In the 21st century, dynamic, accurate digital 3-D geological models are essential to the pursuit of safe, efficient and profitable mining. This is particularly true for the deep-level underground mines in South Africa. The Sirovision® solution is a collaboration project between the Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation), Datamine Software Ltd. and AngloGold Ashanti Ltd (AGA). The purpose of the project is to provide a fully integrated digital rock face imaging, geological mapping and modelling system for the AGA gold mining operations.

Subsequent to promising underground test results from AGA’s Sunrise Dam Gold Mine (SDGM) in Australia and other mining operations worldwide, it was decided to test the Sirovision® system in the South African deep-level gold mines. The first underground tests at Moab Khotson Mine began in January 2009. The objectives of these tests entailed the capturing of 3-D images of selected development ends, mapping of geological features onto the 3-D images and integration of the mapping data with the 3-D geological model. Some downsides have cropped up during the feasibility testing, related to practicality of the SCR for acquisition of 3-D imagery in the deep-level underground operating environment. These constraints will have to be addressed prior to operational implementation. Facing such difficulties is not unusual when attempting to implement new technology in such a challenging working environment and test work is still in progress at the mine in order to prove the concept of using this technology in a Witwatersrand underground gold mine.

The great advantage of the Sirovision® solution is that it offers the geologist the opportunity to work remotely on a 3-D virtual copy of a mining excavation, without the heat, humidity, hazards and time constraints associated with physical mapping in an underground workplace.

**Introduction**

In the 21st century, accurate digital 3-D geological models are essential to the pursuit of safe, efficient and profitable mining. This is particularly true for deep-level underground mines in South Africa. New technology is continuously being developed and tested in different mining environments in pursuit of a more dynamic geological workflow process. The Sirovision® system is a collaboration project among the Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation), Datamine Software Ltd. and AngloGold Ashanti Ltd (AGA). The purpose of the project is to provide a fully integrated digital rock face imaging, geological mapping and modelling system for the AGA gold mining operations.

The purpose of this paper is threefold:

- To provide an overview of the Sirovision® technology and its intended application to mining geology in general
- To consider AGA’s experience to date, in terms of the system’s suitability, test results and implementation at different mining operations around the world
- To highlight the feasibility study currently underway at the company’s Moab Khotson mine, one of its deep-level Witwatersrand gold mines. This study gives a realistic assessment of the opportunities and downsides
associated with the introduction of new technology in a very challenging mining environment. It also provides a view of future expectations of the technology.

**Overview of the Sirovision® technology**

**Background information**

The Sirovision® technology was developed by the Australian CSIRO (Commonwealth Scientific and Industrial Research Organisation) at the Queensland Centre for Advanced Technologies in Brisbane, Queensland with input from relevant scientists, including geologists, physicists, surveyors, engineers and IT professionals (www.sirovision.com). The first commercial sale of the product was already in 2001, with reported successful application from various large mining companies (www.sirovision.com). This technology is best described as a 3-D digital geological mapping acquisition and analysis tool. In the initial stages Sirovision® was appropriate only for geotechnical application, but the system is continuously being improved to make it suitable as a total structural mapping solution.

**Sirovision® equipment**

Different sets of equipment and software solutions have been developed for use in open pit and underground mining environments. The need for different solutions originates from the fact that the physical characteristics of the operating environments are very different and survey control points are obtained in very different ways.

**Open pit equipment**

The open pit solution is not the focus of this paper. However, a brief overview of the system seems to be appropriate for the sake of providing background information. The equipment consists of one high quality digital camera with a selection of lenses appropriate for the operating environment, a rugged case for safe transportation of the equipment and a tripod (Figure 1). A Nikon 300D digital camera was selected for use at Sunrise Dam Gold Mine in Western Australia, but a whole range of different Nikon, Olympus and Canon cameras and lenses are available for use with Sirovision® (www.sirovision.com). The positioning of the camera system is used as input for survey control in the image processing software, and therefore is measured with a high precision differential GPS.

**Underground equipment**

The CSIRO-developed Sirovision® portable stereo camera rig for underground use (Figures 2a and 2b) is a single unit that consists of a built-in rechargeable power supply, a lighting system, a laser guidance system, two Nikon D200 10.2 megapixel digital cameras, a flash unit (all synchronised to activate from a single button) and the image processing software. The containing unit consists of an aluminium frame with durable transparent Perspex panels for ease of operation. The unit can be mounted on a tripod or monopod, whichever is appropriate for the operating conditions.

