

# Using the ANZI Strain Cell in Exploration Boreholes to Determine Three-Dimensional Stresses at Depth

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## Abstract

This paper describes recent use of the ANZI (Australia, New Zealand Inflatable) strain cell and the overcoring method of stress relief in exploration boreholes to determine three dimensional in situ stresses at depths approaching 1km in a one-day operation. The results from each of the various stages of a routine overcoring operation are described to illustrate the information each step can provide. The results from an Australian site is presented to illustrate the opportunities to characterise the three dimensional in situ stress environment when multiple high confidence measurements are achieved.

The ANZI strain cell is an instrument system that uses the overcoring method of stress relief to determine the three dimensional in situ stresses in rock. The instrument has been used successfully for over three decades in numerous underground mining and civil projects, but technical advances over the last decade have allowed the system to be deployed routinely in surface exploration boreholes. Recent development of a downhole high-precision data logger, a wireline enabled drilling system and an instrument deployment system has simplified the process of obtaining three dimensional overcore measurements remote from any underground excavation at depths approaching 1km.

The capability to deploy ANZI strain cells from surface exploration boreholes represents a significant breakthrough for the design of mines and underground civil structures. High confidence characterisation of the in situ stresses at the design stage provides an opportunity to design key infrastructure to take advantage of the in situ stress field from the outset before any excavation even begins. Understanding the three dimensional in situ stress field not only provides a measure of the magnitude and direction of loads acting within the rock mass, it can provide insight into the mechanics of the various processes driving ground deformations.

**Keywords:** overcore, stress measurement, ANZI Strain Cell, in situ stress.

## Introduction

The overcoring method of stress relief is one of the most direct methods for determining three dimensional in situ stresses in rock. Overcoring the ANZI strain cell enables a characterisation of the three dimensional in situ stress field, an assessment of the mechanical properties of the rock at a range of confining pressures, and importantly, provides an indication of how much confidence can be placed in the result.

A brief overview of the history of the ANZI cell is provided for context. Recent advances in the ANZI overcore system to enable measurements in surface exploration boreholes to 850m depth include:

- wireline enabled drilling techniques to prepare the pilot hole
- modular instrument deployment and pressurisation system
- high precision downhole strain, pressure and temperature logging
- increase in the number of axial gauges to measure axial strain variations.

The operation of the instrument and the various stages of testing used to provide confidence in the integrity of each measurement are detailed. Finally, a case study from a multiple-overcore campaigns from an Australian metalliferous mine in the design phase is presented to illustrate the spatial and vertical variability in the stress field that can occur at the local and mine scale.

## **Stress Measurement Technology and Limitations**

The concept of stress is a convenient engineering construct to link displacements and their derivative strain with forces through idealised models of material behaviour. Displacements and strain changes can be measured, but stresses do not actually exist as something that can be measured directly. Changes in stress can be calculated from changes in strain in a continuous, homogeneous, isotropic, linear elastic (CHILE) material.

To determine the in situ stress from overcoring requires:

- a change in loading conditions usually from in situ conditions to, ideally, conditions of zero stress
- the measurement of at least six independent strain changes during this process
- an assumed model of material behaviour relating strain changes to stress changes.

This process means that the in situ stresses determined are based on imperfect measurements of strain change and an idealised model of the rock behaviour. While the term “stress measurement” has been widely adopted, and is convenient to use in some circumstances, the fundamental limitations of the terminology should be recognised.

The overcoring process used with the ANZI strain cell allows a stress change in the rock, from the in situ state of stress at the start of overcoring to a zero state of stress at the end of overcoring. The strain changes measured by the ANZI strain cell during this process allow for the full three dimensional stress tensor to be determined based on an assumption of CHILE material behaviour. In practice, there are a variety of influences that are found to complicate this process, including drilling induced effects described by (Mills et al 2016), and material behaviours that are not captured by the CHILE model (Mills and Gale 2016).

## **Development of Downhole Overcoring Using the ANZI Strain Cell**

Mills and Puller (2017) provide a brief history of the overcoring method of stress relief from its beginnings by Lieurance (1933) in the 1930's, through to the use of strain gauged techniques in single boreholes from the 1950's onward. In the 1970's, Hiltcher et al (1979) developed an overcoring method for use in deep boreholes, where the pilot hole could be drilled without the need to withdraw drilling rods. This method is reported by Hallbjorn (1986) to have been successfully used to measure in situ stresses in exploration boreholes to depths of 500m. The full history of the development of the ANZI strain cell for its downhole application in deep exploration boreholes is described in Mills and Puller (2018).

