Drilling, Mining & Civil Engineering
Research, Development & Consulting

REPORT TO SIMRAC

DEMONSTRATION OF OVERCORE STRESS MEASUREMENT FROM SURFACE USING THE SIGRA IST TOOL

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FOREWORD

This report has been prepared for SIMRAC and contains the results of a demonstration in South Africa of Sigra's in-situ stress testing system by Ian Gray. The test site originally planned was at Nooitgedagt Colliery but the failure of the drilling contractor to drill and deliver intact core meant that the location trial was switched to Goedehoop Colliery. Here Zaaiman Exploration operated the equipment completely successfully. From first seeing the equipment at 10 am to completed packing up at 5 pm three successful overcores were undertaken at 60 to 63 m depth.

This report contains a description of the stress measurement process and the results of the stress measurements at Goedehoop.

The results of the stress measurements show a very low horizontal stress regime but one in which the stresses are consistent in magnitude and direction. The major principal effective stress is in the region of 4 to 5 Mpa, which is small in the context of a rock UCS of 100 MPa. Of more concern if longwall mining were being considered is the minor principal stress which is in the range of 0.4 to 2 MPa. This low stress could lead to caving problems. In the context of the bord and pillar mining being used the stress regime is considered benign.

Ian Gray
January 2003

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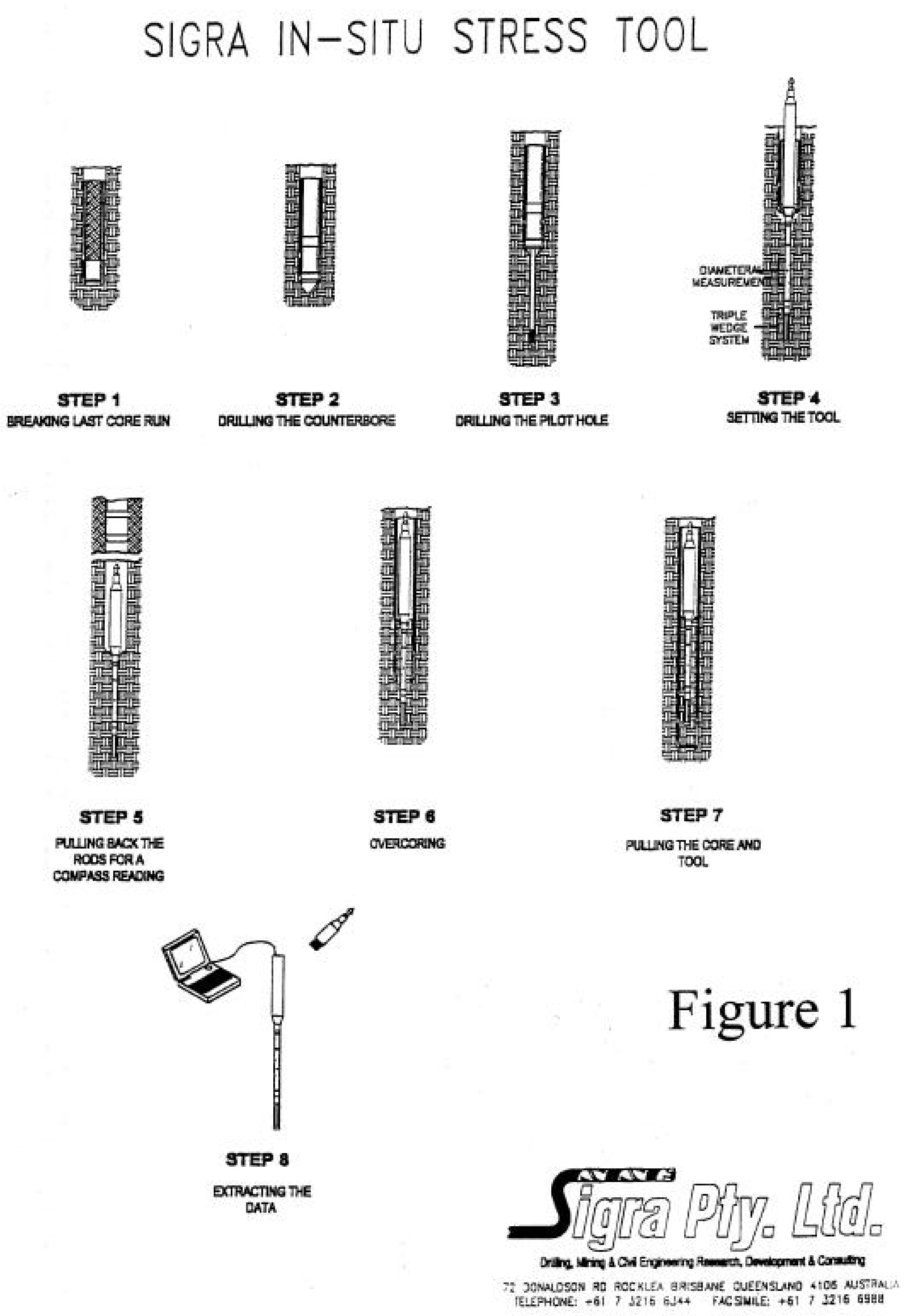
SIGRA IN-SITU STRESS TOOL
DIAMETERAL MEASUREMENT
TRIPLE WEDGE SYSTEM
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BREAKING LAST CORE RUN
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Introduction

Since 1999 there has been interest from South African mines in Sigra's In-situ Stress Measurement Tool (IST). In late 2001 Duncan Adams of SIMRAC visited Sigra's office in Brisbane Australia to look at the equipment and hold discussions with Sigra personnel. Following this Sigra was invited to submit an application for SIMRAC funding to demonstrate the stress measurement system in South Africa. This application was successful and in late September 2002, Dr Ian Gray of Sigra brought a set of test equipment to South Africa for this purpose.

The planned trial site was to be at Nooitgedagt Colliery. However after a week of delays and the failure of the driller to produce a single piece of intact core, another drilling contractor was sought. The contractor was Zaaiman Exploration who drilled hole 15 in the Bultfontein area of Goodehoop Colliery for the trial. Here the procedure was completely successful.

The Drilling Operations

The original plan was to undertake stress measurements in the massive coarse grained sandstone above Nooitgedagt Colliery. This site was chosen because of some roof fall occurrences in the weak laminated mudstone, which forms the immediate roof. In fact the extremely coarse sandstone was probably not the ideal zone for stress testing because the grain size was likely to lead to measurement and interpretation problems. Weak rock is not normally a problem for overcoring provided that the driller is competent. Very successful overcore stress measurements have been made in material down to 2 MPa uniaxial compressive strength. The issue is really whether the core slakes and disintegrates before the laboratory testing can be undertaken.

The tools for the stress measurements arrived in South Africa on Friday 20 September. Ian Gray arrived on Monday 23 September. The tools were rapidly brought through customs under the direction of Bev Hallowes from Destination Hose. The drill rig did not arrive on site till Friday and came without a water pump despite the fact that this had specifically been requested. The pump arrived on Saturday but did not work. Sunday was a holiday and Monday was spent repairing the pump and dealing with extreme drilling vibration because the precollared hole had been drilled too large. Casing was fitted on Tuesday and on Wednesday three attempts were made at overcoring despite drill rig hydraulic failures. These overcores all suffered from fractured core. In total 4 unsuccessful overcores were attempted.

Because of the drilling problems Ian Gray had spoken to Conrad Khats of Sasol on Monday requesting a competent driller. This request was referred to Colin Rice of Professional Diamond Drilling Equipment who happened to have Thinus Zaaiman in his office. Zaaiman Exploration held the contract for drilling at Goedehoop Colliery and on Tuesday permission was obtained to undertake the stress measurements there. On Wednesday the hole was drilled to depth and on Thursday the stress measurement operation took place. Friday was reserved for packing up prior to flying back to Australia in the afternoon.

The Designed Test Procedures

The test procedure involved coring in the roof rocks of the coal seam using a Boart Longyear HQ-2 wireline coring system. Stress measurement was accomplished using the Sigra IST overcore system. This is an integral part of the coring operation which only delayed normal coring by about 1 1/2 hours per overcore. The system used by Zaaiman drilling was not standard as the HQ system was run on the end of N size rods. Therefore the procedure was not as quick as normal due to the HQ rods not fitting through the chuck and some switching of rods and winch had to be undertaken to be able to pull the inner barrel. Also the tool was run with HQ-2 for the first time rather than HQ-3. However this change did not affect the stress measurement operation in any way.

The IST Procedure Is As Follows:

The last core run is pulled as normal. A counterbore tool is pumped in place of the inner barrel and is used to grind any upstanding core away leaving a cone depression in the top of the rock immediately below the HQ bit face mark. This tool is retrieved on wireline and replaced by a pilot hole drill. This is used to drill a 500 mm long by 25.5 mm diameter pilot hole. Once this has been drilled and flushed the pilot hole drill is pulled on wireline and the stress tool is then lowered on a wireline suspended setting tool through the drill string into the pilot hole. The stress tool locks therein using a mechanical wedge system. The tool measures the pilot hole diameter at six locations through the action of pins which press against the pilot hole wall. The remainder of the stress tool protrudes up from the pilot hole and contains an orientation system comprising three magnetometers, three accelerometers and a temperature sensor. It also contains a logging system to measure the diameters across the pins and the orientation devices. Once the stress tool is locked in place the setting tool is withdrawn on wireline. The inner barrel is then dropped back into the rods. The drill string is then pulled back so that the magnetometers may operate free from their influence on the magnetic field. After a set period the rods are lowered to bottom and coring commences over the tool. As the bit progresses past the sets of pins in the pilot hole a change in pilot hole diameter is measured by the tool. At the end of the core run (usually one metre long) the core is pulled as normal but with the tool inside. When on the surface the tool and core are photographed and the tool extracted from the pilot hole. The overcore material is wrapped and sent to a laboratory for the measurement of Young's modulus, Poisson's ratio and uniaxial compressive strength. Data stored within the stress tool is extracted to a laptop and processed. The procedure is shown in Figure 1. The tool is designed to operate to 1500m depth.

Core Sample Mechanical Properties

CSIR Miningtek Pty. Ltd. carried out tests for Uniaxial Compressive Strength, Young's Modulus and Poisson's Ratio on the sampled overcore pin sections. Secant and tangent moduli and Poisson's Ratios were determined from the stress and strain curves. Table 1 gives sample descriptions and rock properties. The original core test data is given in Appendix A. It comprises the plots of axial and peripheral strain for the overcore samples at an increasing stress level. The values plotted are the mean of two axial and two peripheral strain gauges. Because the stress levels were very low the Young's modulus and Poisson's ratio's are drawn from the very low end of the stress strain curves. The lower end of the stress strain curves are replotted in Appendix A.

Stress Measurement Results

The three stress meaurements were all undertaken in a similar grey siltstone. The operation of the tool is considered to be faultless.

The deformation traces measured during overcoring are presented in Appendix B. Here the change in diameter is presented with respect to time. In each case the diametrical pin trace is numbered from 1 to 6. Pin 6 is uppermost and pin 1 lowermost so that the core bit passes over the pins in the order 6,5,4,3,2,1. In every case the deformation proceeds on the pin trace in that order. Due however to the extremely low stresses and high modulus of the rock the amount of deformation is very low having an average about 10 microns (0.01 mm). The traces recorded during the overcoring therefore show slightly more uncertainty than tests where the deformation is higher. This is reflected in the error values assigned to each stress analysis. In each case the core split as the core barrel passed into the zone containing the wedge locking system. This is not a general phenomenon and is certainly due to the fact that the setting tool was dropped on the top of the stress tool, thus dynamically stressing the locking wedges. This was done deliberately having had an inadequately set tool at Nooitgedagt. Normally the setting tools work without any such problems but in view of the time lost at Nooitgedagt and one day available for work at Goedehoop no miss set could be accommodated.

The uncertainty in each measurement is expressed numerically as a percentage error. This number represents the root mean square of the percentage difference in deformation between the measured value and the theoretical best fit value. The stress solution is arrived at by a least squares fitting procedure of the best theoretical value to the experimental data. There are a total of 42 theoretical solutions to the six diametrical change measurements. This comprises one, six pin solution, six, five pin solutions, fifteen, four pin solutions and twenty, three pin solutions. These solutions are shown in Appendix C along with the deformation plots. The error associated with a six pin solution is usually greater than that of the best five pin solution. Likewise the best five pin solution generally shows more error than the best four pin solution. The three pin solutions have no theoretical error as they have no redundancy.

Table 2 presents the mean effective and deviatoric stress results and the directions of major principal stress which were derived from the pin displacements, laboratory tests and compass readings. The major and minor principal effective stress results are also given in Table 2. The tectonic strains are calculated according to the method described in a following section. The results of these calculations are presented in Table 3.