The camera rig unit alone is portable and can be handled by one person (Figure 2d). The dimensions are approximately 88 cm × 30 cm × 25 cm and it weighs 13 kg. A rugged case for safe transportation has been manufactured (Figure 2c). The dimensions of the case are 98 cm × 25 cm × 38 cm and it weighs 14 kg. The combined weight (27 kg) and dimensions of the camera rig and case is an important practical consideration in terms of application in South African deep-level underground mines, and is discussed later on in this paper.

![Figure 1. Sirovision® open pit equipment. The camera and lenses in the container box are shown on the left in Figure 1a. On the right in Figure 1b is an example of field use of the open pit equipment (www.sirovision.com)](image1)

![Figure 2. Sirovision® underground stereo camera rig. Figure 2a is a front view of the camera rig, i.e. the camera lenses, flash unit and lighting system. The control units and LCD camera displays on the back view is shown in Figure 2b. A photograph of the camera rig in the rugged transportation case is shown in Figure 2c. Operation of the camera rig on a monopod is shown in Figure 2c courtesy of www.sirovision.com)](image2)
Fundamental theory of the Sirovision® software

The imaging system operates on the principles of photogrammetry, which is commonly known for its application in using a stereoscope to view aerial photographs (van Wyk, 2008). The stereophotogrammetric process in this application involves the overlaying of two 2-D images with a central focus point, after which mathematical algorithms in the Sirovision® software extract 3-D information from the 2-D image pair (van Wyk, 2008). The principle components of a stereophotogrammetric system are illustrated in Figure 3.

The output from the image processing algorithm is a computer-generated 3-D model of the spatial arrangement of the images that were captured in the 2-D view frames. The 3D model can then be registered in its true spatial orientation by using known survey control points in the images for 3-D georeferencing – this is done in the Sirovision® software. The output from matching several image pairs is a computer-generated, full 3-D, virtual copy of the mining excavation. The image resolution and relief are of sufficient quality to distinguish different rock types and structural contacts (Figure 4).

Integration with Datamine software

In order to make optimal use of the acquired digital 3-D photographic information, the Sirovision® software has been packaged as an integrated module within the Datamine Studio3 geological modelling environment. Datamine Software Ltd. completed the following software developments in association with AngloGold Ashanti Ltd. as part of the Sirovision®-Datamine integration project:

- SiroLink (new application): automatically moves the digital images from the camera and allows the user to visually validate which images to use as stereo image pairs as well as the order of matching. The images and survey information are placed in a data store. The purpose of this application is to minimize the risk of invoking human error in the data handling process.

- MineMapper 3D (enhancements to existing application): retrieves one image of an image pair from the data store and allows mapping, as digitized line work with appropriate descriptions, to take place on the single 3-D image, after which the mapped data are stored in the MineMapper 3D database. The aim of this enhancement was to improve efficiency in terms of the handling of large image file sizes.

- New functionality in Datamine Studio 3:
  - Functionality to allow the creation and positioning of 3-D images (integration of Sirovision® software within the Studio 3 environment).
  - A data driver for Sirovision® 3-D images to enable loading and visualization within the Studio3 modelling environment.
  - Functionality enabling features to be identified on the 3-D images and converted to planes (similar algorithms are used in the SiroJoint module).

The updated functionality within Datamine Studio3 is used to add geological intelligence to the 3-D images provided by Sirovision® solution. The geologist identifies and ‘draws’ lines representing geological features directly onto the image by means of on-screen digitizing (Figures 5 and 6). Figure 5 is an example of geological features mapped onto the 3-D image. Currently the list of geological features is user defined and can be modified to cover a comprehensive range. However, prior to regional implementation it is important to consider a dedicated database and appropriate metadata scheme, as was also suggested by van Wyk (2008). This is essential from a standardizing and data management point of view. Figure 6 is an example of joint plane traces mapped onto the 3-D image of the rock face. By utilizing the inherent ‘topography’ of the 3-D image, the software is able to convert the lines into 3-D surfaces, ready for use in the 3-D geological model (Figure 7). Essential information – such as feature types, lithology, dip and dip direction – for each of the identified surfaces is stored in a local database. This information can be used in analysis applications, e.g. geotechnical analysis of joint set characteristics by using the SiroJoint module.
Sirovision® trials at AngloGold Ashanti (AGA) gold mines worldwide

Testing and implementation of the Sirovision® system has been in progress since 2003 at different mining operations of AGA worldwide. The aim of this section is to provide a summary of the experience recorded by different operations. The map of AGA global mining operations (Figure 8) is provided as a reference in terms of locality of the operations mentioned in the rest of this section.