In 2014, a 48mm diameter (reduced from 58mm) version of the ANZI strain cell was developed to allow overcoring with a standard HQ bit. This version of the instrument was initially monitored using a data cable that ran to a logging system on the surface. Solid installation rods that were used since the instruments conception were replaced with a two-cable system deployed on a mechanised cable drum through the drill pipe. The first cable was connected to the instrument and monitored at the surface for the duration of the overcoring. The second cable was used to pressurise the instrument during installation and the in situ pressure test. This approach becomes cumbersome at depths greater than about 100m.

These limitations were overcome with the development of:

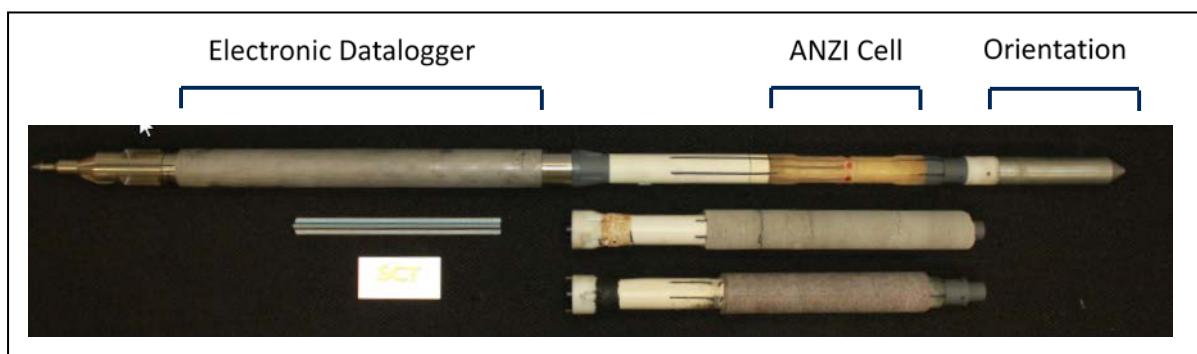
- a drive sub installed behind the core barrel that provides for a wireline deployable downhole drilling system similar in concept to that used by Hiltcher et al (1979)
- a high precision downhole data logging system that is fixed to the back of the ANZI cell
- a wireline enabled deployment system for the instrument and data logger
- an instrument pressurisation system that utilises the drill pipe.

Mills and Puller (2017) describe in detail how these revised drilling, installation and data logging systems now enable routine overcore measurements at depths to 850m within a 12 hour shift.

## Operation of the ANZI Strain Cell

The design of the ANZI strain cell is focused on providing systems to allow the confidence in each point measurement to be assessed while having sufficient duplication of measurement for rock behaviour to be characterised and departures from CHILE behaviour compensated for.

Figure 1 shows a photograph of the 48mm diameter version of the ANZI strain cell with the data logger attached prior to installation and one instrument after overcoring. The instrument has an inflatable polyurethane membrane with 18 electrical resistance strain gauges exposed on its outer surface. When the membrane is covered in epoxy cement and inflated during installation, the electrical resistance strain gauges become directly bonded to the wall of the pilot hole allowing direct measurement of strain changes in the rock as it is overcored. Further detail on the ANZI strain cell and its operation are provided in Mills (1997) and its specific application to overcoring in deep exploration boreholes is described in Mills and Puller (2017).



**Figure 1.** 48mm ANZI strain cell and downhole data logger prior to installation and recovered overcores, the result of which are used as examples throughout this report.

There are six stages in the standard overcoring test procedure using the ANZI strain cell: preparation of the hole, installation, in situ pressure test, overcoring stress relief, biaxial pressure test and laboratory testing of the core recovered from the pilot hole. The following sections provide an overview of each of these stages.

### Borehole Preparation

A borehole is drilled to the measurement depth using standard drilling procedures. The borehole is commonly HQ size and the drive sub is installed behind the core barrel at any time.

The end of the hole is prepared so that the HQ core stub is removed and a centralising conical indentation is formed. A smaller diameter pilot hole is then drilled concentrically from the end of the conical indentation in the end of the HQ hole, for a distance of 1m. The core from this pilot hole is inspected to determine the ideal horizon for instrument installation. The core from the pilot hole is retained for material testing in the laboratory.

