### 7.4.3 Modelling the Piet Retief Colliery Pillars

As SEAMS reproduced the results of in situ experiments well, it was used to simulate the performance of pillars at Piet Retief Colliery. Figure 7.23 shows the stress profile from the program SEAMS using the previous input parameters and at a virgin stress of 10 MPa. The model underestimates the stress in the initial 2,5 m into the pillar side, but it shows that the elements in this zone have failed simulating the extent of fracturing observed underground. The model also shows the maximum stress to be higher than that recorded underground. From approximately 6,0 m into the pillar side the predicted stress profile closely correlates with stress results obtained in situ.

The model is considered to be reasonable as the fractured zone is predicted, as is the reduction in stress from about 6,0 m. Since the model overestimates the peak stress and underestimates the load carried by the fractured zone, it gives a more conservative estimate of the conditions at the edge of the pillar.

Maintaining a virgin stress of 10 MPa, the results of stress profiles for pillars with width to height ratios between four and 14 are shown in Figure 7.24. Fracturing extends throughout the pillar with a width to height ratio of four (8 m wide) while for all other pillar sizes the stress profile near the edge of the pillar and the extent of fracturing remain constant. This result corresponds to the findings by Wagner (1974) that the stress in the pillar side is independent of width to height ratio.

The peak stress increases slightly from approximately 19 to 21 MPa while the reduction in stress up to 6,0 m into the pillar is similar in the cases with width to height ratios of six to 14. The stress in the centre of the pillars increases with decreasing width to height ratio as is shown in Figure 7.25. From the underground measured stress profiles the central core is assumed to start 9,0 m into the pillar. From Figure 7.25 there appears to be no advantage in having a pillar of width greater than 20 m (width to height ratio of 10) as the stress remains relatively constant in this zone with increased width. With pillar widths less than 20 m the stress in the centre of the pillar increases rapidly with decreasing pillar size, Figure 7.25.

## 7.5 ESTIMATING THE PARAMETER $\epsilon$

Figure 7.26 shows the increase in areal percentage extraction over the current design method using the squat pillar formula with $\epsilon$ = 2,5 and assuming a mining height of 2,0 m, a bord width of 6,0 m and a safety factor of 2,0 at depths from 0 - 1000 m. At 200 m the increase in areal percentage extraction is 4,3 per cent and 17,6 per cent at 500 m. Included in the figure is the areal percentage extraction with $\epsilon$ equal to 3,0; 3,5 and 4,0. A sensitivity analysis of $\epsilon$ shows that a small change in pillar width gives a large change in $\epsilon$. Refining $\epsilon$ would be of economic benefit as the difference in areal percentage extraction between $\epsilon$ = 2,5 and $\epsilon$ = 4,0 is 2,1 per cent at 200 m and this increases to 7,8 per cent at 500 m. However, the effects of surrounding strata and their stability during pillar loading have not been investigated. Therefore it is advisable to accept the proven and conservative assumption of $\epsilon$ = 2,5 until other investigations have examined the influence of the surrounding strata.

## 7.6 BENEFITS FROM THE APPLICATION OF THE SQUAT PILLAR FORMULA

### 7.6.1 Increased Extraction

Permanent support pillars are required to be left under surface structures such as buildings, dwellings, railway lines, canals and roads. Main development and shaft bottom design requires pillars to remain stable for the life of the mine, which may exceed 50 years. In these cases a design safety factor in excess of 2,0 is used.

The benefit of the squat pillar design formula, in terms of increased extraction of coal, can be seen in the example used in Figure 7.27. In this case, a five road main development at a depth of 300 m in a 2,0 m seam, using a safety factor of 2,0, results in a 29,7 m pillar according to the current design method and a 20,0 m pillar using the squat pillar design formula.

The reduction in both centre distance (9,7 m) and panel width (38,8 m) results in increased productivity from the shorter tramming distances involved, as well as an increase in coal extracted. The areal percentage extraction is 33,6 per cent for the 29,7 m pillars and 45,2 per cent for the 20,0 m squat pillars. Not only is there less coal locked up in the form of permanent support pillars but narrower panel widths ensure that more coal can be extracted at an earlier date.

In Figure 7.27, assuming that the barrier widths on either side of the main development remain the same in both cases, the application of the squat pillar formula results in an additional strip of coal 38,8 m wide which becomes available for panel extraction. If total extraction is practised as a method of extracting coal from the panels adjacent to the main development, then the application of the squat pillar formula increases the areal extraction to 59,8 per cent over the same panel area. The absolute increase in percentage extraction of 26,2 per cent (59,8 - 33,6 per cent) represents the coal locked up within the larger pillars of the current design. The absolute increase in areal percentage extraction of the squat pillar design over that of the current design is shown in Figure 7.28.

The benefits of increased percentage extraction can also be shown by considering, for example, a deposit of 1,3 m mining height at a depth of 400 m, and assuming that the mine requires one million tons per year for 20 years. Applying the current formula an extraction of 37 per cent can be obtained with bord and pillar workings at a safety factor of 1,6. The in situ reserves required are 20 million tons divided by 0,37, i.e. 54 million tons. Assuming a 20 per cent loss due to geological and mining losses, the total reserves required are 54 divided by 0,8, or, 67,5 million tons.

The squat pillar percentage extraction at 400 m is 50 per cent. The in situ reserves required are 20 million tons divided by 0,5, or, 40 million tons. With the same geological and mining loss (20 per cent), 40 divided by 0,8 or 50 million tons in situ are required. At a height of 1,3 m and specific gravity of 1,5, the area required is 3 461,5 ha using the current design formula, and 2 564,1 ha using the squat pillar formula. This represents a saving of 897,4 ha in mineral rights purchase.

### 7.6.2 Increased Production

The oversupply of coal on the world market and the rising costs of labour and stores has made it essential that working costs be kept to a minimum. One way of reducing the cost of coal per ton mined is to increase productivity. To determine the increase in productivity from the use of the squat pillar design formula, production from sections designed to both formulae were simulated using the program "COMSIM" developed by the Coal Mining division of COMRO, Oberholzer and Hardman (1987). Pillar geometries were calculated using the current and squat pillar formulae for mining heights of 1, 2 and 3 m at depths of between 200 and 500 m, assuming a safety factor of 2,0 and a bord width of 6,0 m.

A five-road development panel for the various geometries was simulated with the following conditions and assumptions: a continuous miner and two shuttle-cars with six ton capacity; no roofbolting required, and a nine-hour face time with 100 per cent machine availability. For the study, tramming speeds, loading rate, discharge time and cutting rates were kept constant in all simulations so that a comparison of the production between various pillar geometries could be obtained. The tons per shift obtained from both the squat pillar and current pillar geometries of pillars 1 and 3 m mining height is shown at depths between 200 and 500 m respectively in Figure 7.29, and Figure 7.30 shows the reduction in tons per shift with increasing pillar size. Table 7.5 summarizes the tons per shift as well as the percentage increase resulting from the application of the squat pillar formula, and shows that the later increases from about five per cent at 200 m depth to about 50 per cent at 500 m depth.

**Table 7.5 Tons per Shift for Pillars Designed by Salamon and Munro and Squat Pillar Formulae.**

| Mining Height | | | |
|---|---|---|---|
| 1 m | | | |
| Depth (m) | Current tons/shift | Squat tons/shift | Increase % |
| 200 | 1334 | 1404 | 5,25 |
| 300 | 1069 | 1366 | 27,76 |
| 400 | 977 | 1301 | 33,11 |
| 500 | 842 | 1285 | 52,54 |
| 2 m | | | |
| 200 | 1183 | 1264 | 6,85 |
| 300 | 907 | 1118 | 23,26 |
| 400 | 794 | 1058 | 33,25 |
| 500 | 643 | 1004 | 56,14 |
| 3 m | | | |
| 200 | 1031 | 1096 | 6,30 |
| 300 | 745 | 950 | 27,52 |
| 400 | 626 | 869 | 38,82 |
| 500 | 524 | 810 | 54,58 |

Tons per kilometre of shuttle-car travel when using both formulae is shown in Table 7.6 and Figure 7.31 plots the percentage increase in tons per shift and tons per kilometre of shuttle-car travel. The figures indicates the tremendous benefit in terms of increased productivity resulting from the application of the squat pillar formula. At a depth of 200 m the shuttle-cars transport about 10 to 16 per cent more coal per kilometre of travel in the squat pillar sections, while at 300 m the gain is between 40 to 50 per cent. This improved utilization of the shuttle-car should result in a significant decrease in transport costs.