Geita, Tanzania

Sirovision® is applied for creating 3-D faces of the open pit walls and subsequent geotechnical analysis. The system is reportedly good for mapping large brittle structures, but poor in delineating lithological contacts and ductile deformational features. This is not regarded as a limitation of the software, but rather due to weathering effects and rock staining in the pit walls. Manual field mapping is still required, but Sirovision® might be used to acquire additional value adding information from areas that are unsafe or out of reach. In such cases, a lot of emphasis will be placed on interpretation of the actual field mapping as a priori data to be used in conjunction with the Sirovision® 3-D imaging. For the moment the focus remains on geotechnical application.

Siguiri, Guinea

Siguiri reported similar results to Geita, where the Sirovision® system is in use only for geotechnical data acquisition and analysis in an open pit environment. The only noteworthy complaint raised was about the intense computing power required to run the virtual reality graphics and image processing algorithms, which are at times frustratingly slow.
SIROVISION®: A PROPOSED SOLUTION FOR THE IMPLEMENTATION OF A DIGITAL SYSTEM

AGA Mineração, Brazil

Sirovision® testing is in progress at Cuiabá mine, an underground trackless mining operation in Brazil. The test results are summarized as follows:

- Hardware constraints were reported. The camera lenses take approximately 40 minutes to acclimatize to hot and humid conditions underground and cannot be used until all of the fog build up disappears. At times the flash unit malfunctioned, and the source of the problem could not be traced.
- Image resolution is of sufficient quality to identify lithological contacts, geological structures (foliation and faults) and reference points, whereas time of image acquisition is short (46 image pairs in one day). Reference points are surveyed by means of Total Station, which is also quick and precise.
- Image processing time is the main problem. Geometric correction takes at least 5 minutes per image plus an additional 15 minutes to process each 3-D image pair.
- The mine only recently upgraded its software to Datamine Studio3, which will now enable the testing of the integrated Sirovision®-Datamine solution.

Sunrise Dam Gold Mine (SDGM), Australia

SDGM is one of the operations where both the open pit and underground applications of Sirovision® could be tested. No noteworthy problems were reported for the open pit application and results were considered to be of good quality. A pilot project was undertaken early in 2008 to put Sirovision® to the test in the trackless underground ore drives (van Wyk, 2008 and Datamine Software Ltd., 2008), producing promising results. Conclusions from the test results are summarized as follows:

- Safety is one of the main reasons for developing Sirovision®. The system makes it possible to capture images of exposed rock from some distance away from the face.
- Illumination: the powerful flash unit of the camera rig provides excellent illumination in order to capture clear images in true 3-D.
- Time: a considerable reduction in mapping time was recorded, i.e. manual mapping of 4 hours replaced by Sirovision® process of 1½ hours (166% improvement).
- Geological data archive: a full 3-D record of the rock face exposure can be kept for future reference. Consistent electronic recording of geological attributes to a database will enable simple retrieval and analysis of data.
- Accuracy: a 20% increase in accuracy is reported, based on the consistent mapping by the system, as opposed to the varied physical skills and capabilities of individual geologists.
- Exposure: an increase of 122% in the amount of exposure mapped is achieved. This is because the camera rig can capture the full picture (4 m high) from the bottom to the top of the excavation, whereas a geologist is limited to approximately 1.8 m height for accurate observation and recording of data.
- Geological mapping: Sirovision® is good for the mapping of large scale structures, but detailed mapping - e.g. mineral lineations, slickensides and foliations - requires manual observation and recording.

Sirovision® at AngloGold Ashanti’s Moab Khotsong Mine, South Africa

Subsequent to promising underground test results from Sunrise Dam Gold Mine (SDGM), it was decided to test the Sirovision® system in AGA’s South African deep-level underground gold mines. A feasibility study is currently in progress to assess the value and suitability of the system in this type of operating environment. The aim of the study is to successfully capture 3-D images of exposed rock faces in selected development ends, map geological features onto the 3-D images and integrate the mapping data with the current 3-D geological model. The first underground tests began at Moab Khotsong Mine in January 2009. These tests indicated that, conceptually, the Sirovision® system has huge potential to add value to the geological workflow process. However, it is also important to take note of the potential pitfalls encountered during this study. The
The remainder of this section is dedicated to discussing these pitfalls and the measures that have been put in place to ameliorate their associated risks, as well as to present some of the results obtained to date.