## Installation

Figure 2 shows a photograph of the instrument during preparation for installation. The outer surface of the ANZI strain cell is coated with a custom epoxy cement and deployed into the drill pipe on the wireline overshot with dry-release. Once the installation assembly is released from the overshot upon striking water, it floats downward until seating on the landing ring in the back of the core barrel. The pre-determined distance from the landing ring to the strain gauges positions the ANZI cell in the pilot hole at the target depth.



**Figure 2.** ANZI strain cell, data logger and installation assembly being readied for deployment in an inclined hole drilled to a depth of 740m. The collar of the hole is approximately 1340m below the ground surface.

Pressure is applied internally to the ANZI cell membrane by generating a positive pressure differential between the inside and the outside of the drill pipe, causing the strain gauges to be pressed directly against the pilot hole wall. Most of the epoxy cement coating is extruded away from the strain gauges and membrane leaving a very thin (0.3-0.5mm) layer of cement between the gauges and the rock. When the cement has cured, typically 3-4 hours depending on rock temperature, the strain gauges are bonded directly to the rock.

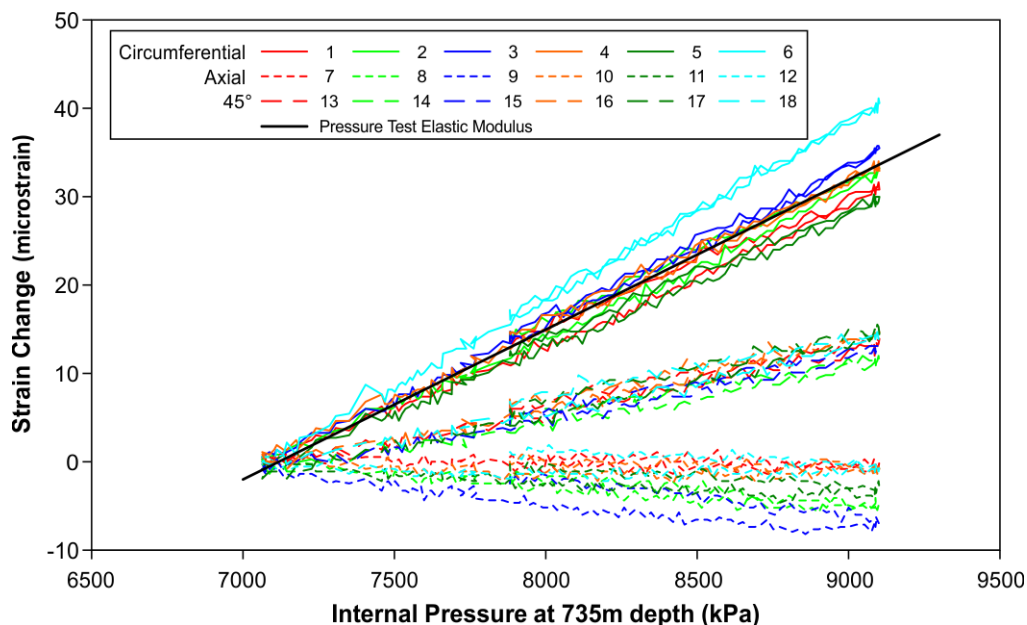
## In Situ Pressure Test

Once the cement has cured, the internal pressure is varied to conduct a pressure test using the instrument as a dilatometer or pressuremeter. This test is used to:

- confirm that the strain gauges are well bonded to the rock

- provide an estimate of the in situ elastic properties of the rock under plane strain conditions prior to any disturbance that may be caused by drilling during the overcoring process
- provide, under some circumstances, independent confirmation of the in situ stress direction based in variation in elastic modulus around the borehole following the technique described by Mills and Gale (2016).

Figure 3 shows an example of a pressure test. The six circumferential gauges show the largest strain change. The six axial gauges show almost no change or a slight stretching consistent with the almost plane strain conditions at the centre of the pressurised length of borehole. The 45° gauges show a strain change midway between the circumferential gauges and axial gauges.