Table 7.6 Tons per Kilometre of Shuttle-car Travel.

| Mining Height | | | |
|---|---|---|---|
| 1 m | | | |
| Depth (m) | Current tons/shift | Squat tons/shift | Increase % |
| 200 | 54,7 | 63,5 | 16,09 |
| 300 | 37,7 | 57,4 | 52,25 |
| 400 | 30,2 | 50,5 | 67,22 |
| 500 | 23,8 | 48,5 | 103,78 |
| 2 m | | | |
| 200 | 37,9 | 43,4 | 14,51 |
| 300 | 24,5 | 34,6 | 41,22 |
| 400 | 20,3 | 31,1 | 53,20 |
| 500 | 14,7 | 28,2 | 81,84 |
| 3 m | | | |
| 200 | 28,9 | 31,9 | 10,38 |
| 300 | 17,9 | 25,3 | 41,34 |
| 400 | 13,9 | 22,1 | 58,99 |
| 500 | 10,7 | 19,9 | 85,98 |

Productivity is also improved by the increase in the cutting times of continuous miners as a result of the reduced travelling times from smaller pillar geometries (see Table 7.7).

**Table 7.7 Continuous Miner Utilization (Cutting Time) for Salamon and Munro and Squat Pillar Formulae.**

| Mining Height | | | |
|---|---|---|---|
| 1 m | | | |
| Depth (m) | Current Pillar Time Cutting Minutes | Squat Pillar Time Cutting Minutes | Increase % |
| 200 | 267 | 280 | 4,87 |
| 300 | 214 | 273 | 27,57 |
| 400 | 195 | 260 | 33,33 |
| 500 | 168 | 257 | 52,98 |
| 2 m | | | |
| 200 | 237 | 253 | 6,57 |
| 300 | 181 | 224 | 23,76 |
| 400 | 159 | 212 | 33,33 |
| 500 | 128 | 201 | 52,98 |
| 3 m | | | |
| 200 | 207 | 219 | 5,80 |
| 300 | 150 | 190 | 26,67 |
| 400 | 125 | 174 | 39,20 |
| 500 | 104 | 162 | 55,77 |

## 7.7 CONCLUSIONS

Extensive field trials at Hlobane and Piet Retief Collieries have shown that, using the squat pillar strength formula, stable pillar dimensions can be designed. The pillar dimensions are substantially reduced compared to those of current methods of pillar design.

Measurements of pillar dilation in the stooping section at Hlobane Colliery showed that pillars with high width to height ratios were stable during their extraction while increasing overburden load was being carried.

The results of stress monitoring at Piet Retief Colliery showed that the stress in the centre of pillars designed to the squat pillar strength formula had returned to near virgin conditions. These results were examined using the program SEAMS. Although the program has limitations and underestimates the load carrying capability of the fractured zone as well as overestimating the peak stress, the stress in the central portion of the pillar was accurately modelled.

The field trials have shown that the extent of fracturing is confined to the perimeter of the pillar; using the squat pillar strength formula and a safety factor of 2,0, a large central portion of the pillar remains unfractured. This research has shown that, for high width to height ratio pillars, the squat pillar strength formula gives a more realistic estimate of pillar strength than that calculated by Salamon and Munro's formula.

It was not possible to determine an alternative value for the parameter $\epsilon$ as it is sensitive to a small change in pillar width. As the stress in the centre of the pillars at Piet Retief Colliery was near to virgin stress, this indicates that the value of 2,5 for $\epsilon$ is a conservative estimate but still results in a substantially improved design method.

The reduced pillar sizes resulting from the application of the squat pillar formula lead to an increase in percentage extraction and in productivity. In addition, benefits will be gained from better ventilation and improved equipment utilization. Overall, working costs will be lower and the safety of men and equipment will remain secure. To date six collieries have successfully utilized the squat pillar design formula with benefits of increased extraction and improved productivity.

The extension of the design formula of Salamon and Munro (1967) by the squat pillar formula provides a realistic design method that can be applied safely.

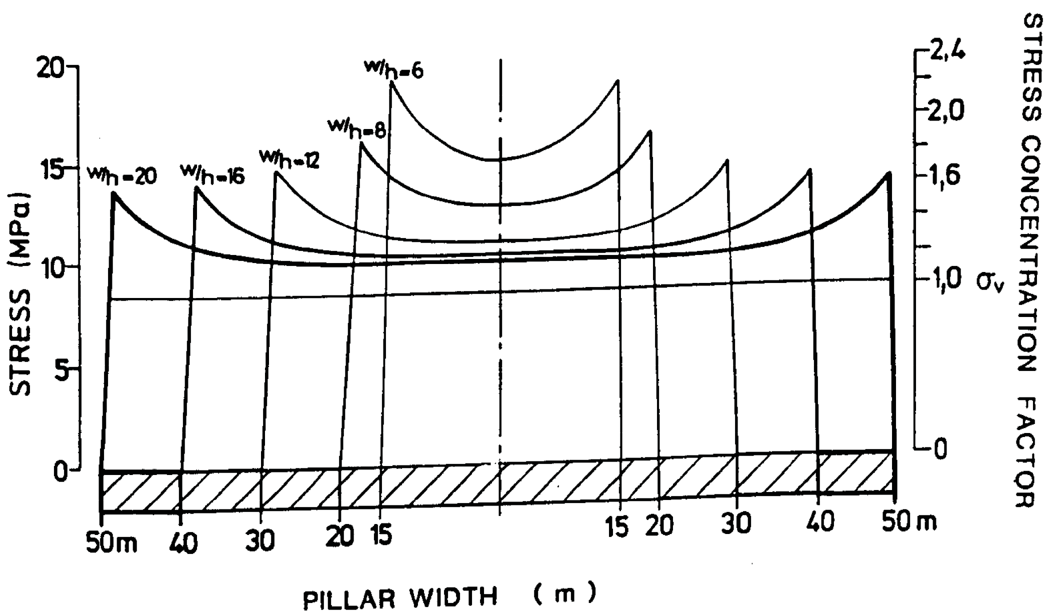



Figure 7.1 Stress and stress concentration factor on 15 to 50 m pillars at 320 m depth. Mining height = 2,5 m.