The direction of major principal stress is given relative to magnetic north, clockwise positive. The direction is derived from the survey tool section of the stress measurement tool. This comprises triaxial magnetometers and triaxial accelerometers and a temperature sensor. The results derived from this are given in Appendix D. These show consistent inclination, azimuth and gravitational field. The total magnetic field shows some slight variation due to differences in the distance the rods are pulled up. This variation has also affected the angle between the magnetic field and the tool axis. At approximately 6 m pull up there is still some magnetic interference from the drill rods. This interference is not enough to cause an error of more than 1 degree in stress direction and is therefore irrelevant from this viewpoint. The pin 1 orientation is in each case derived from magnetometers and accelerometers rather than just the magnetometers alone plus the assumption that the hole is vertical.

Principal and Tectonic Stresses and Tectonic Strains

It has been found useful in previous stress analysis to examine the stress situation at a site in terms of tectonic strain. This is explained below.

The relationships between the mean effective stress ($?_{m}$) and the deviatoric stress ($?_{d}$) and the major ($?_{1}$) and minor ($?_{2}$) principal effective stresses are given below

$$?_{1} = ?_{m} + ?_{d} \qquad (1)$$

$$?_{2} = ?_{m} - ?_{d} \qquad (2)$$

The vertical stress ($?_{v}$) in sedimentary rocks is due to self weight and can be calculated on the basis of 0.025 MPa/m depth. In the case of this testing procedure, from this figure must be subtracted the effect of the water column in the borehole which is 0.010 MPa/m depth. Assuming the rock is laterally constrained, such that there is no allowable strain in the horizontal plane, the horizontal effective stress due to self weight ($?_{h/sw}$) can be calculated using the following equation

$$?_{h/sw} = ?_{v} \times \frac{?}{1-?} \qquad (3)$$

where ? is Poissons Ratio.

This is a simplified elastic model, which does not account for creep processes. The other component of horizontal stress present is the horizontal tectonic stress ($?_{tec}$), which is generated by tectonic movement. This is due to tectonic plate loading as well as local structural conditions. The major and minor principal tectonic stresses are calculated as

$$?_{tec/1} = ?_1 - ?_{h/sw} \qquad (4)$$

and

$$?_{tec/2} = ?_2 - ?_{h/sw} \qquad (5)$$

respectively.

It is desirable regionally to consider the strain caused by tectonic movements rather than focussing on stress fields. Stresses vary with the modulus of the rock. The stiffer the rock the more stress it carries for a given strain. Using the values of tectonic stress calculated from equations (4) & (5) the components of tectonic strain can be calculated by equations (6) & (7) below.

$$?_{tec/1} = (?_{tec/1} - ? \; ?_{tec/2})/ E \qquad (6)$$

$$?_{tec/2} = (?_{tec/2} - ? \; ?_{tec/1})/ E \qquad (7)$$

To examine the average tectonic strain for a group of stress measurements the procedure is to rotate the principal strains into direct N-S & E-W strain and shear strain components and to find the mean of these. The principal tectonic strains and their direction may be calculated from these three mean strains.

If tectonic strains are relatively uniform between adjacent stress measurements they may be used to calculate stresses in rock of varying stiffness and Poisson's Ratio. The process is the reverse of that used to derive the tectonic strain

In these cases the horizontal stress due to overburden is calculated according to equation (3). The effective stresses due to tectonic strain may be calculated using equations (8) and (9).

$$?_{tec/1} = \frac{E}{1-?^2} (?_{tec/1} + ? \; ?_{tec/2}) \qquad (8)$$

$$?_{tec/2} = \frac{E}{1-?^2} (?_{tec/2} + ? \; ?_{tec/1}) \qquad (9)$$

The principal effective stresses may be calculated by adding the horizontal stress due to self weight to the above figures.

In the case of the stress measurements undertaken at Goedehoop there is little advantage to be gained by looking at the stresses in terms of tectonic strains. The reason for this is that the tests were all conducted in similar material. Where the strata vary in stiffness there is a corresponding wide variation in horizontal stress and the best way to check for uniformity of measurement is to calculate tectonic strains. These are normally uniform or uniformly varying with depth. A sudden change in tectonic strain is indicative of an unconformity and a changed stress regime.

Conclusions

The conclusion to be gained from the operation is that the Sigra in-situ stress measurement system can be used quite readily in South Africa. The limitation is the same as in Australia, namely that it requires an attentive and competent driller with serviceable equipment to run the tool. Given the latter and some time to adjust to local conditions, the system can be implemented readily. The drilling conditions that are likely to cause the most problems are related to bit type and groundwater conditions. In the sedimentary sequences drilled in this field operation the bit wear was greater than most of the coal measure rocks drilled in Australia and in two instances the pilot bit had to be changed during the drilling of the pilot hole. A PCD bit should avoid this problem but at a significantly greater cost per bit. The groundwater issue became apparent on a field operation in Colorado in the United States as the stress measurement process becomes more difficult if there are no drilling fluid returns. A different tool to that brought to South Africa has been developed to handle these conditions. The stress measurement system is designed to operate to 1500 m depth and has been used to 750 m. These depth capabilities should make it attractive in deeper operations.

The stress measurement results from Goedehoop were quite satisfactory from a technical point of view and given the extremely low stress levels in quite stiff rock were reasonably consistent.

Acknowledgments

The people who were instrumental in getting this operation to take place in the first instance were Duncan Adams of SIMRAC and Dave Minney of Anglo Coal. In South Africa Johan Erasmus of Greenside Mine looked after me to the extent that he even lent me his bakkie (ute) to drive the gear around in after no suitable vehicles could be hired in Witbank. Greenside Mine kindly provided a guest house as an operating base. The operation nearly foundered for want of an operational drilling rig but the help afforded by Conrad Khats and Colin Rice saved the day by finding Zaaiman Exploration. Thinus Zaimann and his crew worked efficiently to provide a successful demonstration of the equipment at Goedehoop Colliery, courtesy of their geologist Bert Schalekamp.

TABLE 1

HOLE NAME	DEPTH	OVERCORE NUMBER	DESCRIPTION	YOUNG'S MODULUS	POISSON'S RATIO	UCS
	(m)			(GPa)		(MPa)
BULT 15	60.57	72.009	UNIFORM GREY SILTSTONE	16.41	0.12	105
BULT 15	61.79	73.009	UNIFORM GREY SILTSTONE	13.22	0.11	98
BULT 15	62.59	74.009	UNIFORM GREY SILTSTONE	14.80	0.18	108

GOEDEHOOP COLLIERY SAMPLE DESCRIPTIONS AND MATERIAL PROPERTIES

TABLE 2

HOLE	OVERCORE	DEPTH	NO PINS USED	RMS ERROR %	EFFECTIVE MEAN STRESS	DEVIATORIC STRESS Mpa	ANGLE FROM MAG NTH	YOUNG'S MODULUS MPa	POISSON'S RATIO	MAJOR EFFECTIVE PRINCIPAL STRESS MPa	MINOR EFFECTIVE PRINCIPAL STRESS MPa
BULT 15	72.009	60.57	6	11.7	2.31	1.35	22.53	16409	0.12	3.66	0.96
BULT 15	73.009	61.79	6	16.1	1.88	1.44	30.11	13218	0.11	3.32	0.44
BULT 15	73.009	61.79	5	8.5	2.39	1.64	21.23	13218	0.11	4.03	0.75
BULT 15	73.009	61.79	4	4.5	2.61	1.42	21.12	13218	0.11	4.03	1.19
BULT 15	74.009	62.59	6	10.0	3.33	1.52	30.48	14801	0.18	4.85	1.81
BULT 15	74.009	62.59	5	5.1	2.89	1.20	23.54	14801	0.18	4.09	1.69
	MEAN VALUES						24.9				

TABLE 2 PRINCIPAL STRESSES AND DIRECTIONS

TABLE 3

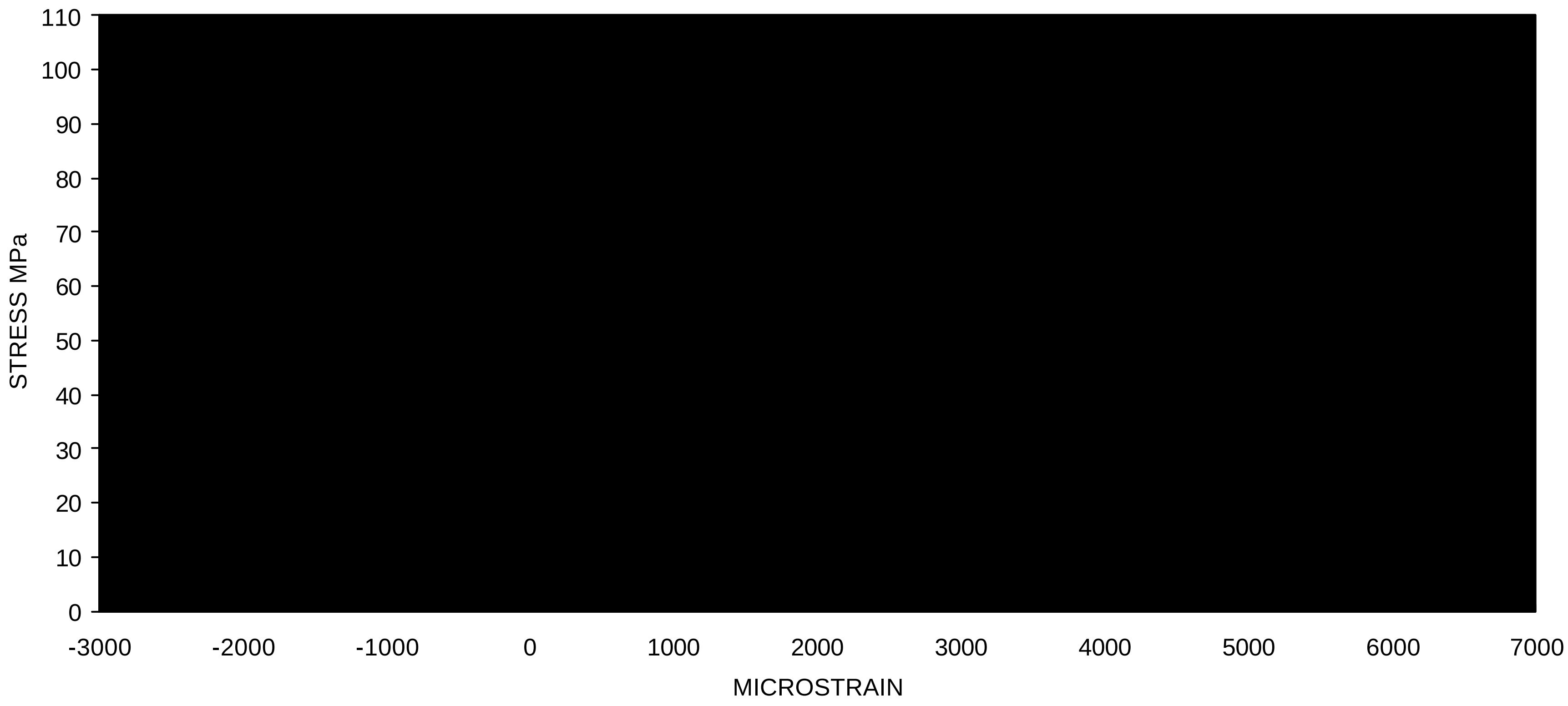
HOLE	OVERCORE	DEPTH	NO PINS USED	RMS ERROR %	EFFECTIVE MEAN STRESS	DEVIATORIC STRESS Mpa	ANGLE FROM MAG NTH	YOUNG'S MODULUS MPa	POISSON'S RATIO	MAJOR TECTONIC STRAIN	MINOR TECTONIC STRAIN
BULT 15	72.009	60.57	6	11.7	2.31	1.35	22.53	16409	0.12	2.09E-04	2.51E-05
BULT 15	73.009	61.79	6	16.1	1.88	1.44	30.11	13218	0.11	2.40E-04	-2.05E-06
BULT 15	73.009	61.79	5	8.5	2.39	1.64	21.23	13218	0.11	2.91E-04	1.55E-05
BULT 15	73.009	61.79	4	4.5	2.61	1.42	21.12	13218	0.11	2.87E-04	4.88E-05
BULT 15	74.009	62.59	6	10.0	3.33	1.52	30.48	14801	0.18	2.94E-04	5.19E-05
BULT 15	74.009	62.59	5	5.1	2.89	1.20	23.54	14801	0.18	2.44E-04	5.30E-05
	MEAN VALUES						24.9			2.60E-04	3.32E-05