Risk assessment

A valid risk assessment document must be available for all equipment utilized on the mine premises or in the underground working places. The risk assessment documentation for the Sirovision® Stereo Camera Rig (SCR) was compiled by Datamine South Africa and accepted by the Moab Khotsong Mine Safety and Health department (a copy of the document can be supplied upon request). The key issues addressed in the risk assessment are the handling of the heavy equipment, and the fact that the equipment is not classified as intrinsically safe (i.e. the SCR is not fireproof). The Witwatersrand gold mines are well known for containing sources of flammable gas that can possibly ignite due to the slightest electrical spark or the use of a camera flash unit. Therefore it is imperative that a burning permission document is obtained from the appointed section manager prior to each underground test. Furthermore, it is required that flammable gas concentration measurements are conducted continuously by means of a certified flammable gas monitoring device.

Practical constraints and limitations

Size matters

The dimensions (98 cm x 25 cm x 38 cm) and weight (27 kg) of the SCR is not problematic in a trackless mining environment where the equipment can be transported on the back of a pick-up truck and handled over short distances by one person. However, this is a very important practical consideration in terms of transportation in a South African deep-level underground mine:

- The SCR equipment has to travel down a vertical shaft in a cage (conveyance used to transport persons and materials). In this situation the persons travelling in the cage are at risk of being injured by the equipment. The equipment is also at risk of being damaged by persons leaning against or standing on the case. At Moab Khotsong Mine, there is often water seepage into the shaft. To accommodate this, a waterproof bag was designed to cover the SCR case (Figure 9). The bag was designed with 6 handles to make it possible for two or more persons to carry the equipment whilst travelling on foot.
- Horizontal transportation on some levels is done by means of man carriages. In such cases the SCR is transported to the designated carriage bay of that level.
- From the man carriage bay persons are generally required to walk up to 3 km to the development working places. It is not always possible to arrange additional carriage transport, as the conveyances are used for production activities. Walking long distances underground on rail tracks, while carrying an uncomfortable load, is very strenuous and time consuming, and probably the main limitation with respect to operational implementation of the system. Datamine Software Ltd. has taken note of this, and is in the process of redesigning and building a new SCR, which should be more practical for underground use.

Humidity

During underground tests at Moab Khotsong Mine, it was noted that the camera lenses take up to 45 minutes (after being removed from the case) to acclimatize to the humid underground conditions. The cameras cannot be used before the fog build up disappears, as it causes hazy, unusable photographs. This is problematic, as underground time at the face is extremely limited in this type of mining environment.

Hardware malfunction

During the initial underground tests only one of the cameras on the SCR functioned at times. This meant that for some images the stereo pairs could not be generated as the anticipated matching image did not exist. The only explanation for this was that the shutter release system was temporarily faulty and did not trigger the second camera. Being intermittent, the fault is difficult to remedy. It might be that transportation of the equipment, combined with the heat and humidity present at the test site led to temporary malfunctioning of some electronic components – this has been observed in other electronic equipment tested in some of AGA’s other Witwatersrand gold mines.

Focal length and camera positioning

The focal length of the Sirovision® SCR is optimized for photography approximately 5 m away from the camera lenses. In principle, this should work well when recording
images of the advancing face of the development tunnel. The underground development ends at Moab Khotsong Mine have dimensions of approximately 4 m in height and 3.8 m in width, which is problematic for the photography of sidewalls as images are out of focus. The SiroLink image pairing process still creates a 3-D image from the two 2-D images, but the matching algorithm has difficulty matching ‘out of focus’ points. The resultant 3-D wireframe is ‘spiky’ as shown in Figure 10 and not useful for mapping or combining with adjacent image pairs.

Another problem encountered was the orientation of the camera relative to the rock face to be photographed. If this relative angle is not close to 90 degrees, a ‘curved’ model is derived, due to the different relative distances of the camera to the rock face. An example is shown in Figure 11. Even though the image resolution is good, geological mapping in 3-D space cannot be done by using this image pair.

**Interfering objects**

During the underground trial another important observation was made. Figure 12 is an example of how objects (hoses, in this case) between the SCR lenses and the observed rock face will cause distortion in the 3-D model. This interference is problematic when acquiring underground 3-D image pairs at Moab Khotsong Mine.

Figure 13 shows a blasted rock face before temporary support is installed. Temporary support is installed directly after the broken rock has been removed, (Figure 13.b.) to ensure the safety of the persons that will be drilling the face for the next blast. This process leaves very little time available for the acquisition of images for use in the 3-D model. During underground trials it was found that in most cases the temporary support was installed before the photographs could be taken.