**Figure 3.** In situ pressure test result for ANZI instrument

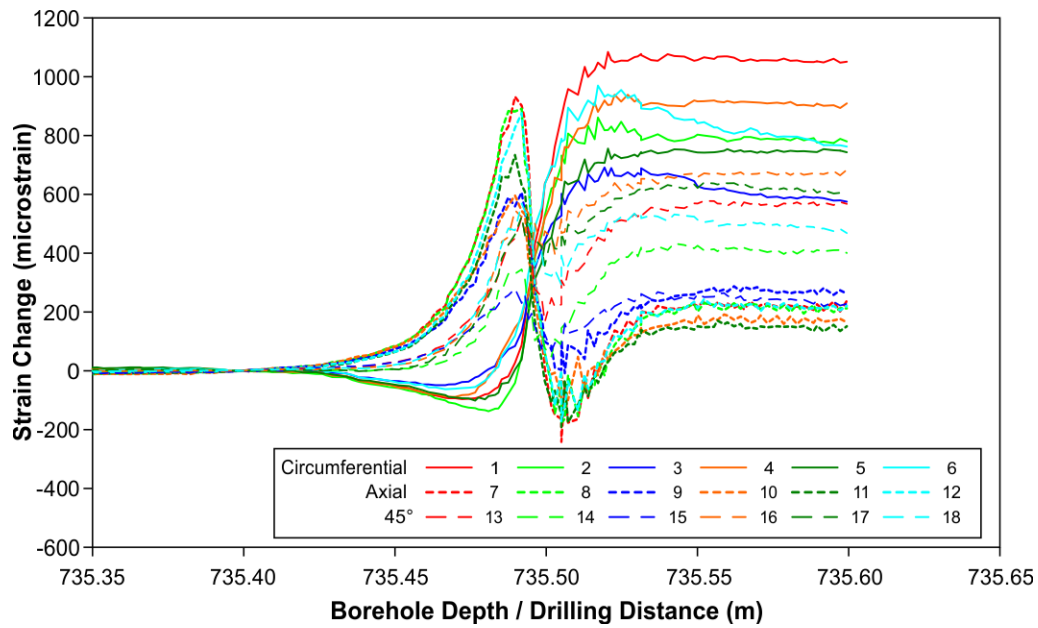
## Overcoring

The ANZI strain cell overcoring operation is conducted in much the same way as for other instruments that use the overcoring stress relief method. Figure 4 shows an example of an ANZI overcoring result with the strain changes plotted relative to borehole depth/drilling distance. The final strains on all gauges are tensile, consistent with the relief of the compressive in situ stresses.

The logger records strain, pressure and temperature every few seconds commencing before the instrument is deployed until it is recovered. The general form of the overcoring strain changes can be used as a basis to identify rosettes of strain gauges that may be behaving irregularly and should be ignored in the final analysis. Correlation of strains between opposing gauges and by the six independent measurements of axial strain provides an insight into rock behaviour during stress relief and an immediate indication of the level of confidence that can be placed in the strain data.

## Biaxial Pressure Test

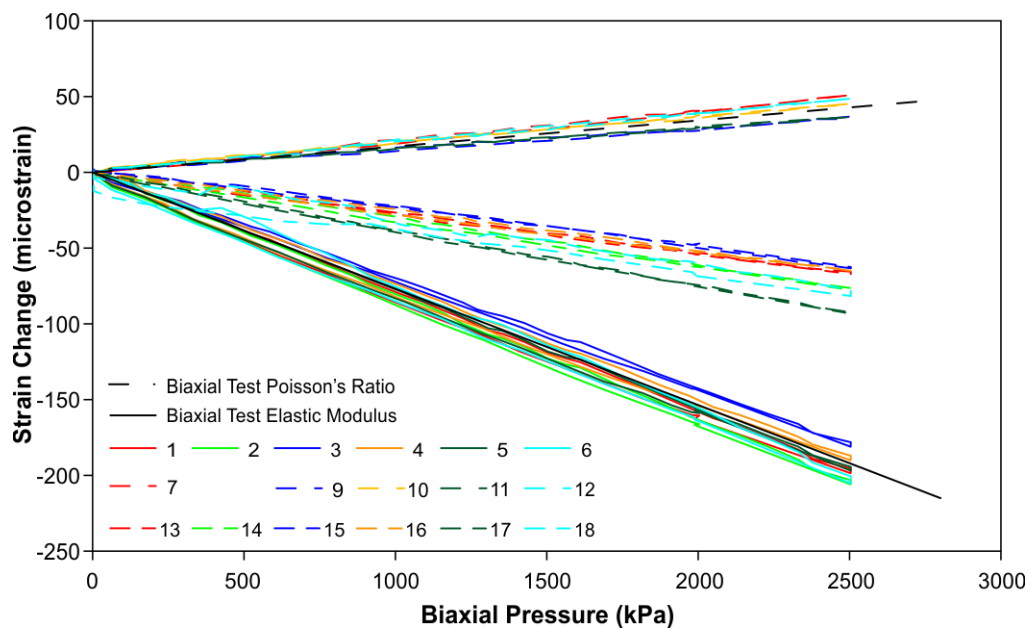
A biaxial pressure test is conducted after the overcore is recovered. External pressure is applied incrementally to the outside of the rock annulus recovered when the pilot hole has been overcored with the instrument inside it.