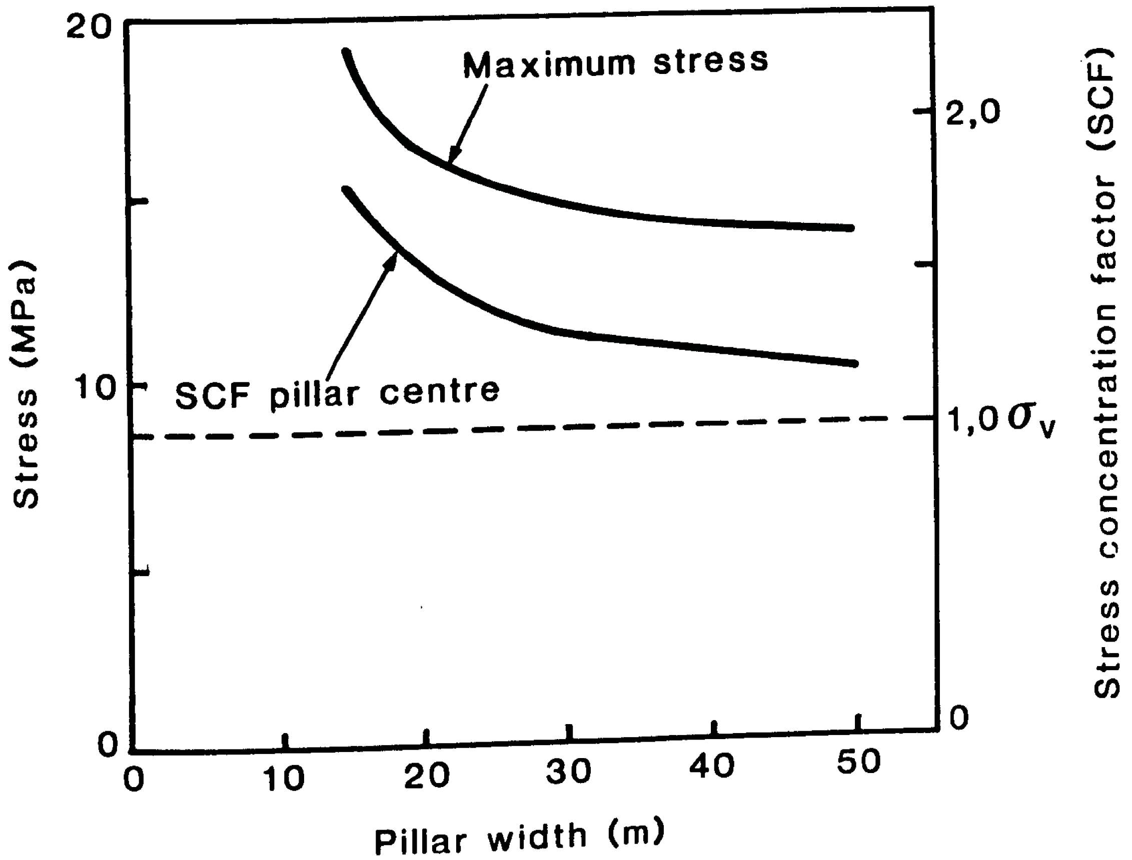



Figure 7.2 Maximum stress and stress concentration in the pillar centre for pillars 15 to 50 m at 320 m depth. Mining height = 2,5 m.

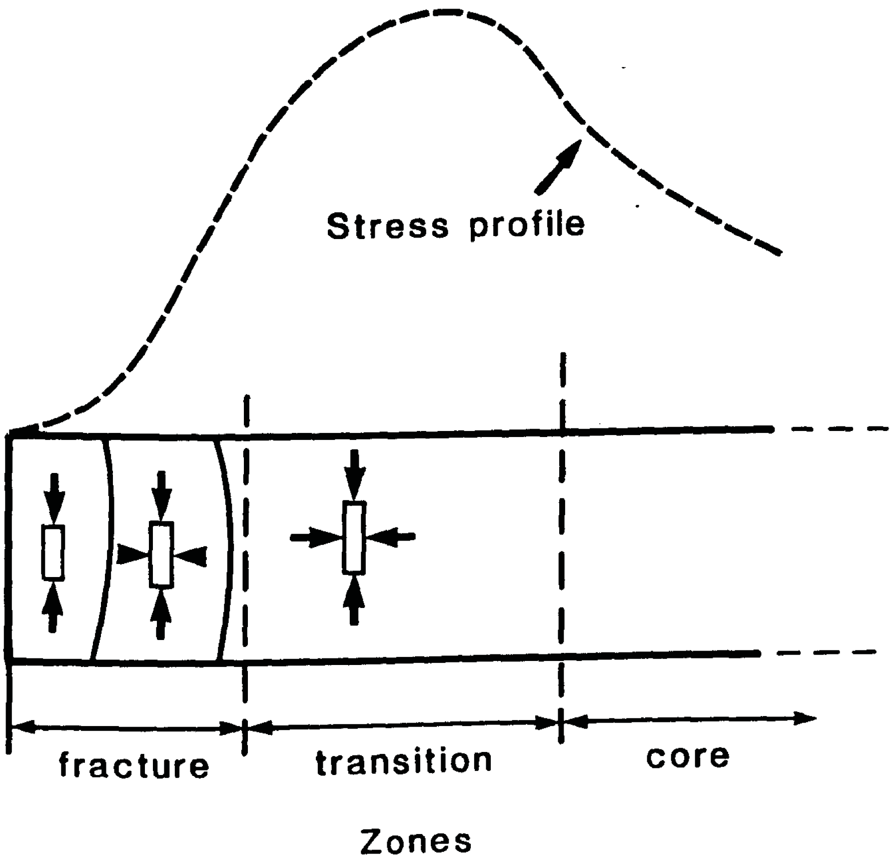



Figure 7.3 Idealized zones with a stable pillar.

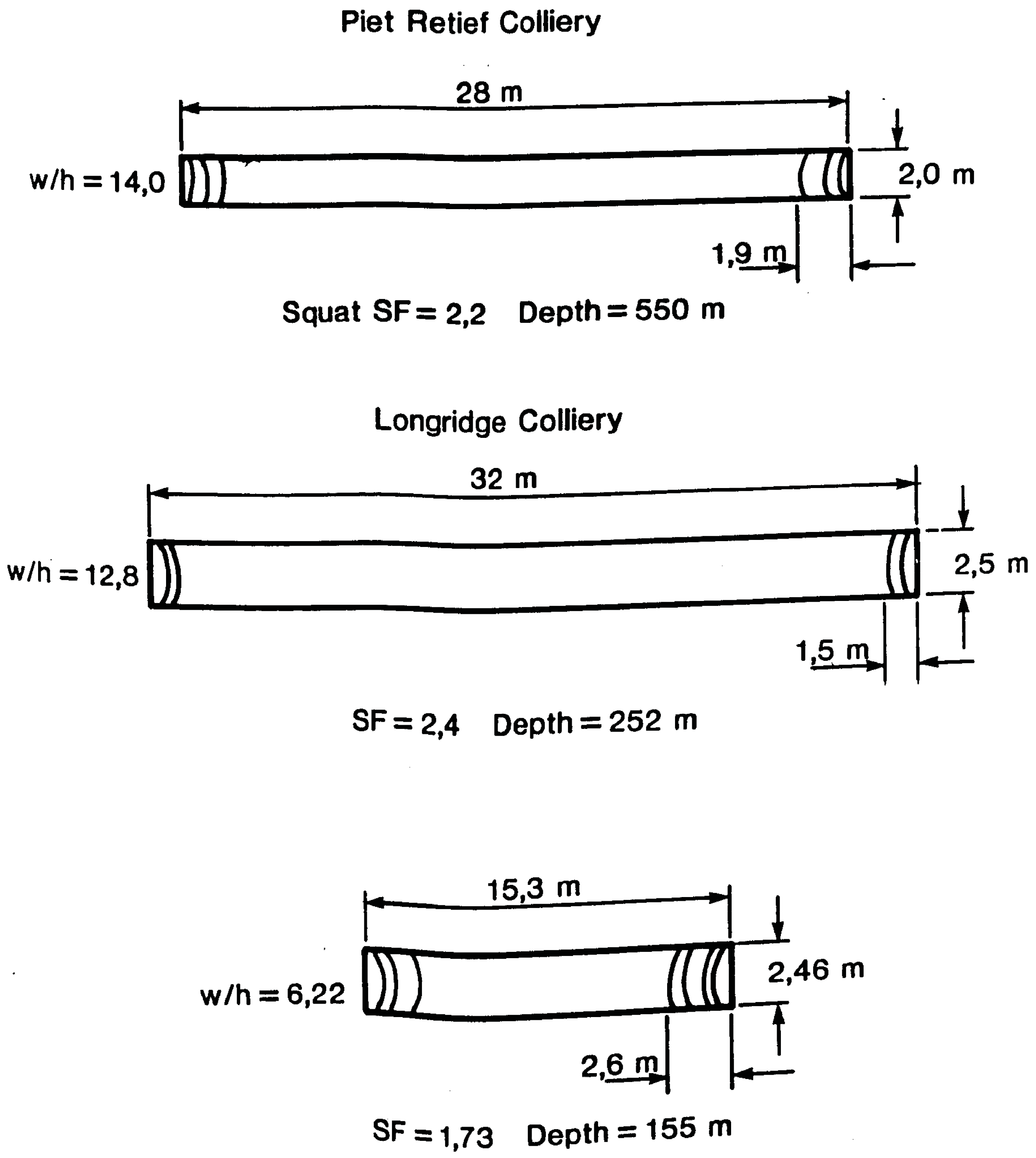
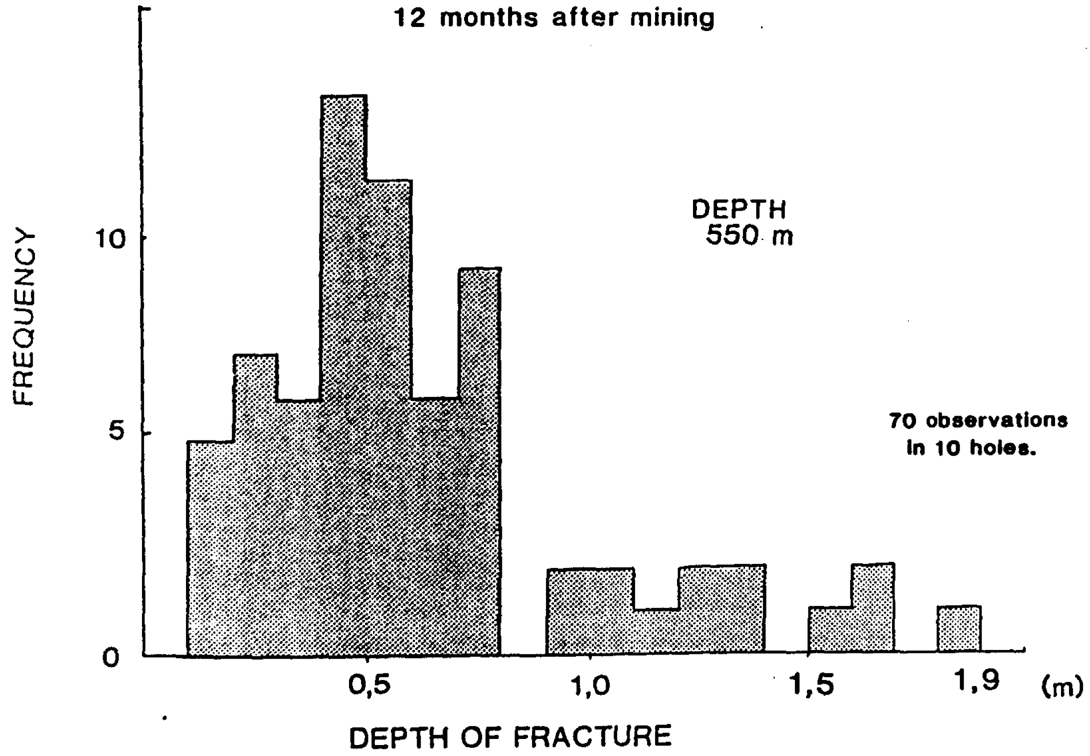