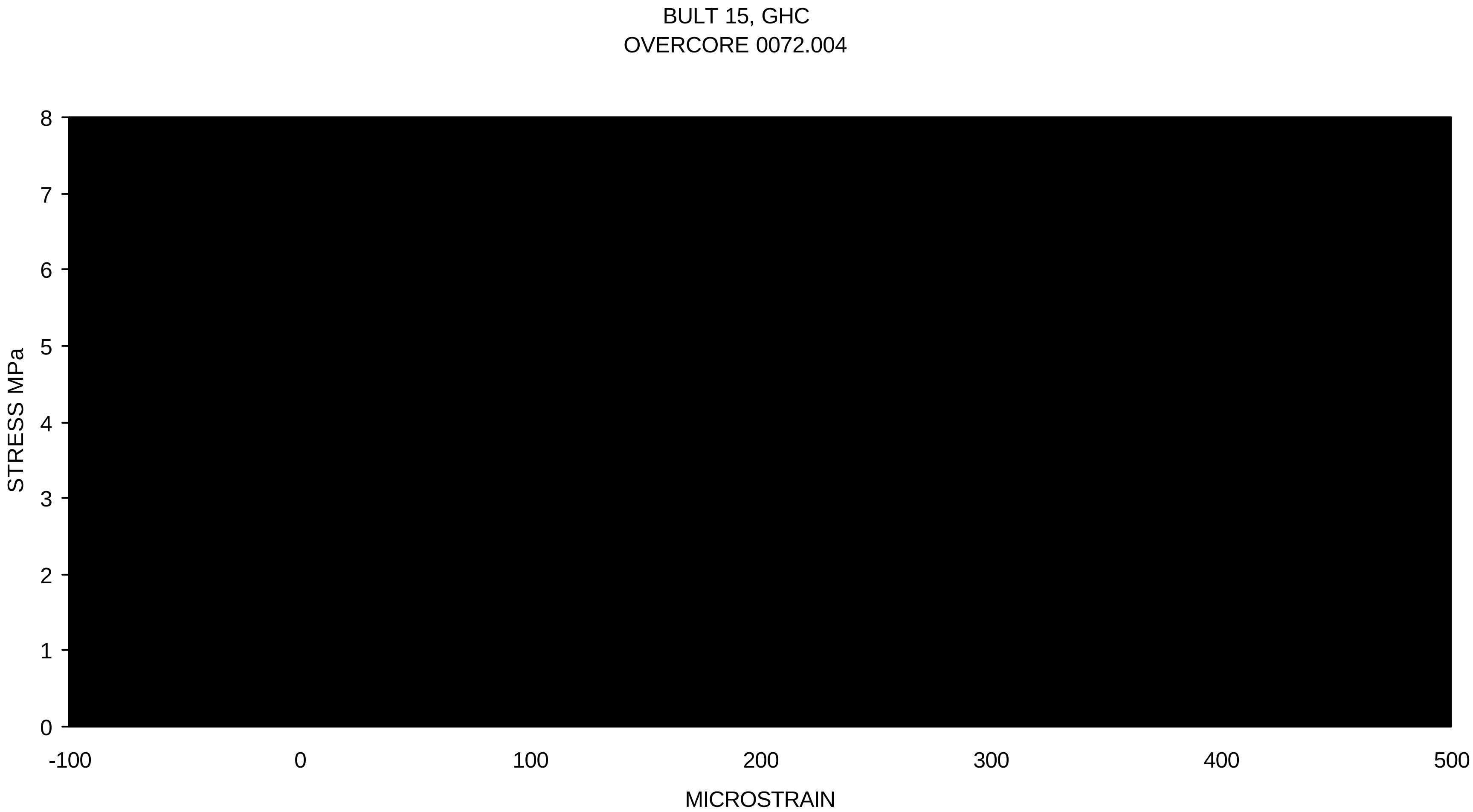
TABLE 3 CALCULATED TECTONIC STRAINS

APPENDIX A

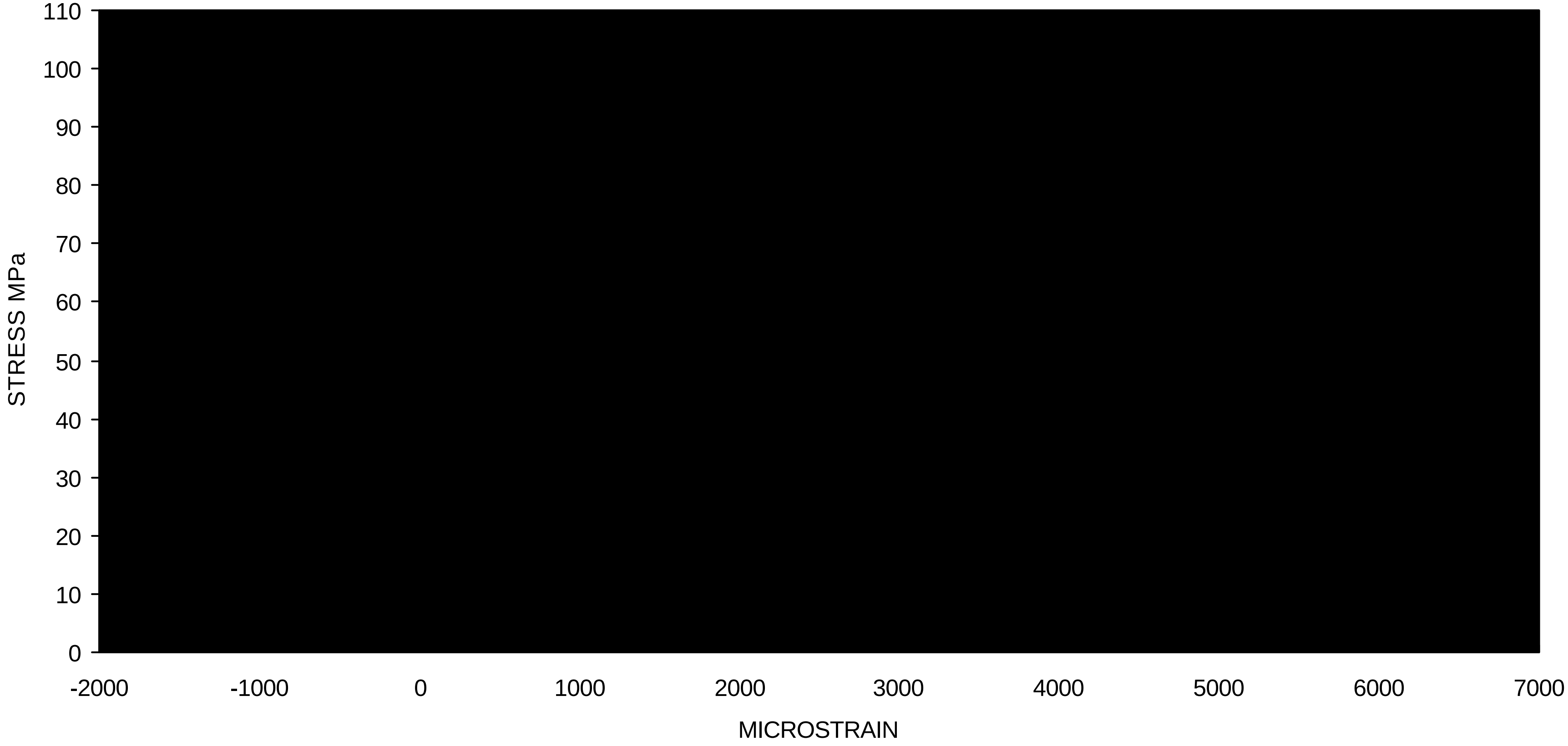
CSIR Miningtek Core Test Results

BULT 15, GHC
OVERCORE 0072.009

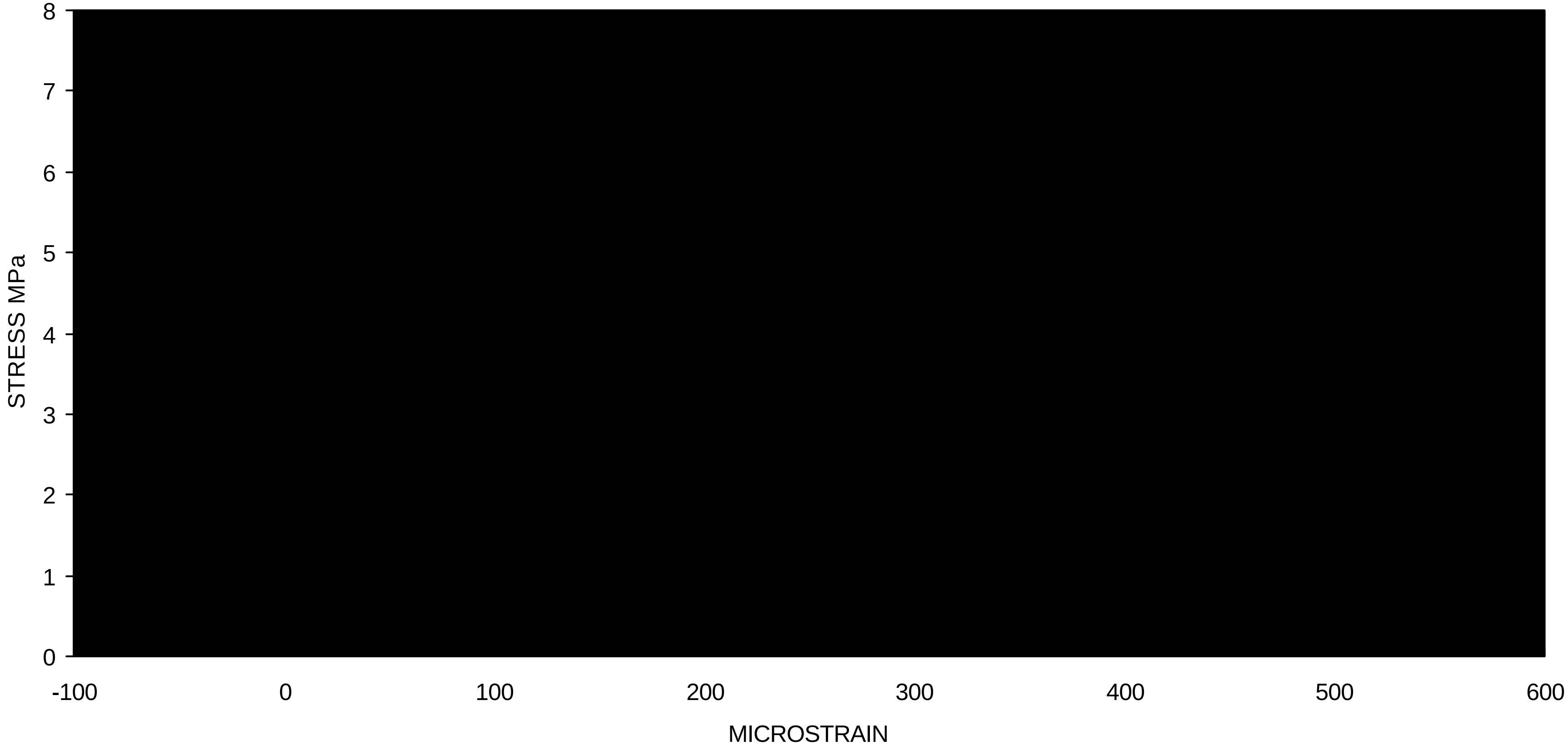


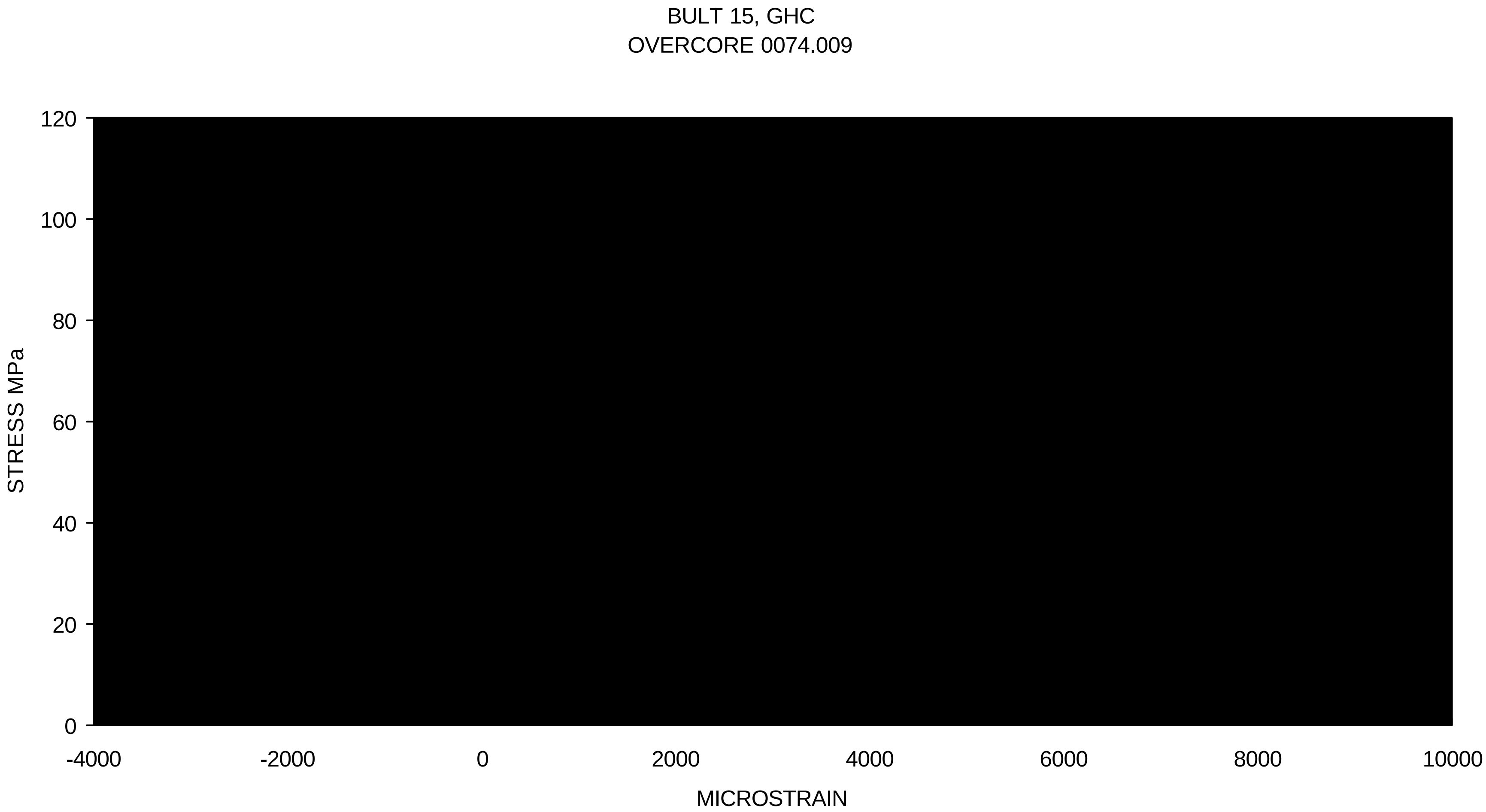

BULT 15, GHC
OVERCORE 0072.004
STRESS MPa
8
7
6
5
4
3
2
1
0
-100
0
100
200
300
400
500
MICROSTRAIN

BULT15, GHC
OVERCORE 0073.009

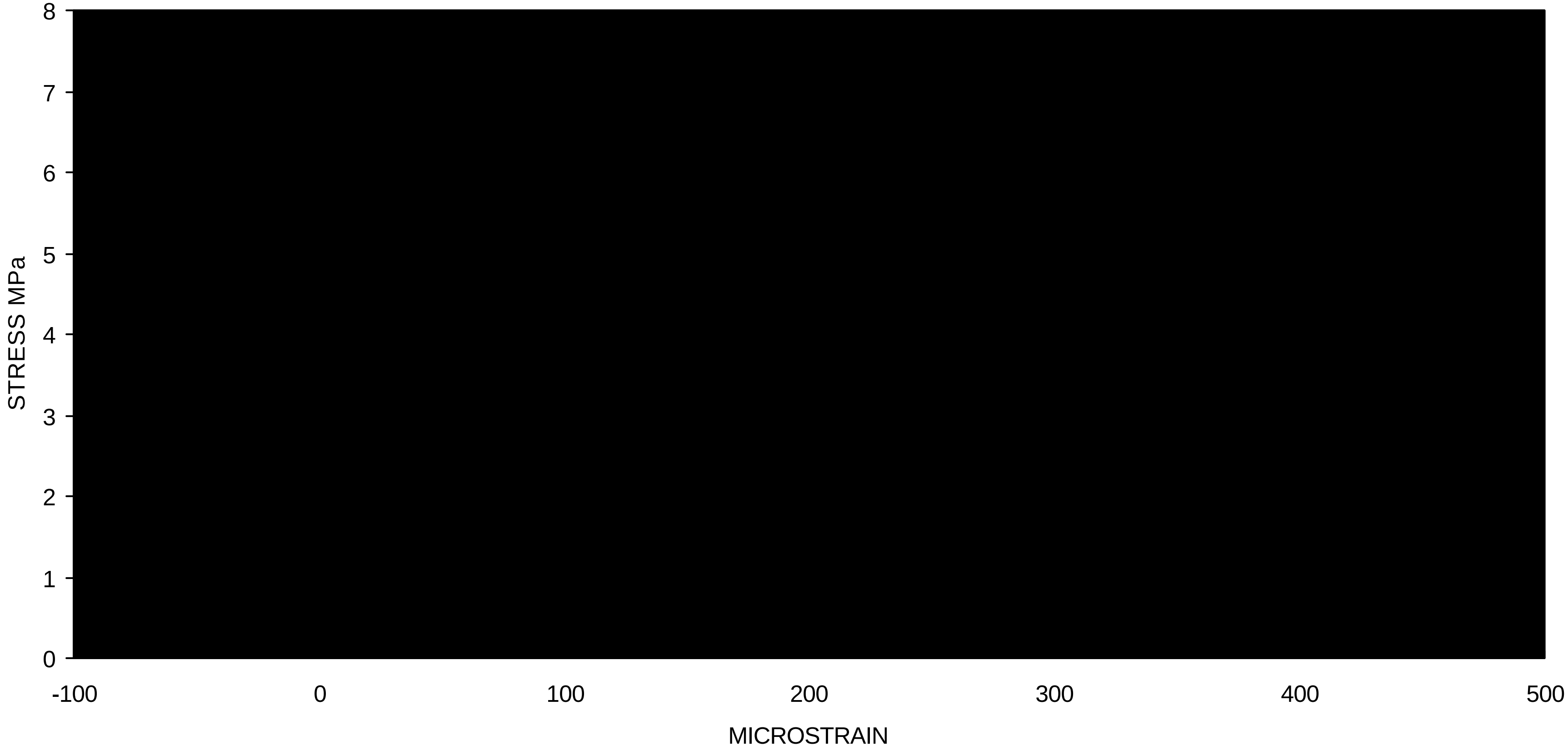


BULT15, GHC
OVERCORE 0073.009



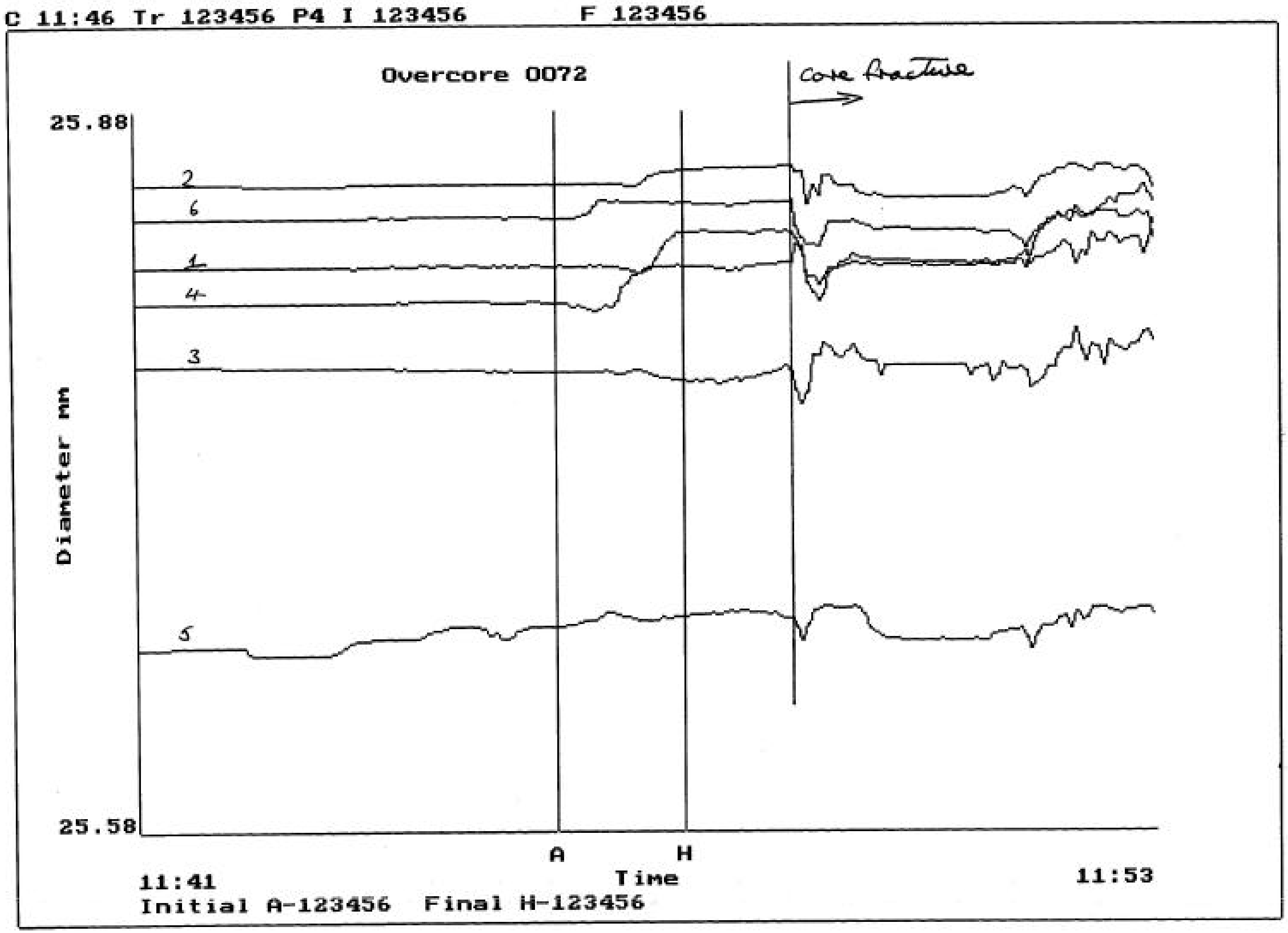

BULT 15, GHC
OVERCORE 0074.009
STRESS MPa
120
100
80
60
40
20
0
-4000
-2000
0
2000
4000
6000
8000
10000
MICROSTRAIN

BULT 15, GHC
OVERCORE 0074.009

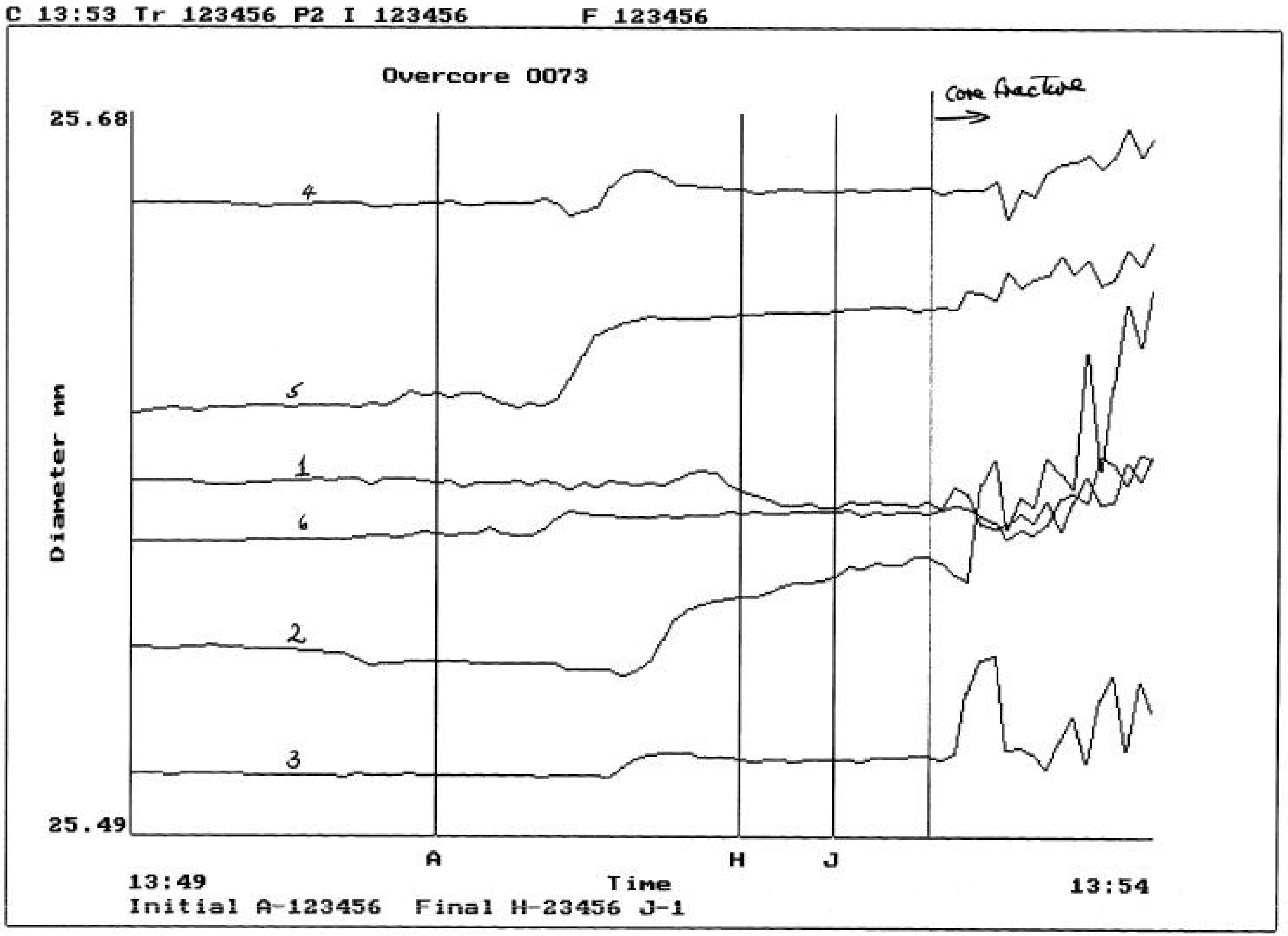


APPENDIX B

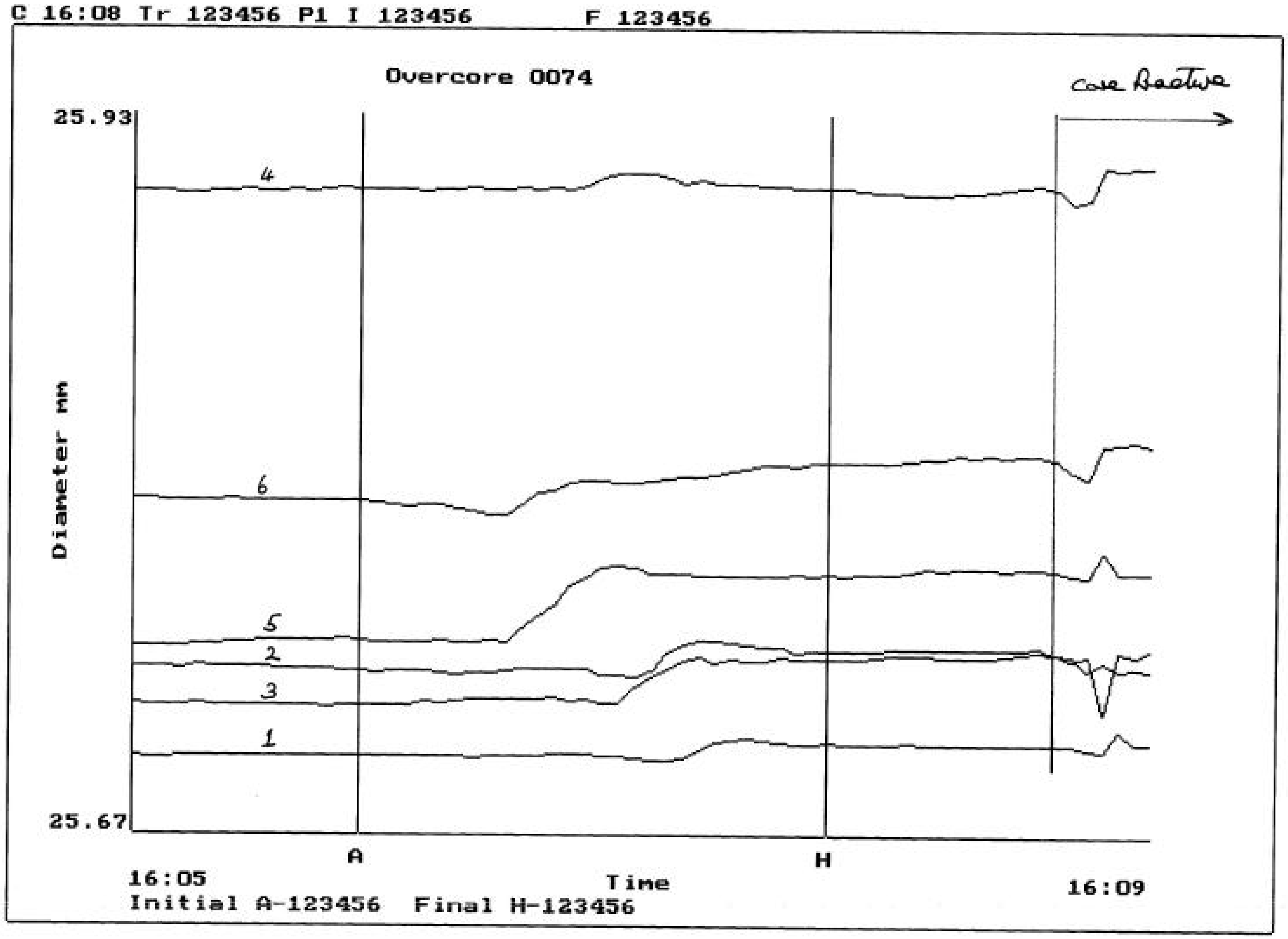
Overcore Deformation Traces



C 11:46 Tr 123456 P4 I 123456 F 123456
Overcore 0072
core fracture
25.88
25.58
Diameter mm
2
6
1
4
3
5
A
H
11:41
Time
11:53
Initial A-123456 Final H-123456



C 13:53 Tr 123456 P2 I 123456 F 123456
Overcore 0073
core fracture
25.68
25.49
Diameter mm
4
5
1
6
2
3
A
H
J
13:49
Time
13:54
Initial A-123456 Final H-23456 J-1


C 16:08 Tr 123456 P1 I 123456 F 123456
Overcore 0074
25.93
25.67
Diameter mm
4
6
5
2
3
1
A
H
16:05
Time
16:09
Initial A-123456 Final H-123456

APPENDIX C

Stress Solutions

```
SIGRA STRESS MEASUREMENT SOLUTION
BULT 15, GHC
RUN NUMBER:   72
TOOL NUMBER:   9
PICK FILE NUMBER:  4
DATAFILE: d:\sdata\STR0072.009

DATE:  2/ 2/2003
TIME: 17:40

  25.81700        DIAMETER OF SAMPLE (mm)
   16409.0       MODULUS OF SAMPLE (MPa)