**Figure 4.** Strain changes observed during overcoring for ANZI instrument

The elastic modulus and Poisson's ratio of the rock material can be estimated from this test at a range of different pressures. The strain changes measured provide not only an estimate of the CHILE rock properties but are also useful as an indicator of non-CHILE behaviour that may have been caused by permanent deformation during the overcoring process.

Figure 5 shows an example of a biaxial test result. The circumferential gauges show compressive strain changes consistent with the application of external pressure to the outside of the overcored rock annulus. The axial gauges show tensile going strain changes due to the Poisson's ratio effect of the external pressure being applied to the rock annulus.



**Figure 5.** Biaxial test result for ANZI instrument

## Laboratory Testing

Core recovered from the pilot hole at the location of the strain measurements is tested in a multi-stage uniaxial compression test to confirm the elastic properties of the rock material across a range of loading conditions. Axial and circumferential strain gauges and the load/displacement records of the compression test all the elastic properties of the rock to be estimated during three or more load/unload cycles up to failure in uniaxial compression.

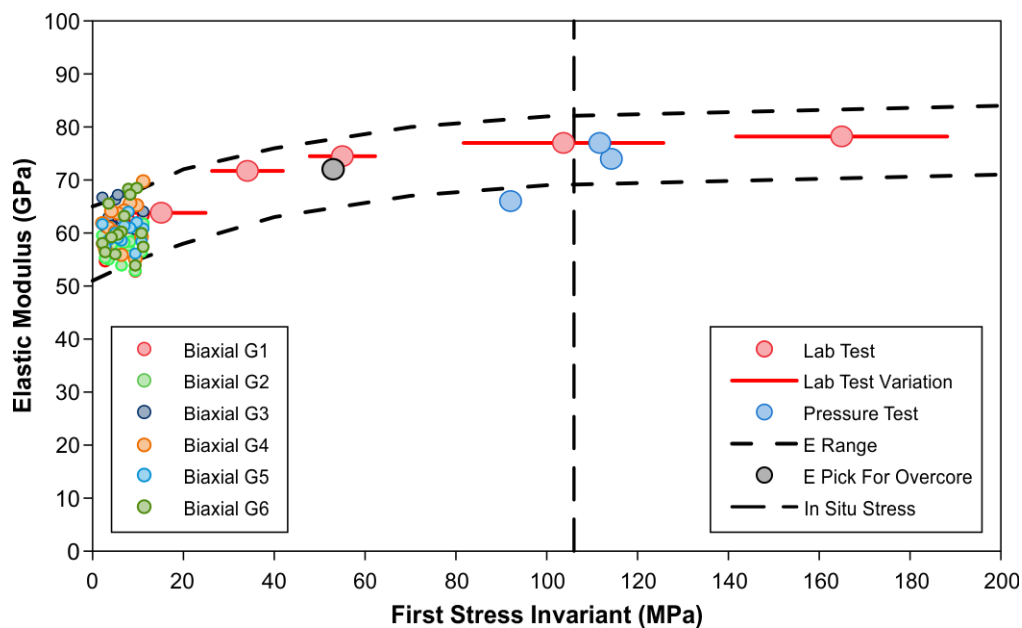
## Assessment of Elastic Properties

The elastic properties of the rock are determined in three separate tests:

- in situ pressure test conducted prior to overcoring
- biaxial pressure test conducted after overcoring
- laboratory test on core recovered from the pilot hole.

The three tests are conducted on the rock at various stages of the measurement process and therefore, at various levels of confining stress. The different stress conditions provide insight into the rock behaviour and the impact of drilling on the rock as it is unloaded and recovered from the hole. In a CHILE material all three tests would indicate the same values of elastic properties.