Figure 7.4 Fractures observed in pillars at Piet Retief and Longridge Collieries.



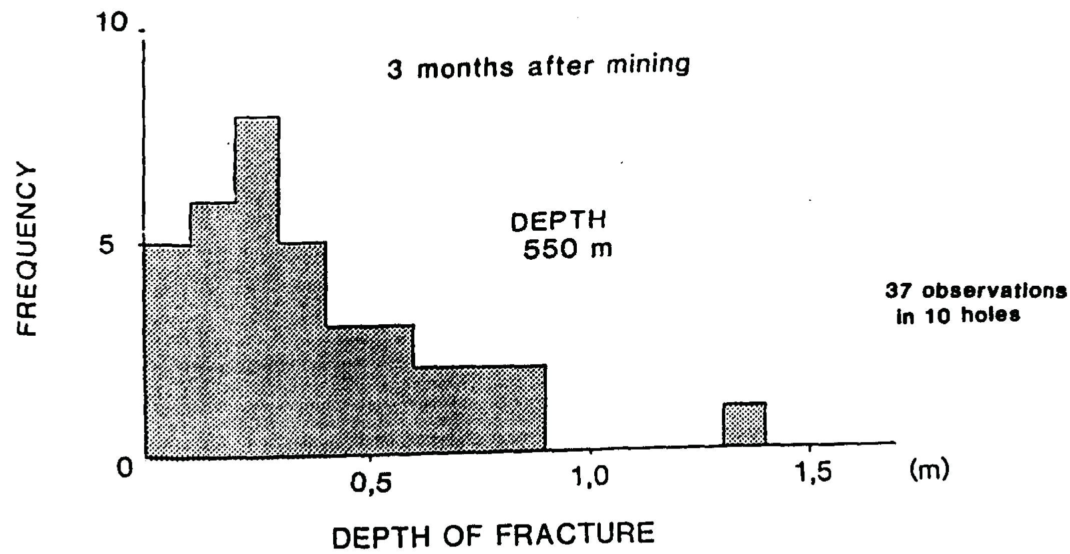




Figure 7.6 Fracture frequency versus depth observed in pillars mined at 550 m depth, three months and 12 months after mining.

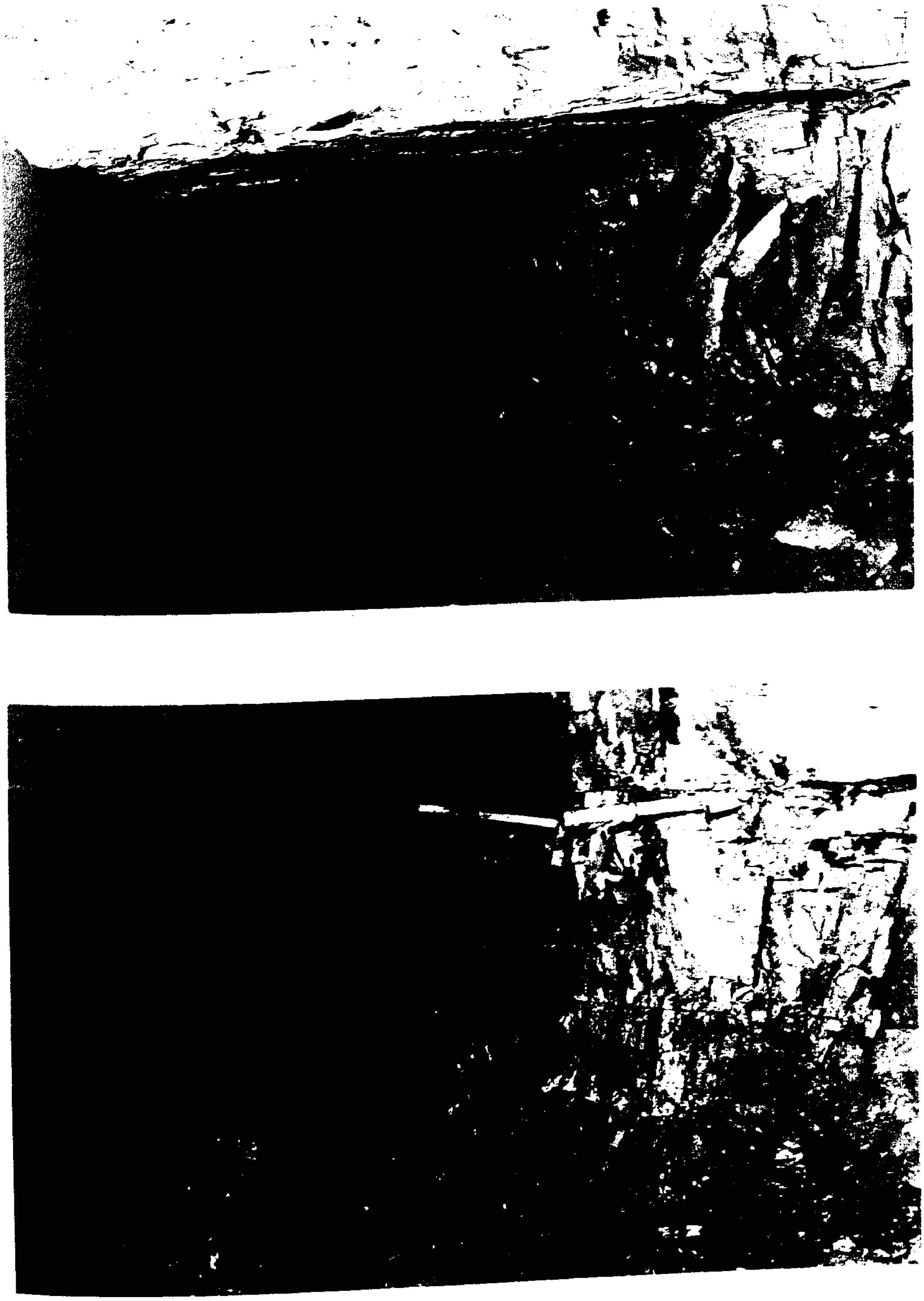
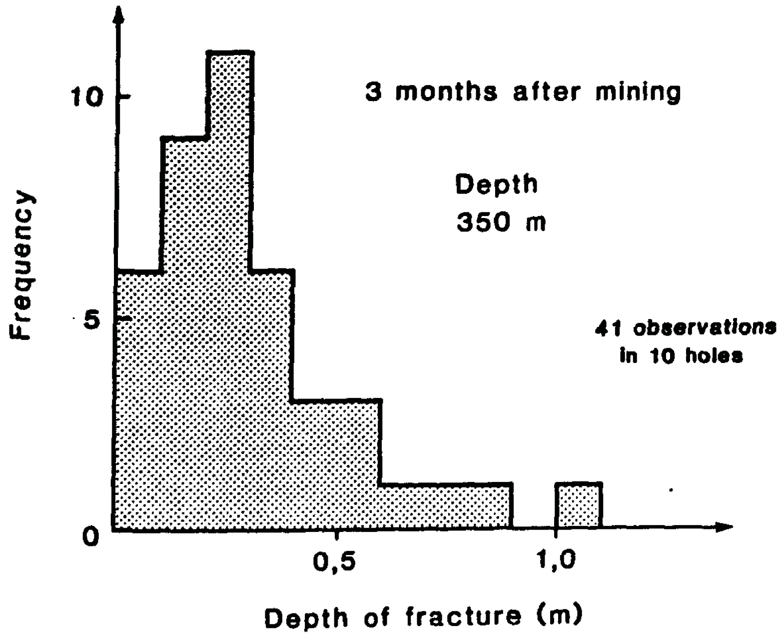


