely manual sample preparation methods are still used in heavy mineral laboratories. These particularly include the labour-intensive methods necessary to obtain, firstly, the heavy mineral fraction of sand samples and, secondly, the various magnetic fractions of these heavy mineral fractions. These are required for evaluating the precise distribution of valuable heavy minerals in orebodies and for plant control purposes. R&D could be carried out to investigate the feasibility of automating all or some of these procedures.

The methods of analysis used in heavy mineral laboratories include XRFS, XRD, wet chemistry, and quantitative mineralogical microbeam techniques. All aspects of XRFS have been fully automated. A method for XRD sample preparation is under development. Sample preparation methods for microbeam techniques are very labour-intensive but some have been developed and it is likely that more could be automated.

Virtually any procedure can be automated. If large numbers of samples need to be processed then it could justify initiating R&D to investigate the feasibility of automating the required procedures.
**Automated sample preparation and analytical methods**

Most instrumental analytical techniques are fully automated so in this context automation involves sample preparation, moving samples around between the sample preparation stages and transporting the samples to the analytical circuit. Automation also involves the computerized tracking of samples from initial input to final output of data.

Automated sample preparation procedures and analyses which have been developed and are now in place in various mining analytical laboratories around the world now include:

- Drying of hard rock samples, e.g. bore-core, and blast-hole chips
- Filter-pressing and drying of slurries
- Crushing of hard rock, e.g. bore-core
- Milling of crushed material
- Preparation of pressed powder pellets for XRFS and XRD
- Preparation of fusion discs for XRFS
- Determination of loss on ignition at four temperatures
- Determination of density by pycnometer
- Determination of the individual precious metals (Au, Ag, Pt, Pd, Rh, Ru and Ir) by automated fire assay
- Wet chemical analysis including all sample preparation and analysis stages and including cleaning of all glassware.

**Advantages of automation**

The advantages of automated over manual procedures in the analytical laboratory are:

- Much fewer staff required, leading to obvious cost savings. A leading automated laboratory estimates these to be of the order of 25–30%.
- Fewer manual procedures result in higher quality of data as human errors such as sample mix-ups are reduced or eliminated. This is subjective and difficult to quantify accurately. However, one automated laboratory manager estimates the necessity for repeats to be reduced by 40–50%.
- Inter-operator bias is removed, also leading to higher quality data as operators all have slightly different ways of doing things.
- An observed result of fewer manual procedures is fewer breakdowns of equipment also leading to cost savings and improved quality of data.
- Analytical laboratories controlling mining and mineral processing in remote areas particularly in first-world countries have great difficulty in attracting and retaining competent staff. A lower required staff complement ameliorates this problem.
- As samples are processed sequentially rather than in batches, as is the practice in a manual laboratory, turnaround time is far quicker, making the data of more use for plant control purposes.
- The quicker turnaround times result in lower unit costs of analysis.
- There are health and safety advantages to operators as they are removed from the dangers of fine dust inhalation (including toxic litharge) and chemical fumes.
- A high degree of consistency is obtained with automated systems as all procedures are carried out in an identical manner.

**Common sample preparation procedures and analyses carried out in heavy mineral mining laboratories**

Common sample preparation procedures, which are typically carried out in heavy mineral mining laboratories are:

- Desliming samples
- Screening samples to typically -175 +75µm
- Drying
- Heavy liquid/medium separation
- Magnetic separation
- Electrostatic separation
- Preparation of pressed powder pellets for XRFS and XRD
- Preparation of fusion discs for XRFS
- Potting, grinding and polishing samples for petrological microscope and mineralogical microbeam techniques
- Dissolution of samples for wet chemical techniques.

Common analyses typically carried out in heavy mineral mining analytical laboratories are:

- XRFS
- Quantitative XRD
- Quantitative mineralogical microbeam analysis
- Wet chemical analysis, e.g. Environmental samples.

**Automation in heavy mineral laboratories**

Most automation in analytical laboratories is associated with XRFS and the necessary sample preparation that goes with it, and heavy mineral laboratories are no exception. In these laboratories typically after manual drying and the other required sample preparation methods, samples commence the automated route of milling, pressed powder pellet preparation and XRFS analysis. Samples are sometimes brought to the laboratory rapidly by air-tube after which they are manually logged in, some sample preparation procedures carried out manually and then enter the automated circuit where they are moved by robot through the XRFS sample preparation and analytical procedures.

As yet there are no automated procedures available for many of the heavy mineral sample procedures used. For some, automated sample preparation procedures are in the process of being developed. For others, automated sample procedures are available but have not yet been used in the heavy mineral laboratory application.