Variations in elastic properties are commonly observed and these variations have provided useful insights into the processes that occur at the tip of a borehole during drilling and a range of factors that affect the behaviour of rock materials. Figure 6 shows an example of the elastic modulus variation at different confining pressures, represented in this figure as the first stress invariant or sum of the three principal stresses. A refined estimate of the elastic modulus of the rock midway between the in situ first stress invariant and zero is typically used for the calculation of in situ stresses from the measured strains.



**Figure 6.** Variation of elastic modulus with first stress invariant (sum of the three principal stresses) for ANZI instrument



## **Case Study – Overcoring in exploration boreholes at an Australian Metalliferous deposit**

A multiple measurement field campaign was undertaken for a company planning the development of an underground metalliferous mine in Australia. The orebody is roughly cylindrical in shape, has an upper discontinuity surface, and is overlain by approximately 400m of waste rock. Six high confidence measurements were conducted in three geological units from three different boreholes drilled into, and adjacent from the orebody. The principal stresses determined from these six overcores are presented in Figure 7.

Figure 8 shows a plan of the site indicating the location of the three boreholes where the measurements were made including the orientation and magnitude of the measured stress field. The point measurements indicate that the major principal stress is effectively horizontal and oriented between  $310^{\circ}$  and  $330^{\circ}\text{GN}$ . There is a slight variation in stress orientation between each of the three rock units. The average major principal stress in the overburden, country rock and orebody is oriented at approximately  $320^{\circ}\text{GN}$ ,  $310^{\circ}\text{GN}$  and  $330^{\circ}\text{GN}$  respectively.

Insight into the relationship between depth and stress becomes possible when multiple high confidence point measurements become available. Figure 9 shows the depth/stress relationship for the principal stresses and for the first stress invariant at the site. The six measurements indicate there is an increase in the major principal stress with depth. The stress magnitude ranges 23-26MPa in the overburden rock at 400m depth, with a small increase to 24-31MPa in the country rock and orebody at 600m. The depth/stress relationship becomes stronger when the effect of the first stress invariant on elastic modulus is considered because the variability in the ratios of the three principal stress caused by rock inhomogeneity is then removed.

The ratio of the maximum horizontal effective stress to the minimum horizontal effective stress is consistent across the site at 2.0-2.1 and considered high when compared to other locations in Australia where overcoring using the ANZI cell has been undertaken. The comparison between results from different locations has increased confidence in the overall characterisation of the in situ stress field at this site.