Figure 7.5 **Sidewall fracturing at Piet Retief Colliery, depth 500 - 550 m.**



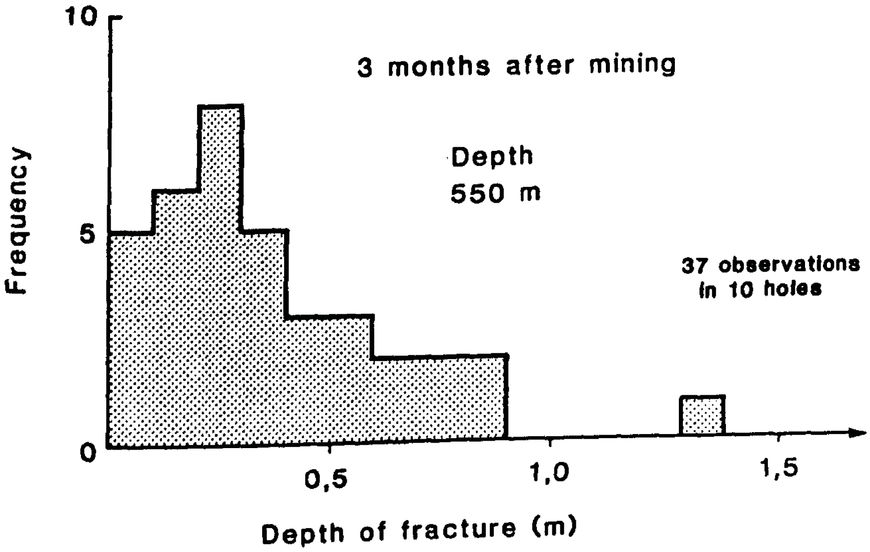
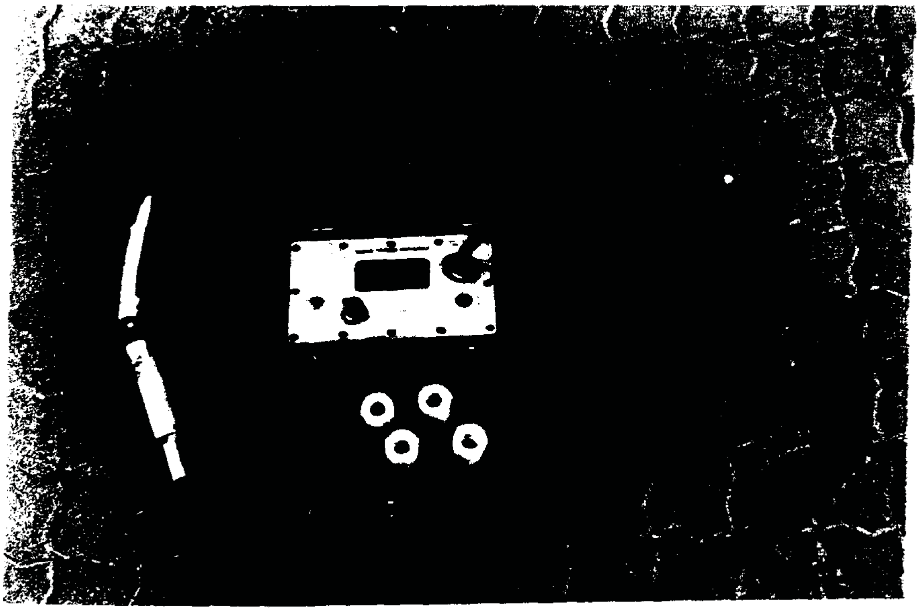




Figure 7.7 Fracture frequency versus depth observed in pillars at 350 and 550 m depth, three months after mining.



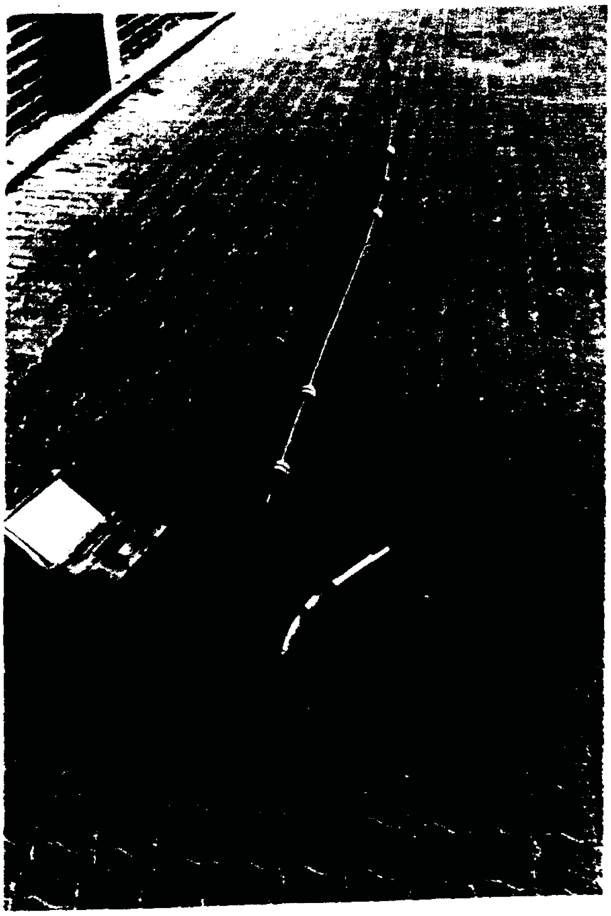


Figure 7.8 IRAD sonic probe and magnetic anchors used to measure pillar dilation.