   0.12000       POISSONS RATIO OF SAMPLE
  60.57000            DEPTH OF SAMPLE (m)
 0.0150000     WEIGHT PER VOLUME (MPa/m)
-137.47146  ANGLE OF FIRST PIN IN DEGREES
  30095.19  MAGNETIC FIELD STRENGTH (nT)

MEASURED DISPLACEMENTS OF PINS (mm)
  0.01390  0.00580 -0.00350  0.01560  0.00450  0.00630

ANGLE OF PINS IN RADIANS
  0.00000 -1.04720 -2.09440 -0.52360 -1.57080 -2.61799

SOLUTIONS WITH LOWEST ERROR
Pins    ERROR   SIGM     SIGD   ANGLE    CASE
          %     (MPa)    (MPa)  (degrees)
  6    11.7521   2.311   1.347   22.53    1
  5     3.3333   1.908   1.680   27.02    6
  4     0.0000   1.977   1.802   28.17   11

SIGM is the mean horizontal stress.
SIGD is the difference between
the mean stress and the principal stress.
Angle is the bearing of the major principal
axis relative to magnetic north.
```

SOLUTIONS FOR ALL PIN COMBINATIONS

Case #	error %	SIGM (MPa)	SIGD (MPa)	ANGLE (degrees)	pins considered					
1	11.7521	2.311	1.347	22.53	1	2	3	4	5	6
2	14.1026	2.268	1.314	21.93	2	3	4	5	6	-1
3	10.0855	2.602	1.428	16.65	1	3	4	5	6	-1
4	10.0855	2.602	1.074	25.23	1	2	4	5	6	-1
5	15.2038	2.242	1.281	23.07	1	2	3	5	6	-1
6	3.3333	1.908	1.680	27.02	1	2	3	4	6	-1
7	13.5470	2.242	1.361	21.08	1	2	3	4	5	-1
8	11.7521	2.560	1.402	15.96	3	4	5	6	-1	-1
9	11.7521	2.560	1.039	24.56	2	4	5	6	-1	-1
10	39.2857	1.977	1.058	21.37	2	3	5	6	-1	-1
11	0.0000	1.977	1.802	28.17	2	3	4	6	-1	-1
12	15.8654	1.977	1.285	16.28	2	3	4	5	-1	-1
13	1.7094	2.893	1.136	17.72	1	4	5	6	-1	-1
14	11.0072	2.978	1.720	13.74	1	3	5	6	-1	-1