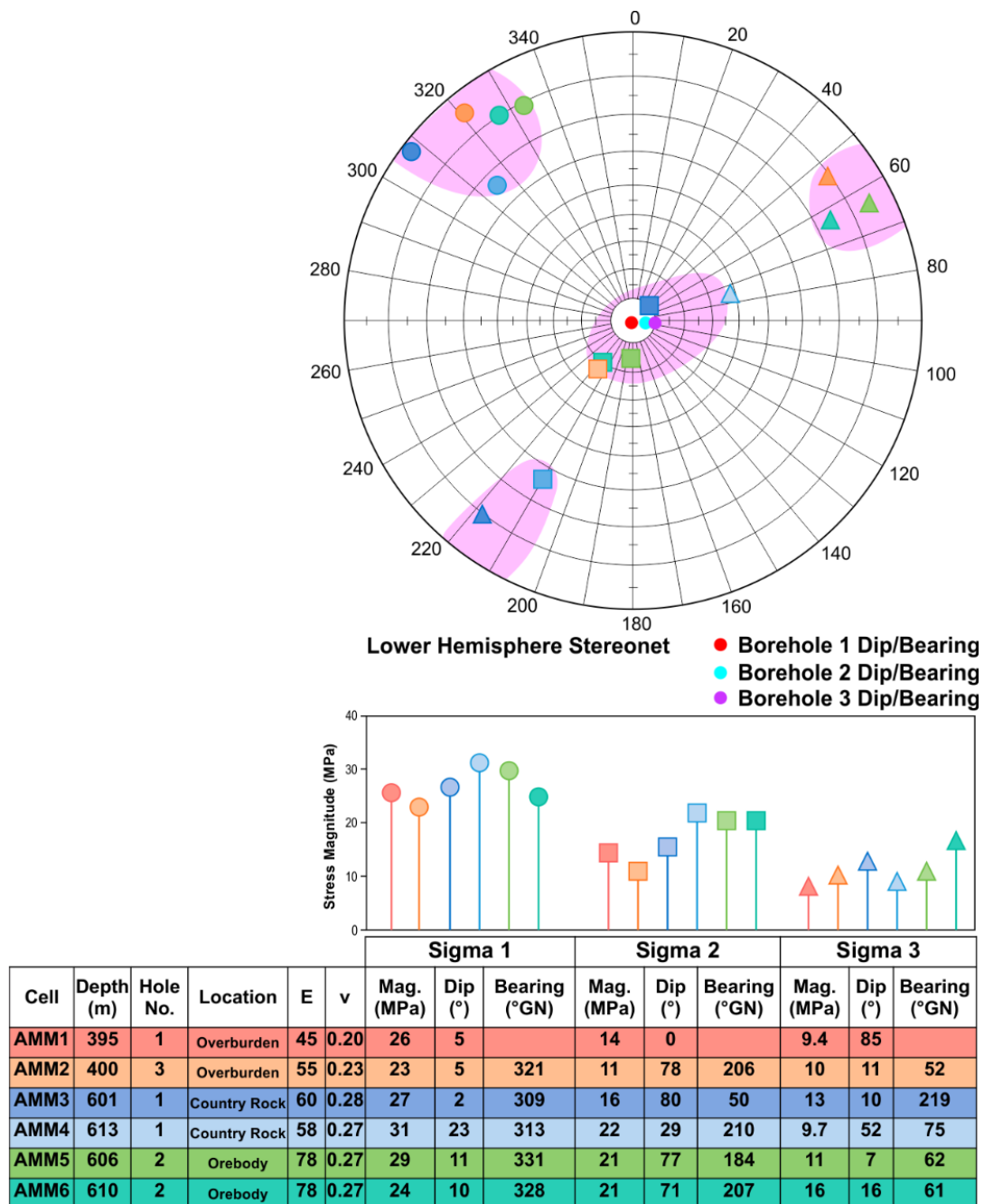
## **Conclusions**

The capability to deploy ANZI strain cells in exploration boreholes represents a significant breakthrough for the design of underground mines and underground excavations generally. Being able to obtain high confidence measurements of the three dimensional in situ stresses at the planning stage of any underground construction activity provides the opportunity to take advantage of these stresses in design of underground structures. Not only does it become possible to protect key infrastructure by locating it away from areas of stress concentration, advantage can be taken of the major stresses to promote caving through appropriate design.