**Underground test results from Moab Khotsong Mine**

In the preceding sections a few results from underground tests at Moab Khotsong mine were presented (Figures 10 to 12) and discussed. In Figure 14 an example is shown of geological features ‘drawn’ onto the 3-D image by means of on-screen digitizing along with the 3-D planes generated from the line work. This image pair was again slightly out of focus, and therefore the 3-D model was not to the required standard of accuracy. As a result it can be observed that the calculated planes do not coincide exactly with the features on the image.

**Project status discussion**

The feasibility study underway at Moab Khotsong Mine is still at a very early stage. The concept and its suitability to this type of mining environment still need to be proven. Limitations and errors are documented in detail in order to derive the suitable ‘best practice’ when utilizing the Sirovision® in these conditions.
To date, no perfect set of 3-D images has been captured, and could thus not be combined to generate a completely accurate 3-D virtual copy of the mining excavation as anticipated. Nevertheless, valuable lessons have been learnt during the underground trials at Moab Khotsong Mine, as discussed in the preceding sections. Another important factor to consider is the extensive processing time required to produce the 3-D image models. In ideal conditions the photography will be quicker than conventional mapping, but the processing of images can take up to 4 hours, depending on computer specifications. Digital mapping of elements onto the images can begin only after this processing is complete.

Image resolution is of a high standard and the Sirovision® imaging system has the potential to add value to the geological workflow process in the form of input for the 3-D geological and geotechnical models. It will also provide a permanent true 3-D record of the mined-out excavations. Therefore, further tests are planned to take place at Moab Khotsong. Another test site of appropriate dimensions will be selected, and timing will be planned carefully, in order to conclude the imaging process prior to support installation. As soon as a useful set of 3-D images is obtained, attempts will be made to integrate the acquired data with the existing 3-D geological model in use at Moab Khotsong Mine. This will also be a challenging exercise, as
AGA’s South African mines do not currently use Datamine products for 3-D modelling and some customization to the applications and data management systems will have to be considered in order to achieve full integration.

Additional underground testing is also planned to take place at AGA’s Mponeng Mine on the West Wits line, where an appropriate test site might be more easily accessible and more often available.

Conclusions and recommendations

Results from test work underway at Moab Khotsong mine indicate that the Sirovisor® system could be beneficial in the acquisition of high quality digital geological mapping data, ready for integration with the 3-D geological model. A permanent 3-D record of the underground excavations would add value to the geological workflow process. However, the system still has to be proven to deliver useful results in the required operating environment. To date, no perfect set of 3-D images has been captured, and could thus not be combined to generate a 3-D virtual copy of the mining excavation as anticipated. Nevertheless, a number of valuable lessons have been learnt during the underground trials at Moab Khotsong mine, which will aid in refining and ultimately perfecting the 3-D imaging process.

Some practical constraints related to the application of the Sirovisor® system in a Witwatersrand gold mine need to be considered. The current format of the Sirovisor® Stereo Camera Rig (SCR) is impractical for daily routine usage at Moab Khotsong mine. The size and weight of the camera rig has a large impact on transportation within the underground mining environment. The Sirovisor® SCR in its current format would most likely be suitable only for application in high priority development projects where the time and effort required to acquire and process 3-D images are warranted. Datamine Software Ltd. has reported that a redesigned SCR is currently being built, as a result of the impracticalities associated with the current SCR, but no details have been disclosed to date. Test work will continue in the feasibility study in order to prove that the concept will work for AngloGold Ashanti’s South African deep-level underground gold mines. The introduction of the improved and more practical hardware will assist in the implementation process.

The great advantage of the Sirovisor® system is that it would offer the geologist the opportunity to work remotely on a 3-D virtual copy of a mining excavation, without the heat, humidity, hazards and time constraints associated with physical mapping in an underground workplace. It is, however, important to note that ‘ground-truthing’ of detailed underground geological mapping data will still be required.

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Directly after graduating from the University of Pretoria in 2003 my career within AngloGold Ashanti commenced. I have had the opportunity to work at two of the Witwatersrand gold mines in the Vaal River region (Moab Khotsong and Tau Lekoa), fulfilling different roles within the mining geology and local resource estimation sub-disciplines. I have also had the opportunity of fulfilling exploration duties from the SA Exploration office. I am currently based at the SA Division Geoscience Technical Office (GTO) with responsibility for geoscience technical systems and technology.