15	3.7500	1.977	1.658	26.05	1	3	4	6	-1	-1
16	10.0962	2.478	1.540	12.27	1	3	4	5	-1	-1
17	11.3309	2.478	0.853	28.88	1	2	5	6	-1	-1
18	3.7500	1.977	1.620	27.13	1	2	4	6	-1	-1
19	9.8077	2.978	0.964	34.11	1	2	4	5	-1	-1
20	3.1175	1.839	1.620	27.62	1	2	3	6	-1	-1
21	18.2254	2.173	1.294	21.54	1	2	3	5	-1	-1
22	2.7778	1.839	1.683	25.84	1	2	3	4	-1	-1
23	*.****	1.771	1.621	26.39	1	2	3	-1	-1	-1
24	*.****	1.357	2.001	23.59	1	2	4	-1	-1	-1
25	*.****	2.978	0.783	49.76	1	2	5	-1	-1	-1
26	*.****	1.977	1.439	28.33	1	2	6	-1	-1	-1
27	*.****	1.977	1.643	22.73	1	3	4	-1	-1	-1
28	*.****	2.978	2.070	8.26	1	3	5	-1	-1	-1
29	*.****	1.357	1.658	33.70	1	3	6	-1	-1	-1
30	*.****	2.978	1.069	20.10	1	4	5	-1	-1	-1
31	*.****	2.597	1.286	21.38	1	4	6	-1	-1	-1
32	*.****	2.978	1.237	16.42	1	5	6	-1	-1	-1
33	*.****	1.977	1.802	28.17	2	3	4	-1	-1	-1
34	*.****	-0.645	1.384	-28.12	2	3	5	-1	-1	-1
35	*.****	1.977	1.802	28.17	2	3	6	-1	-1	-1
36	*.****	4.599	1.716	54.02	2	4	5	-1	-1	-1
37	*.****	1.977	1.802	28.17	2	4	6	-1	-1	-1
38	*.****	1.977	0.268	31.85	2	5	6	-1	-1	-1
39	*.****	1.977	1.653	1.88	3	4	5	-1	-1	-1
40	*.****	1.977	1.802	28.17	3	4	6	-1	-1	-1
41	*.****	4.599	2.875	14.20	3	5	6	-1	-1	-1
42	*.****	2.851	1.109	16.87	4	5	6	-1	-1	-1

Sigra Stress Measurement

http://www.sigra.com.au/

BULT 15, GHC

d:\sdata\STR0072.009

DATE: 2/ 2/2003

TIME: 17:40

Mag Field (nT): 30095

Modulus (MPa): 16409

Poisson: 0.12

Depth (m): 60.57

STR MEAN (MPa): 2.311

STR DEV (MPa): 1.347

ANGLE (degrees): 22.53

ERROR (%): 11.752

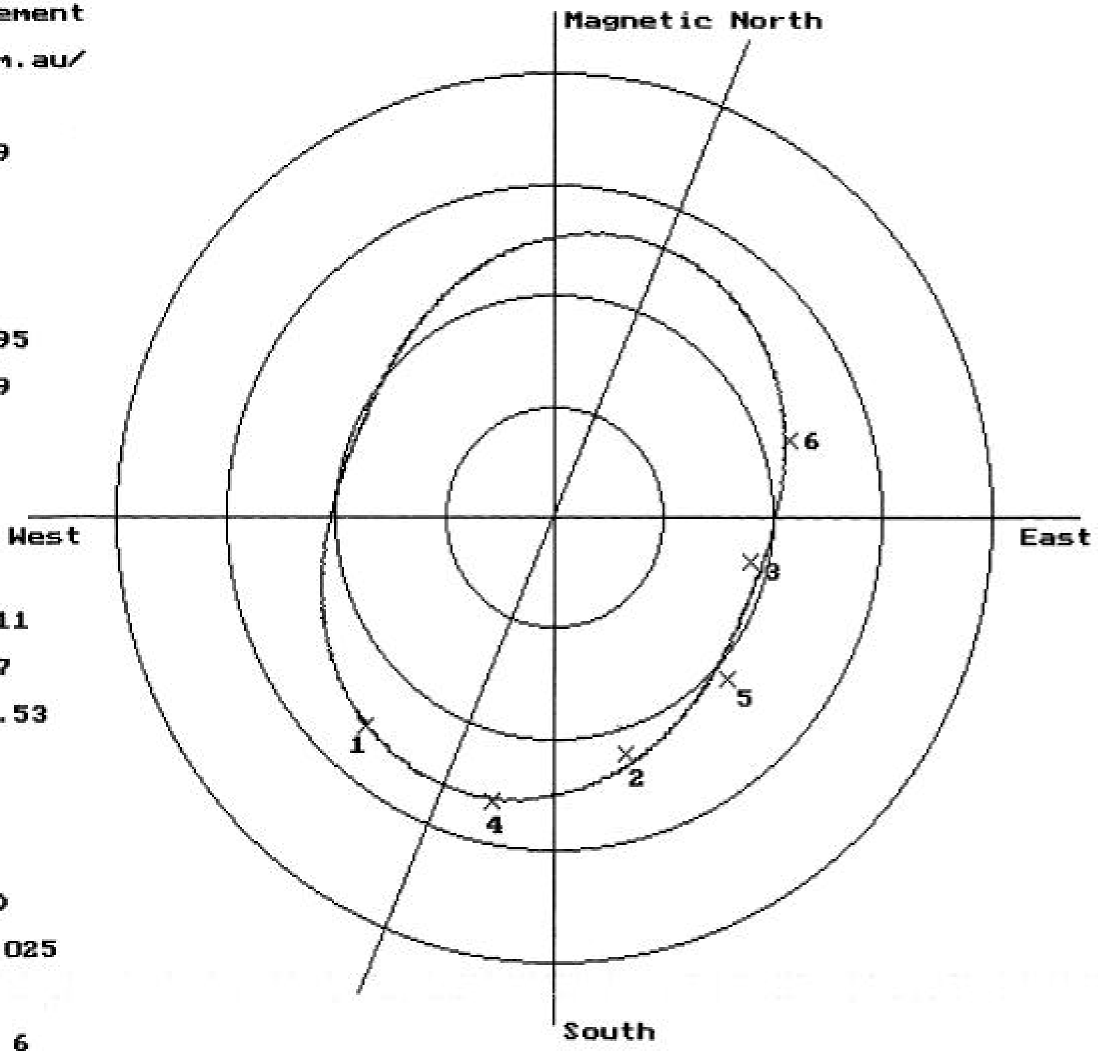
CASE : 1

Pin deflections (mm)