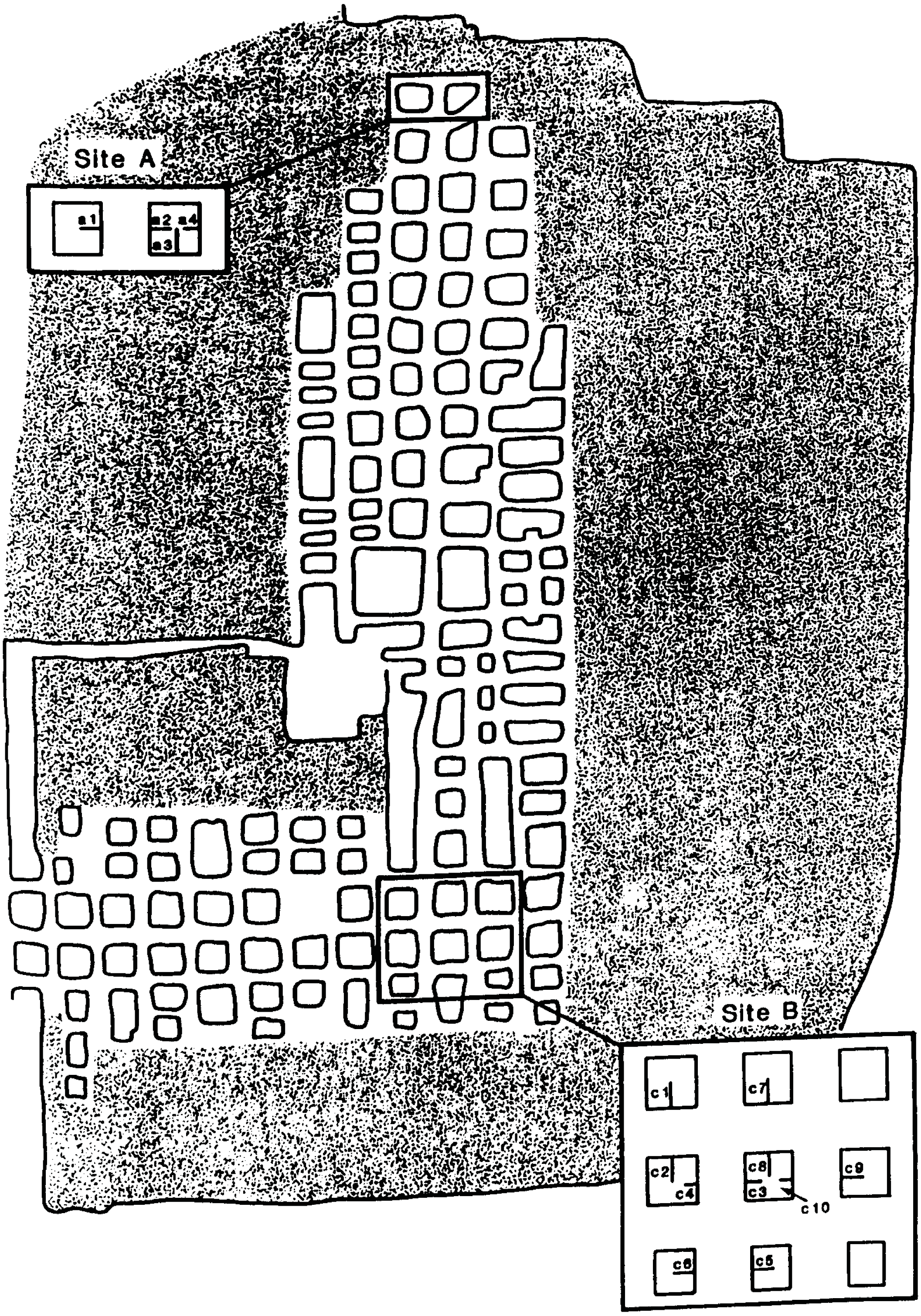



Figure 7.9 Schematic location of Irad probe holes at sites A and B in Section 614, Hlobane Colliery.

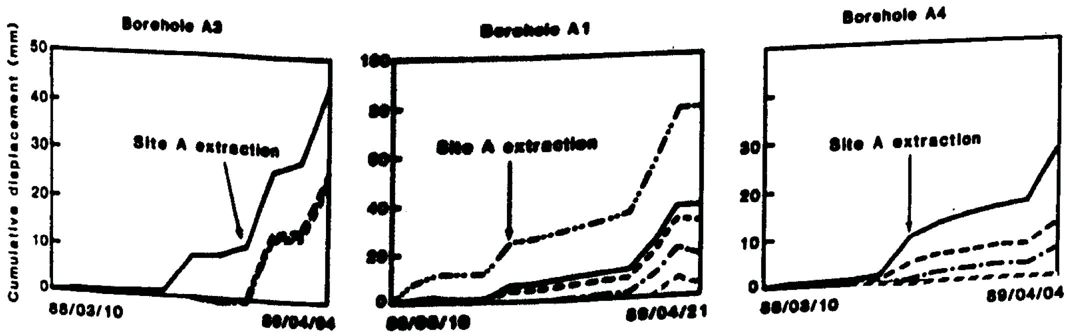



Figure 7.10 Pillar dilation results from site A, Section 614, Hlobane Colliery.

Figure 7.11 Severe floor heave Section 614, Hlobane Colliery.

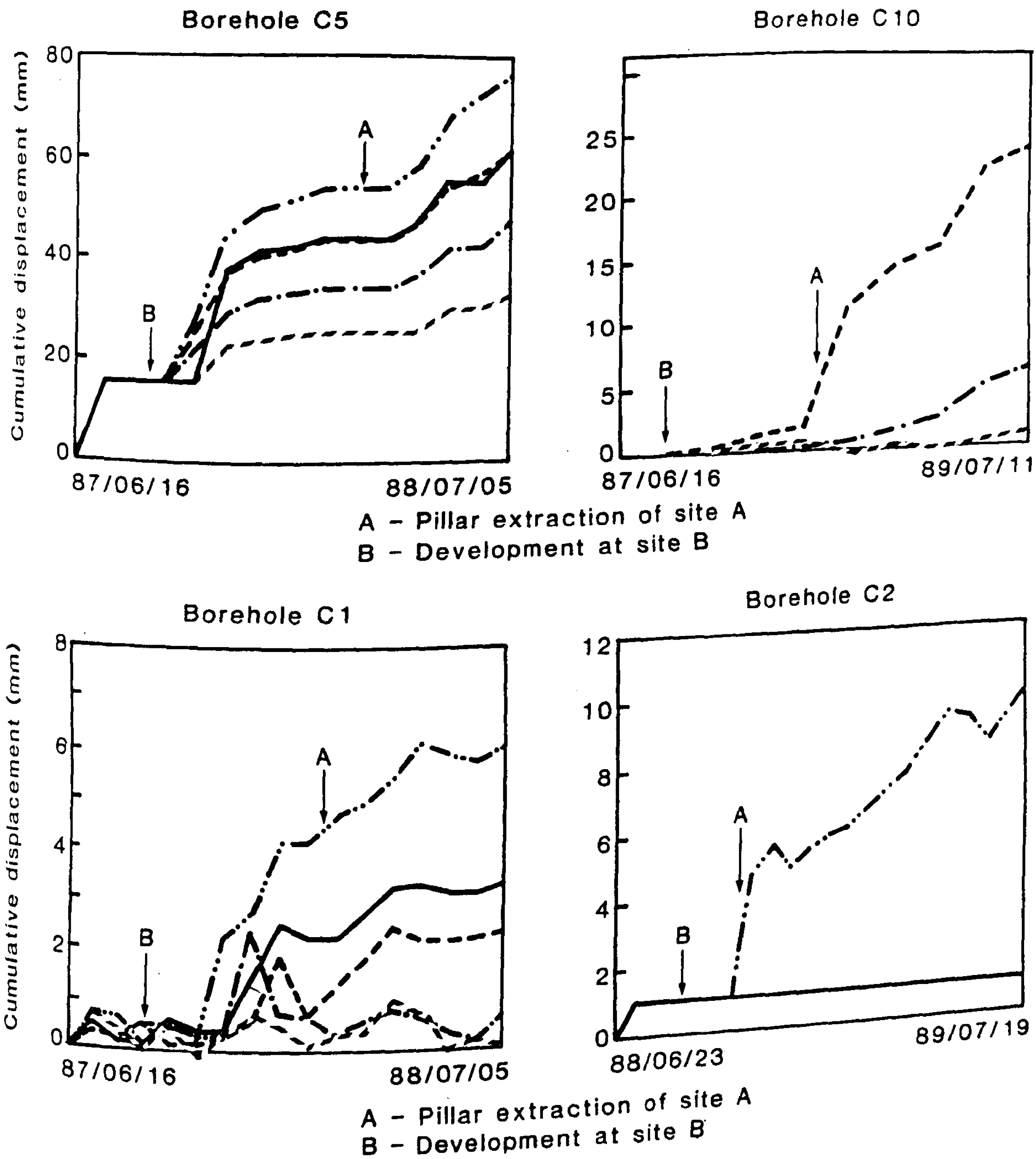



Figure 7.12 Pillar dilation results from site B, Section 614, Hlobane Colliery.

Figure 7.13 CSIR doorstopper strain cell installation in coal.