What appears to be common to all heavy mineral laboratories is that sample preparation is very labour intensive and most of the staff employed in these laboratories are used in this capacity.

**Existing automated methods that could be used in heavy mineral laboratory applications**

Existing automated methods that could be used in the heavy mineral laboratory application are:

- Drying. Automated drying ovens served by robots have long been in use in the platinum mining laboratory application as the first stage in fire assay and XRFS analysis.
- Density measurement by pycnometer. This has found an important application in the platinum exploration industry where accurate density measurements are required for orebody tonnage calculations. The same might apply in the heavy mineral industry.
• Automated wet chemistry. This has found a very successful application in the copper mining industry in North America where analyses by wet chemistry are preferred to XRFS. It could also find an application in a heavy mineral laboratory application
• Loss on ignition. This measurement, which is required for the XRFS determination of major elements by fusion disc, can be added to an existing automated XRFS circuit or included as part of a new laboratory.

Obviously the economic feasibility of using these automated methods in a heavy mineral laboratory application would depend on the required daily throughput of samples for these analyses.

Heavy mineral sample preparation methods that could be automated

The sample preparation methods used in heavy mineral laboratories, which could be considered for automation include:

• Screening into different size fractions. This is difficult but could be done. Screening of large, dry samples with automated sample handling and screen cleaning is already carried out on iron-ore mines. This could be applied directly to beach sands, especially if only two screens were used, e.g. 75\(\mu\)m and 175\(\mu\)m. Virtually all the HM fraction occurs in this size range with most of the quartz being discarded in the oversize fraction. However, desliming prior to screening might be necessary and this would probably be achieved manually
• Heavy liquid separation to obtain a heavy mineral fraction. Automation of this procedure is desirable because of the health risks involved in carrying out this procedure manually with bromoform or tetrabromo-ethane (TBE). This is the conventional approach for beach sand heavy mineral fractions. This would also be a difficult procedure to automate but it is possible that it could be done. Lateral thinking would be required to develop a method to achieve the same ends but using a more automation friendly approach. Such a method could be dense media separation (DMS). This has been done on iron-ore mines where an automated DMS system has been developed to remove light particles from large iron-ore samples
• Magnetic separation. Being a dry process this would be a very feasible process to automate. However, a microprocessor-controllable magnetic separator might have to be developed unless this has already been done. A conventional Carpo magnetic separator could not be used as it is essentially a manual instrument. Modern instruments are virtually exactly the same as those of 30 years ago. The only change is that the amp read-out is now digital. For automation it is essential that the amp splitter settings should be microprocessor-controlled
• Electrostatic separation. Also being a dry process this process should be feasible to automate although a more modern instrument might have to be developed. However, not much of this procedure still seems to be relevant in a heavy minerals laboratory
• Potting of samples in resin for petrological microscope and quantitative mineralogical microbeam techniques. This procedure is already under development
• Sample preparation for quantitative XRD. It would be useful to have an automated method for this procedure which would be reproducible and would avoid problem areas such as preferred orientation. Such a procedure is also currently under development
• Plant simulation. Some laboratories put large samples through a simulated plant procedure to evaluate how that material is likely to perform in the plant (called the Geomet method) by RBM. This involves all the procedures carried out in the plant. It is very labour intensive as large samples, typically 1 ton, have to be processed in this way. This set of procedures could be automated. In effect it would be a miniature automated pilot plant.

In principle, virtually any procedure can be automated. If large enough numbers of samples need to be processed using that procedure then it could justify an R&D project to investigate the feasibility of automating that procedure.

Conclusions

It is concluded that:
• Many available automated procedures are already in use in heavy mineral analytical laboratories
• There is scope for other existing automated procedures to be applied in heavy mineral laboratories
• Many currently manual sample preparation procedures could possibly be automated
• Some of these required automated procedures are already under development.

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Pierre obtained his PhD from the Geochemistry Dept., University of Cape Town, in 1972 and was on the research staff of that department for the preceding 7 years. His research work there included analysis of moon rocks and soils brought back by the Apollo 11 moon mission. He then joined Union Corporation, (which became Gencor Mining and finally BHP Billiton), for 25 years where he was Head of Mineralogy, finally retiring in 1998 as Consulting Geochemist. His main function was applied mineralogical research to improve metal recoveries at the Group’s gold, platinum and Base Metal mines. For the last 10 years he has been working for IMP helping develop and implement the automation of mining analytical laboratories.