0.05 0.025 0.0 -0.025

X considered

x c - + l n b h 4 5 6



SIGRA STRESS MEASUREMENT SOLUTION
BULT 15, GHC
RUN NUMBER: 73
TOOL NUMBER: 9
PICK FILE NUMBER: 2
DATAFILE: d:\sdata\STR0073.009

DATE: 2/ 2/2003
TIME: 17:46

25.58200	DIAMETER OF SAMPLE (mm)
13218.0	MODULUS OF SAMPLE (MPa)
0.11000	POISSONS RATIO OF SAMPLE
61.79000	DEPTH OF SAMPLE (m)
0.0150000	WEIGHT PER VOLUME (MPa/m)
111.97803	ANGLE OF FIRST PIN IN DEGREES
29774.46	MAGNETIC FIELD STRENGTH (nT)

MEASURED DISPLACEMENTS OF PINS (mm)
-0.00600 0.01640 0.00380 0.00330 0.01990 0.00520

ANGLE OF PINS IN RADIANS
0.00000 -1.04720 -2.09440 -0.52360 -1.57080 -2.61799

SOLUTIONS WITH LOWEST ERROR

Pins	ERROR %	SIGM (MPa)	SIGD (MPa)	ANGLE (degrees)	CASE
6	16.1083	1.885	1.442	30.11	1
5	7.5265	1.363	1.860	35.78	7
4	0.2261	1.846	1.753	29.21	19

SIGM is the mean horizontal stress.
SIGD is the difference between
the mean stress and the principal stress.
Angle is the bearing of the major principal
axis relative to magnetic north.

SOLUTIONS FOR ALL PIN COMBINATIONS

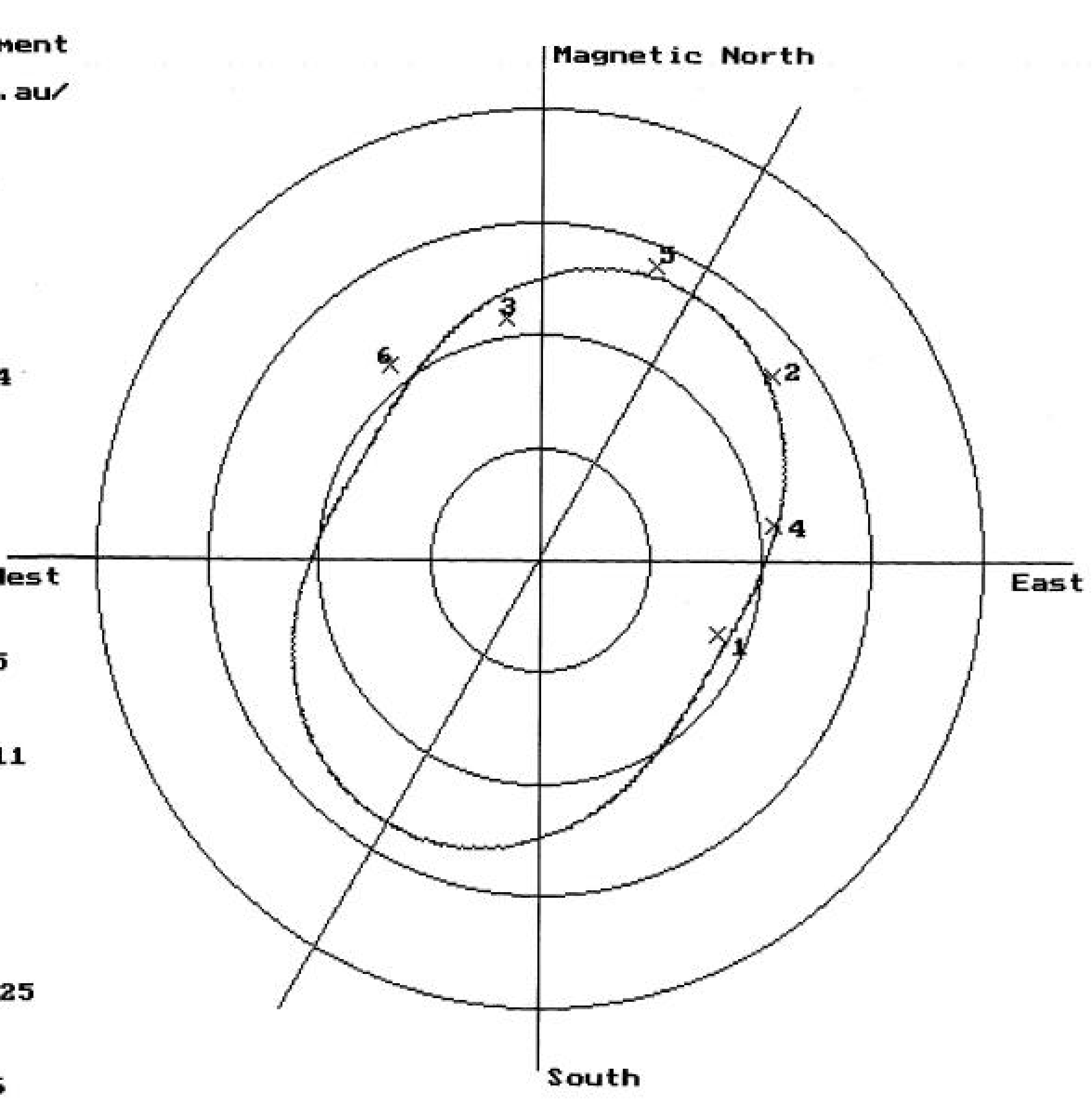
Case #	error %	SIGM (MPa)	SIGD (MPa)	ANGLE (degrees)	pins considered					
1	16.1083	1.885	1.442	30.11	1	2	3	4	5	6
2	17.6438	2.102	1.232	31.54	2	3	4	5	6	-1
3	17.5433	1.770	1.360	28.42	1	3	4	5	6	-1
4	8.5315	2.395	1.642	21.23	1	2	4	5	6	-1
5	17.7443	1.987	1.421	32.14	1	2	3	5	6	-1
6	21.6531	1.694	1.257	31.35	1	2	3	4	6	-1
7	7.5265	1.363	1.860	35.78	1	2	3	4	5	-1
8	19.8213	1.987	1.147	29.64	3	4	5	6	-1	-1
9	4.4668	2.611	1.423	21.12	2	4	5	6	-1	-1
10	15.8291	2.841	1.019	47.50	2	3	5	6	-1	-1
11	22.1037	1.905	0.865	35.90	2	3	4	6	-1	-1
12	4.8995	0.968	2.207	35.45	2	3	4	5	-1	-1
13	8.4310	2.280	1.590	19.39	1	4	5	6	-1	-1
14	21.6332	1.846	1.369	29.82	1	3	5	6	-1	-1
15	54.7500	0.968	0.676	22.91	1	3	4	6	-1	-1
16	8.5427	1.407	1.937	36.49	1	3	4	5	-1	-1
17	9.6734	2.344	1.698	19.75	1	2	5	6	-1	-1
18	6.7683	2.841	2.013	19.14	1	2	4	6	-1	-1
19	0.2261	1.846	1.753	29.21	1	2	4	5	-1	-1
20	24.6612	1.796	1.241	33.68	1	2	3	6	-1	-1
21	7.4260	1.465	1.859	37.37	1	2	3	5	-1	-1
22	4.8103	1.172	1.691	37.30	1	2	3	4	-1	-1
23	*.****	1.274	1.695	39.04	1	2	3	-1	-1	-1
24	*.****	1.885	1.762	28.79	1	2	4	-1	-1	-1
25	*.****	1.846	1.752	29.41	1	2	5	-1	-1	-1
26	*.****	2.841	2.237	16.53	1	2	6	-1	-1	-1
27	*.****	0.968	1.423	36.32	1	3	4	-1	-1	-1
28	*.****	1.846	2.231	42.30	1	3	5	-1	-1	-1
29	*.****	-1.861	1.806	-25.93	1	3	6	-1	-1	-1
30	*.****	1.846	1.746	29.05	1	4	5	-1	-1	-1
31	*.****	3.797	2.684	20.45	1	4	6	-1	-1	-1
32	*.****	1.846	1.837	10.55	1	5	6	-1	-1	-1
33	*.****	0.968	1.959	36.50	2	3	4	-1	-1	-1
34	*.****	0.128	2.734	32.16	2	3	5	-1	-1	-1
35	*.****	2.841	0.969	72.42	2	3	6	-1	-1	-1
36	*.****	1.808	1.774	29.50	2	4	5	-1	-1	-1
37	*.****	2.841	1.719	19.58	2	4	6	-1	-1	-1
38	*.****	2.841	1.200	25.77	2	5	6	-1	-1	-1
39	*.****	0.968	2.450	36.60	3	4	5	-1	-1	-1
40	*.****	0.968	0.233	-48.98	3	4	6	-1	-1	-1
41	*.****	5.554	2.543	69.04	3	5	6	-1	-1	-1
42	*.****	2.497	1.372	18.98	4	5	6	-1	-1	-1

Sigra Stress Measurement
http://www.sigra.com.au/
BULT 15, GHC
d:\sdata\STR0073.009
DATE: 2/ 2/2003
TIME: 17:46

Mag Field (nT): 29774
Modulus (MPa): 13218
Poisson: 0.11
Depth (m): 61.79

STR MEAN (MPa): 1.885
STR DEV (MPa): 1.442
ANGLE (degrees): 30.11
ERROR (%): 16.108
CASE : 1

Pin deflections (mm)
0.05 0.025 0.0 -0.025
× considered
x c - + l n b h 4 5 6

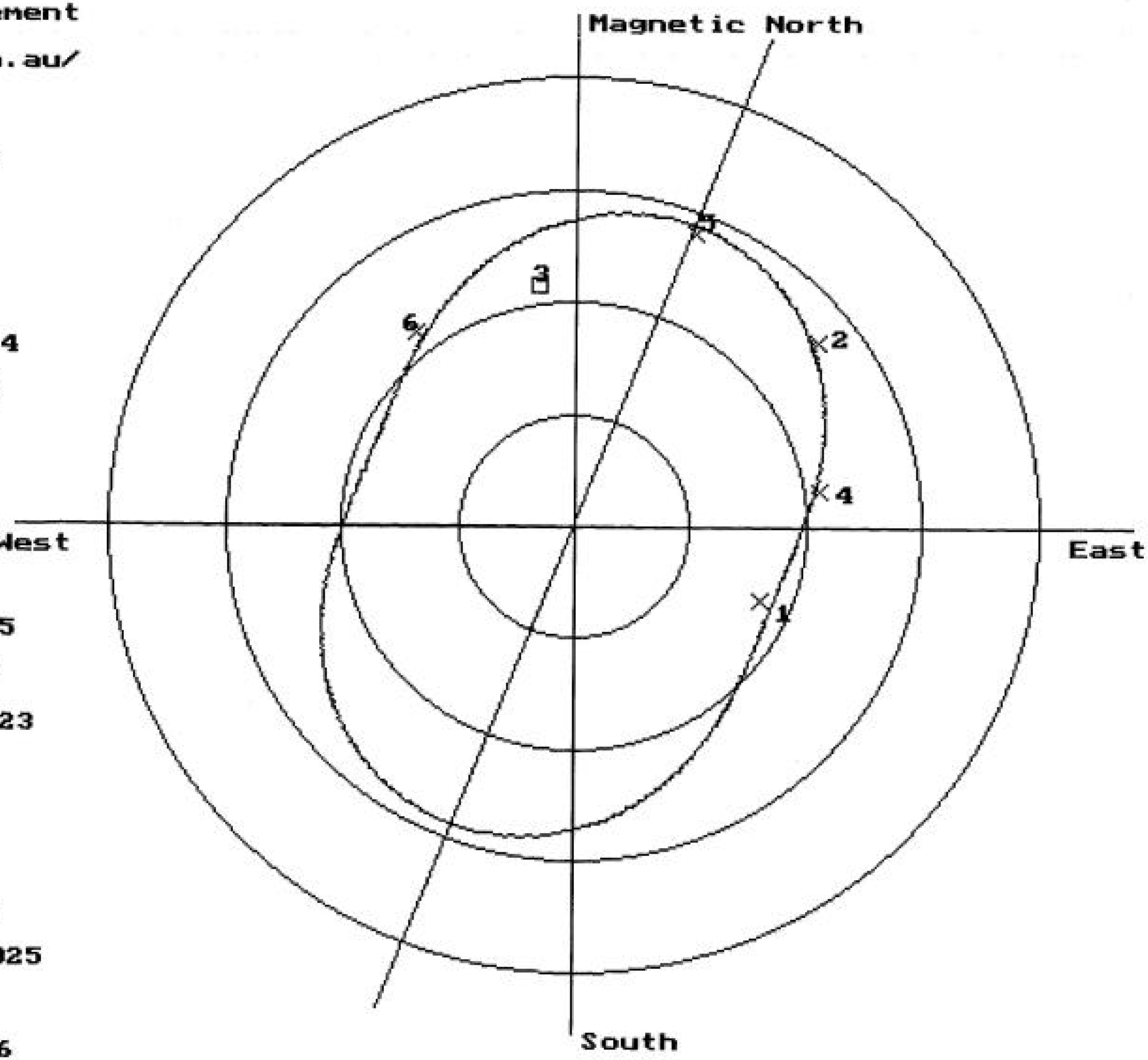


Sigra Stress Measurement
http://www.sigra.com.au/
BULT 15, GHC
d:\sdata\STR0073.009
DATE: 2/ 2/2003
TIME: 17:46