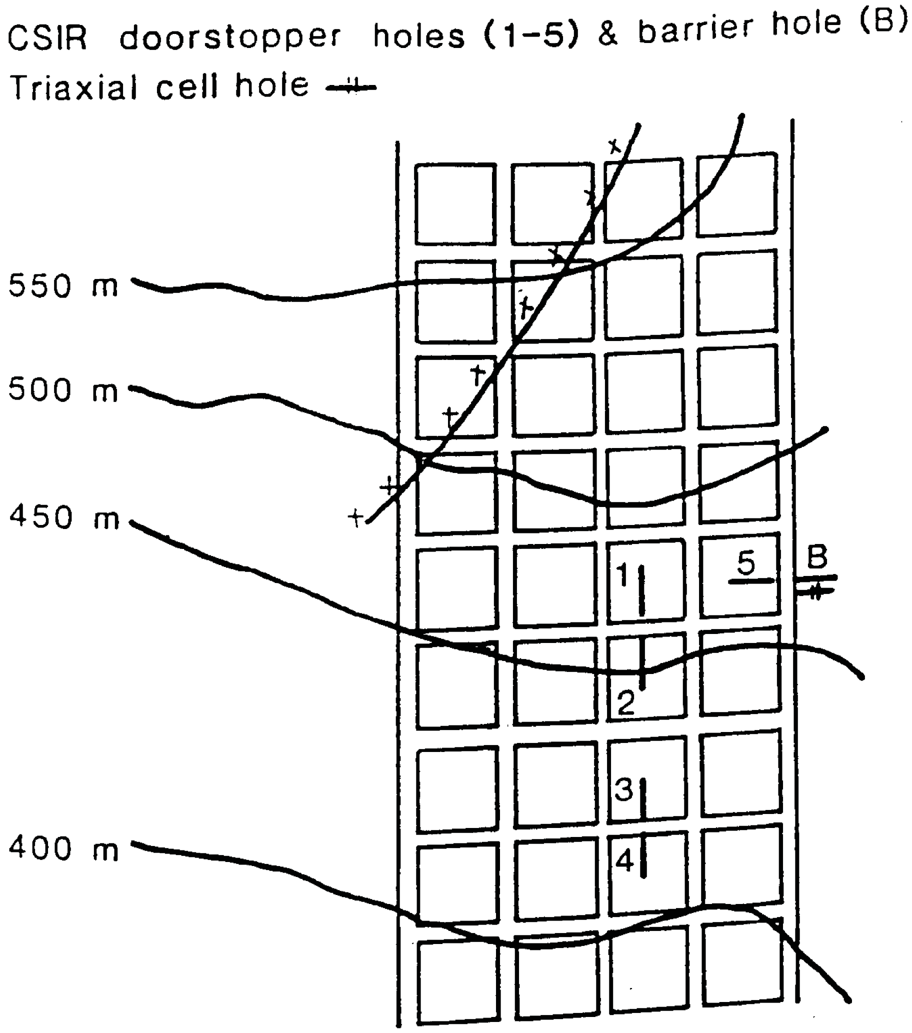



Figure 7.14 Location of stress holes at Piet Retief Colliery.

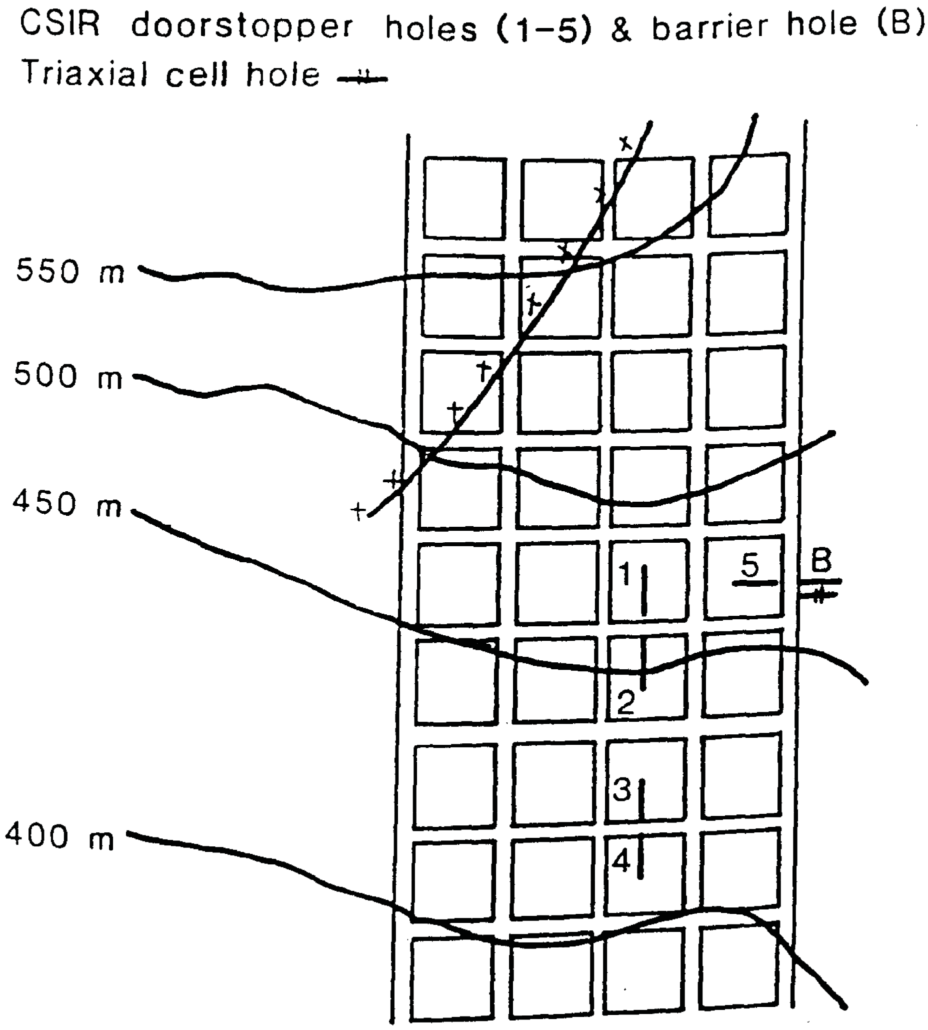



Figure 7.14 Location of stress holes at Piet Retief Colliery.

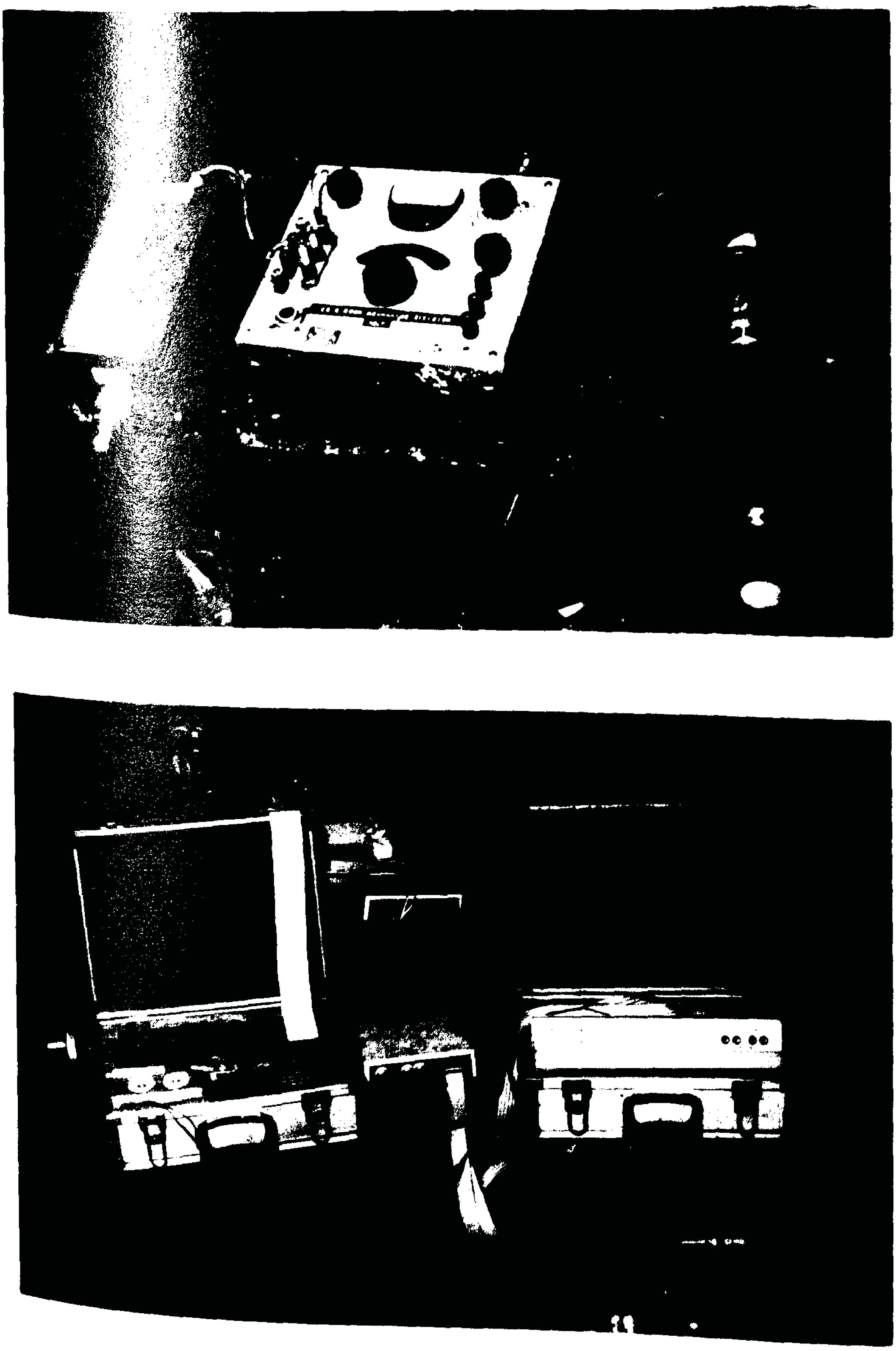


Figure 7.15 Strain recording equipment used at Piet Retief Colliery.