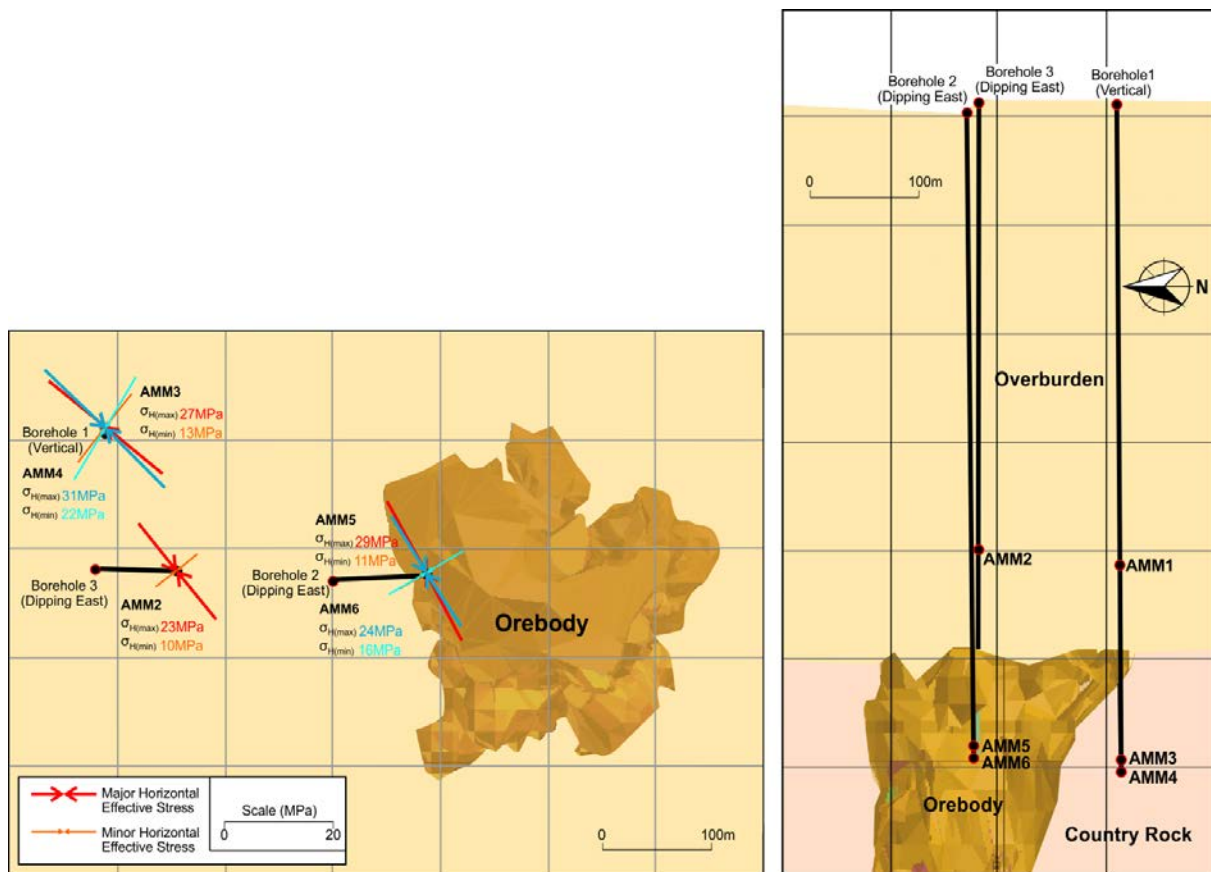
The high levels of redundancy in both the instrument and the measurement technique are designed to provide an indication of the confidence that can be placed in each result and to enhance the understanding of material behaviour at the point of measurement and ground behaviour at the site more generally.

The key steps that enable high confidence measurements to now be possible in exploration boreholes at depths approaching 1km have been described in this paper. The ability to characterise the three dimensional in situ stresses at a site where multiple point measurements are made has been demonstrated. Multiple high confidence measurements provide the basis to understand the spatial and depth related variability in the stress field at a local and mine scale.

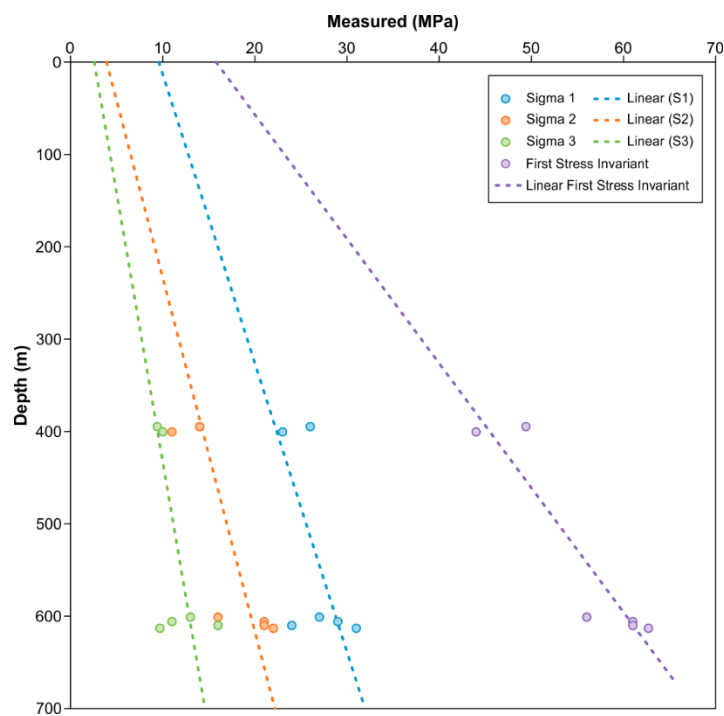




**Figure 7.** Detailed in situ stress measurement from an Australian metalliferous deposit



**Figure 8.** Site plan and section showing the location of the overcores and the orientation and magnitude of the in situ stresses



**Figure 9.** Depth/Stress relationship for the three principal stresses and first stress invariant at an Australian metalliferous mine

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