Mag Field (nT): 29774
Modulus (MPa): 13218
Poisson: 0.11
Depth (m): 61.79

STR MEAN (MPa): 2.395
STR DEV (MPa): 1.642
ANGLE (degrees): 21.23
ERROR (%): 8.5315
CASE : 4

Pin deflections (mm)
0.05 0.025 0.0 -0.025
× considered
x c - + l n b h 4 5 6

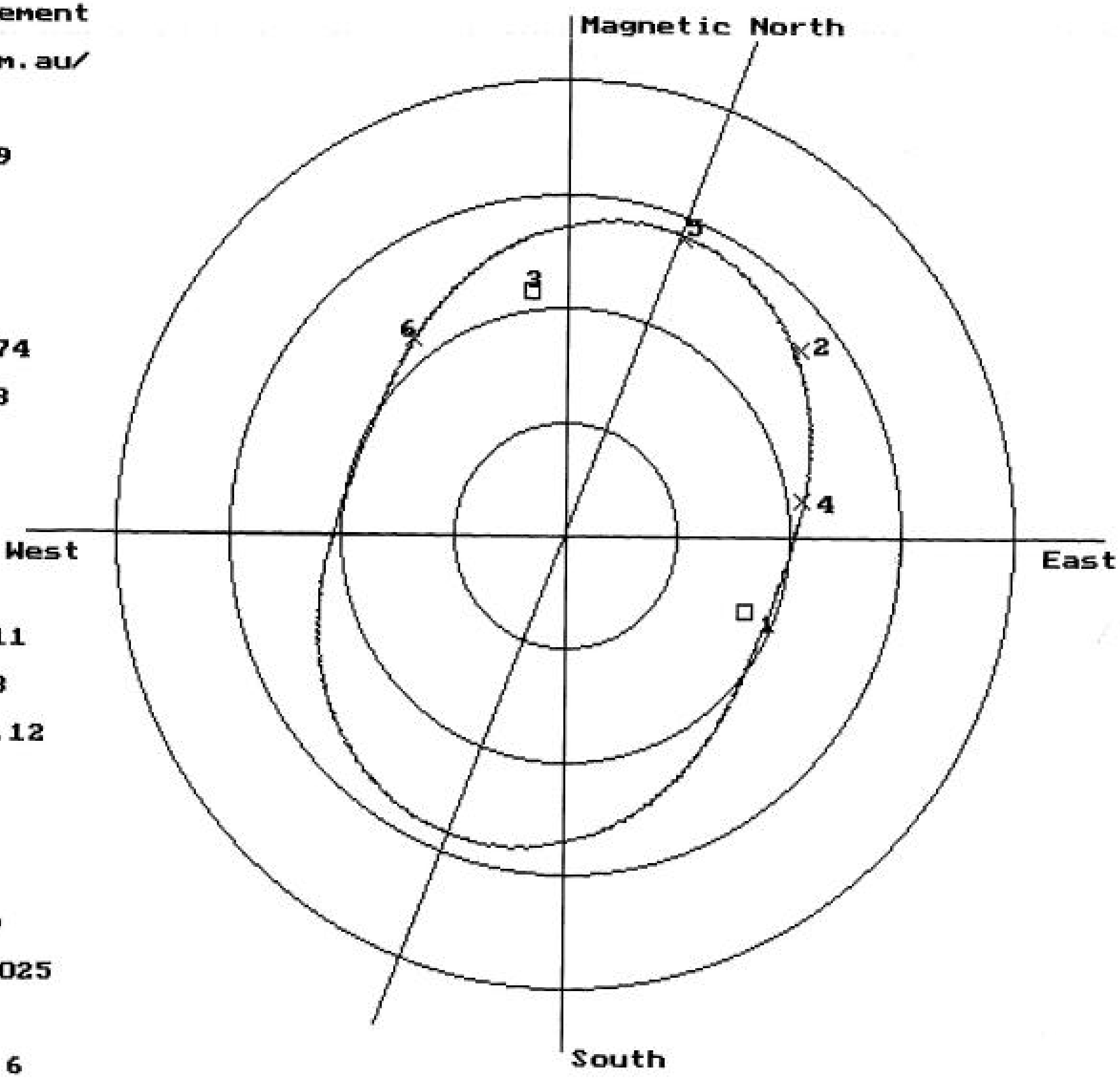


Sigra Stress Measurement
http://www.sigra.com.au/
BULT 15, GHC
d:\sdata\STR0073.009
DATE: 2/ 2/2003
TIME: 17:46

Mag Field (nT): 29774
Modulus (MPa): 13218
Poisson: 0.11
Depth (m): 61.79

STR MEAN (MPa): 2.611
STR DEV (MPa): 1.423
ANGLE (degrees): 21.12
ERROR (%): 4.4668
CASE : 9

Pin deflections (mm)
0.05 0.025 0.0 -0.025
× considered
x c - + l n b h 4 5 6



```
SIGRA STRESS MEASUREMENT SOLUTION
BULT 15, GHC
RUN NUMBER:   74
TOOL NUMBER:   9
PICK FILE NUMBER:  1
DATAFILE: d:\sdata\STR0074.009

DATE:  2/ 2/2003
TIME: 18:06

  25.69500        DIAMETER OF SAMPLE (mm)
   14801.0       MODULUS OF SAMPLE (MPa)
   0.18000       POISSONS RATIO OF SAMPLE
  62.59000             DEPTH OF SAMPLE (m)
 0.0150000     WEIGHT PER VOLUME (MPa/m)
 -39.81318  ANGLE OF FIRST PIN IN DEGREES
  30164.67  MAGNETIC FIELD STRENGTH (nT)

MEASURED DISPLACEMENTS OF PINS (mm)
  0.00490  0.00760  0.01670  0.00070  0.02370  0.01400

ANGLE OF PINS IN RADIANS
  0.00000 -1.04720 -2.09440 -0.52360 -1.57080 -2.61799

SOLUTIONS WITH LOWEST ERROR
Pins    ERROR   SIGM     SIGD   ANGLE    CASE
          %     (MPa)    (MPa)  (degrees)
  6    10.0328   3.329   1.516   30.48    1
  5     5.0566   2.891   1.201   23.54    6
  4     1.9760   2.590   1.230   17.18   15

SIGM is the mean horizontal stress.
SIGD is the difference between
the mean stress and the principal stress.
Angle is the bearing of the major principal
axis relative to magnetic north.
```

SOLUTIONS FOR ALL PIN COMBINATIONS

Case #	error %	SIGM (MPa)	SIGD (MPa)	ANGLE (degrees)	pins considered					
1	10.0328	3.329	1.516	30.48	1	2	3	4	5	6
2	10.3516	3.185	1.633	32.14	2	3	4	5	6	-1
3	10.9142	3.521	1.496	34.24	1	3	4	5	6	-1
4	6.1885	3.723	1.902	28.32	1	2	4	5	6	-1
5	10.8767	3.429	1.420	31.20	1	2	3	5	6	-1
6	5.0566	2.891	1.201	23.54	1	2	3	4	6	-1
7	11.4393	3.227	1.502	32.47	1	2	3	4	5	-1
8	11.5331	3.377	1.624	35.62	3	4	5	6	-1	-1
9	5.6259	3.579	2.012	29.79	2	4	5	6	-1	-1
10	12.9114	3.195	1.625	32.14	2	3	5	6	-1	-1
11	6.2874	2.893	1.199	23.48	2	3	4	6	-1	-1
12	10.2532	2.590	1.865	40.10	2	3	4	5	-1	-1
13	4.2194	3.915	1.865	31.29	1	4	5	6	-1	-1
14	8.4810	4.203	1.213	45.91	1	3	5	6	-1	-1
15	1.9760	2.590	1.230	17.18	1	3	4	6	-1	-1
16	11.8143	3.397	1.510	39.15	1	3	4	5	-1	-1
17	7.3840	3.699	1.949	28.12	1	2	5	6	-1	-1
18	2.1429	3.195	1.465	25.08	1	2	4	6	-1	-1
19	3.1646	4.203	2.190	23.79	1	2	4	5	-1	-1
20	4.2582	2.990	1.099	23.86	1	2	3	6	-1	-1
21	12.8458	3.326	1.409	33.34	1	2	3	5	-1	-1
22	4.1251	2.789	1.163	25.94	1	2	3	4	-1	-1
23	*.****	2.888	1.062	26.49	1	2	3	-1	-1	-1
24	*.****	3.483	1.668	24.18	1	2	4	-1	-1	-1
25	*.****	4.203	2.407	22.95	1	2	5	-1	-1	-1
26	*.****	3.195	1.374	25.05	1	2	6	-1	-1	-1
27	*.****	2.590	1.191	19.36	1	3	4	-1	-1	-1
28	*.****	4.203	1.454	58.08	1	3	5	-1	-1	-1
29	*.****	2.273	1.391	13.58	1	3	6	-1	-1	-1
30	*.****	4.203	2.073	26.41	1	4	5	-1	-1	-1
31	*.****	2.907	1.356	21.46	1	4	6	-1	-1	-1
32	*.****	4.203	1.590	35.99	1	5	6	-1	-1	-1
33	*.****	2.590	1.291	31.54	2	3	4	-1	-1	-1
34	*.****	0.257	3.526	43.78	2	3	5	-1	-1	-1
35	*.****	3.195	0.879	18.79	2	3	6	-1	-1	-1
36	*.****	4.923	2.404	17.83	2	4	5	-1	-1	-1
37	*.****	3.195	1.536	26.16	2	4	6	-1	-1	-1
38	*.****	3.195	2.537	29.78	2	5	6	-1	-1	-1
39	*.****	2.590	2.234	49.08	3	4	5	-1	-1	-1
40	*.****	2.590	1.211	14.87	3	4	6	-1	-1	-1
41	*.****	6.133	1.051	83.95	3	5	6	-1	-1	-1
42	*.****	3.771	1.984	32.60	4	5	6	-1	-1	-1

Sigra Stress Measurement

http://www.sigra.com.au/

BULT 15, GHC

d:\sdata\STR0074.009

DATE: 2/ 2/2003

TIME: 18:06

Mag Field (nT): 30165

Modulus (MPa): 14801

Poisson: 0.18

Depth (m): 62.59

STR MEAN (MPa): 3.329

STR DEV (MPa): 1.516

ANGLE (degrees): 30.48

ERROR (%): 10.033

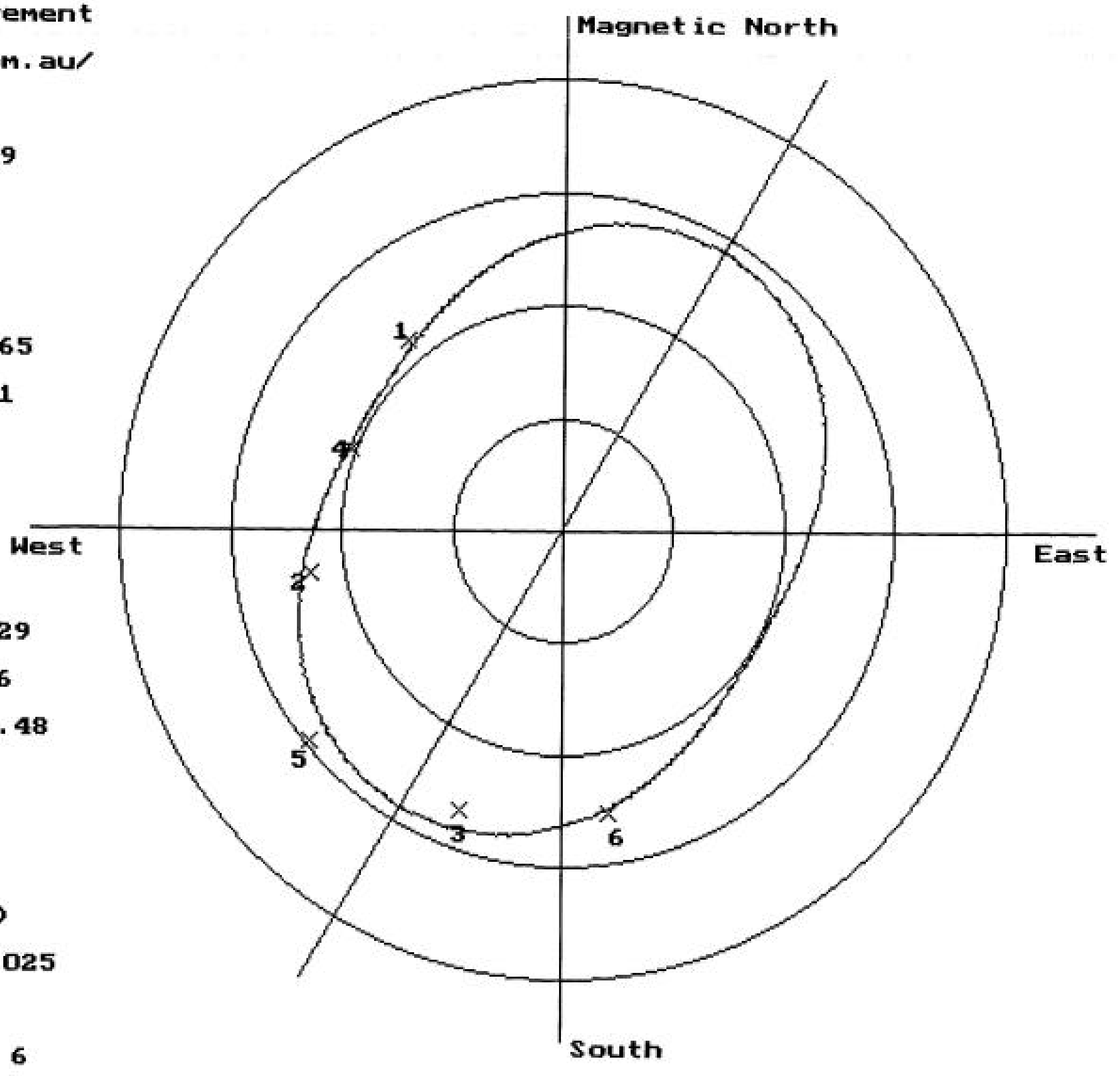
CASE : 1

Pin deflections (mm)

0.05 0.025 0.0 -0.025

× considered

x c - + l n b h 4 5 6



Sigra Stress Measurement

http://www.sigra.com.au/

BULT 15, GHC

d:\sdata\STR0074.009

DATE: 2/ 2/2003

TIME: 18:06

Mag Field (nT): 30165

Modulus (MPa): 14801

Poisson: 0.18

Depth (m): 62.59

STR MEAN (MPa): 2.891

STR DEV (MPa): 1.201

ANGLE (degrees): 23.54

ERROR (%): 5.0566

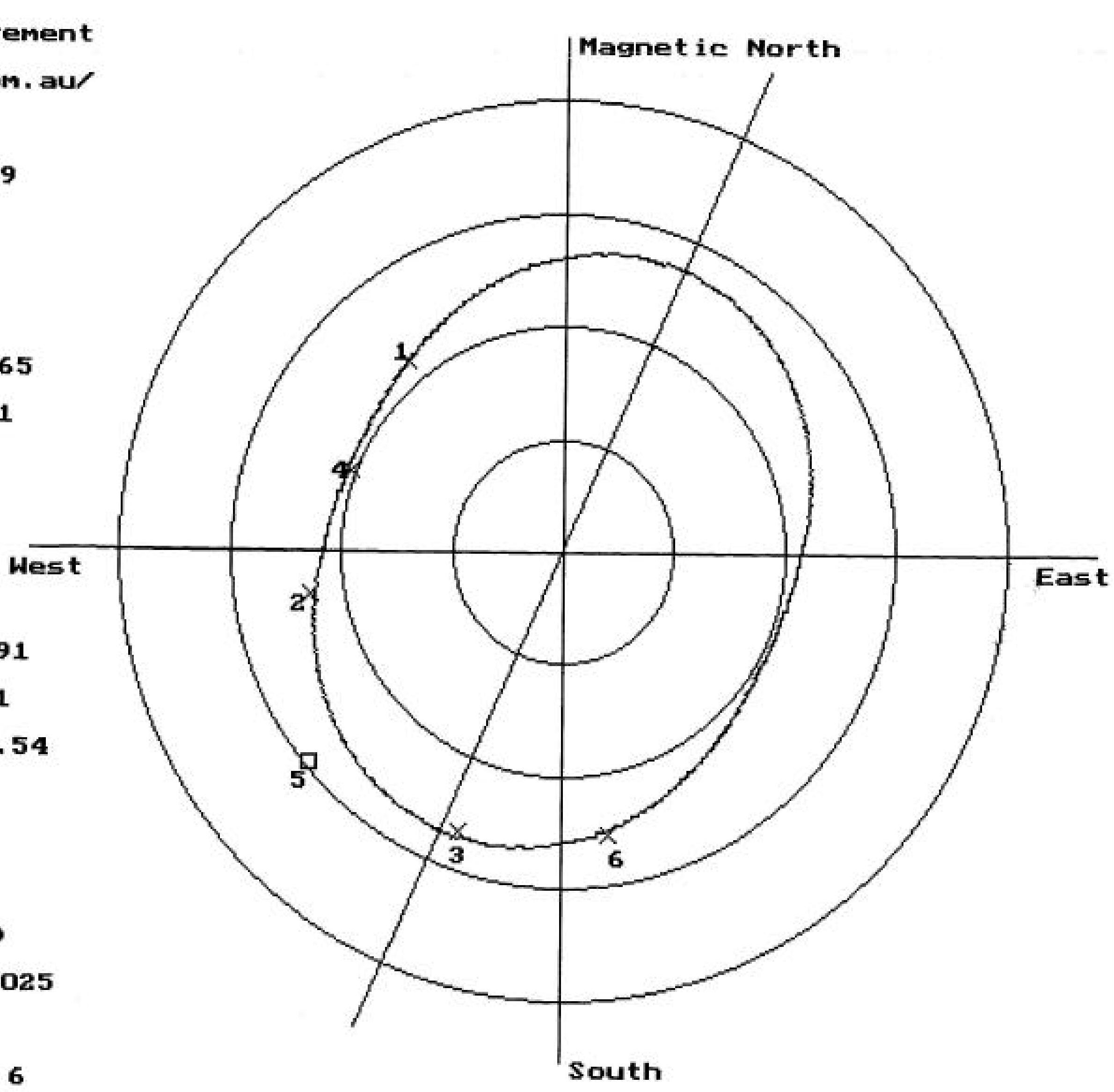
CASE : 6

Pin deflections (mm)

0.05 0.025 0.0 -0.025

× considered

x c - + l n b h 4 5 6



APPENDIX D

Directional Survey Information

DIRECTIONAL SURVEY INFORMATION FROM STRESS TOOL

```
OVERCORE 0072.009

ANGLE FROM MAGS AND ACCEL
PIN1 ORIENTATION ACTUALLY USED  =   -137.471 deg
MAGNETIC FIELD STRENGTH         =  30095.192 nT
GRAVITATIONAL FIELD STRENGTH    =      9.836 m/s^2
ANGLE BETWEEN MAG AND GRAV FIELD=    152.636 deg
TOOL INCLINATION                =      0.561 deg
AZIMUTH BASED ON GRAV AND MAG   =    158.328 deg
TOOL FACE HOZ ON MAGS AND GRAV  =   -137.471 deg
TOOL FACE HOZ ON MAGS ONLY      =   -137.881 deg
ANGLE BETWEEN MAG FLD AND AXIS  =    153.156 deg


OVERCORE 0073.009

ANGLE FROM MAGS AND ACCEL
PIN1 ORIENTATION ACTUALLY USED  =    111.978 deg
MAGNETIC FIELD STRENGTH         =  29774.454 nT
GRAVITATIONAL FIELD STRENGTH    =      9.836 m/s^2
ANGLE BETWEEN MAG AND GRAV FIELD=    155.275 deg
TOOL INCLINATION                =      0.575 deg
AZIMUTH BASED ON GRAV AND MAG   =    156.874 deg
TOOL FACE HOZ ON MAGS AND GRAV  =    111.978 deg
TOOL FACE HOZ ON MAGS ONLY      =    111.478 deg
ANGLE BETWEEN MAG FLD AND AXIS  =    155.803 deg


OVERCORE 0074.009

ANGLE FROM MAGS AND ACCEL
PIN1 ORIENTATION ACTUALLY USED  =    -39.813 deg
MAGNETIC FIELD STRENGTH         =  30164.670 nT
GRAVITATIONAL FIELD STRENGTH    =      9.840 m/s^2
ANGLE BETWEEN MAG AND GRAV FIELD=    153.451 deg
TOOL INCLINATION                =      0.562 deg
AZIMUTH BASED ON GRAV AND MAG   =    147.951 deg
TOOL FACE HOZ ON MAGS AND GRAV  =    -39.813 deg
TOOL FACE HOZ ON MAGS ONLY      =    -40.422 deg
ANGLE BETWEEN MAG FLD AND AXIS  =    153.927 deg
```

APPENDIX E

Photographs of Each Test Core

Plate 1: Overcore No 0072.009

Plate 2: Overcore No 0073.009

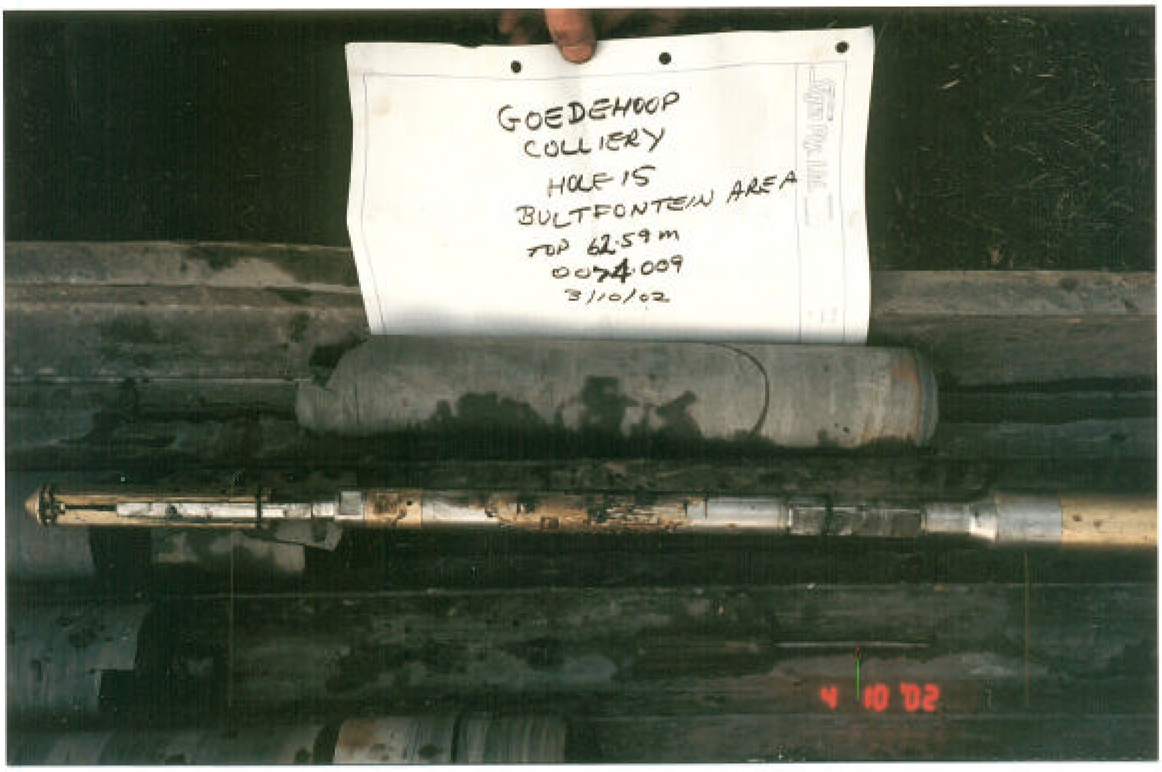


Plate 3: Overcore No 0074.009