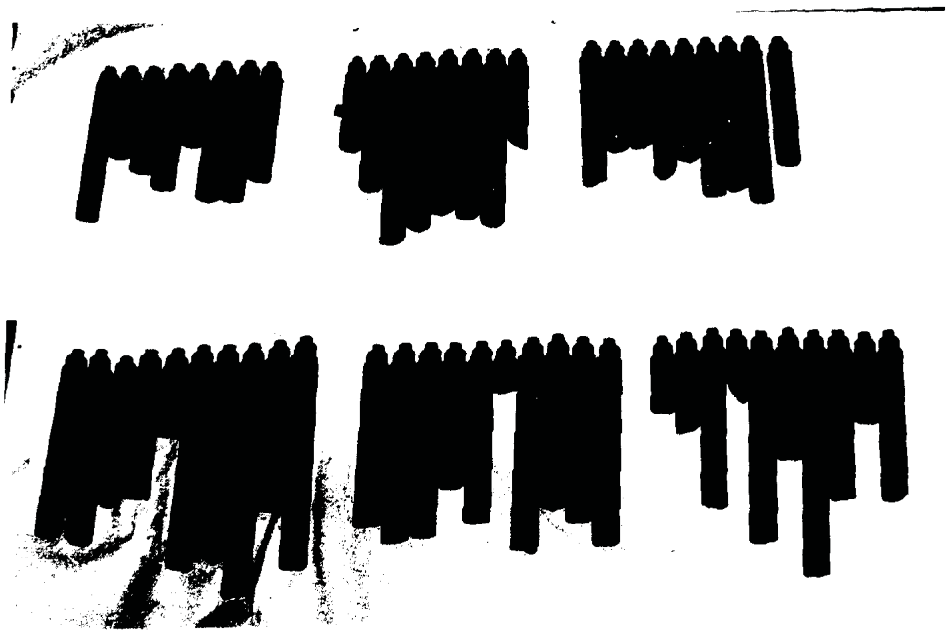
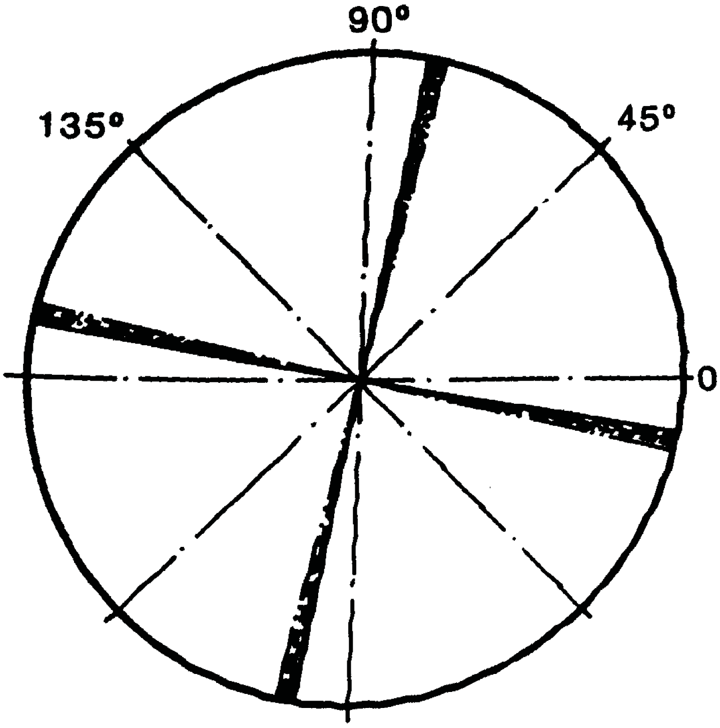


Figure 7.16 CSIR doorstopper stain cell installation in sandstone at Piet Retief Colliery.




| | | |
|---|---|---|
| 1 | 77,4 | 167,4 |
| 2 | 78,2 | 168,2 |
| 3 | 80,4 | 170,4 |
| 4 | 79,5 | 169,5 |
| Av | 78,9 | 168,9 |

Sig 1 14,49 MPa
Sig 2 5,71 MPa

Figure 7.17 Typical result from analysis of *CSIR doorstopper* strain cell, Piet Retief Colliery.

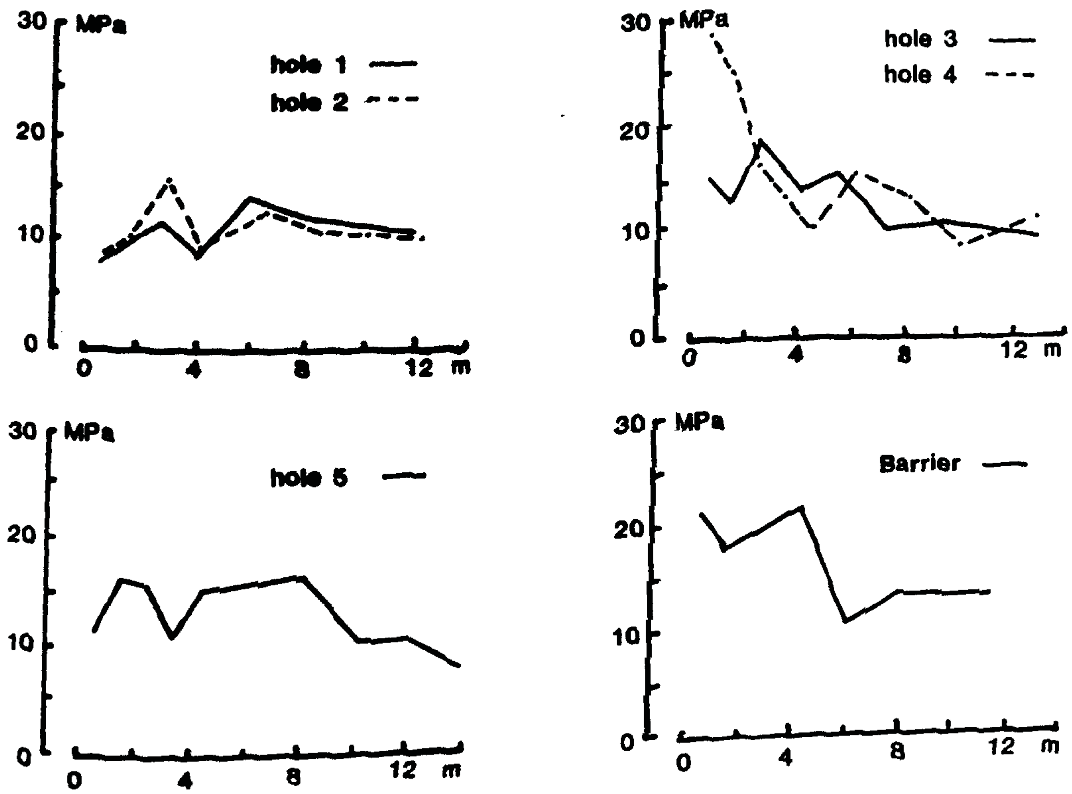



Figure 7.18 Stress profiles above coal pillars at *Piet Retief* Colliery.

Figure 7.19 Triaxial cells, Piet Retief Colliery.

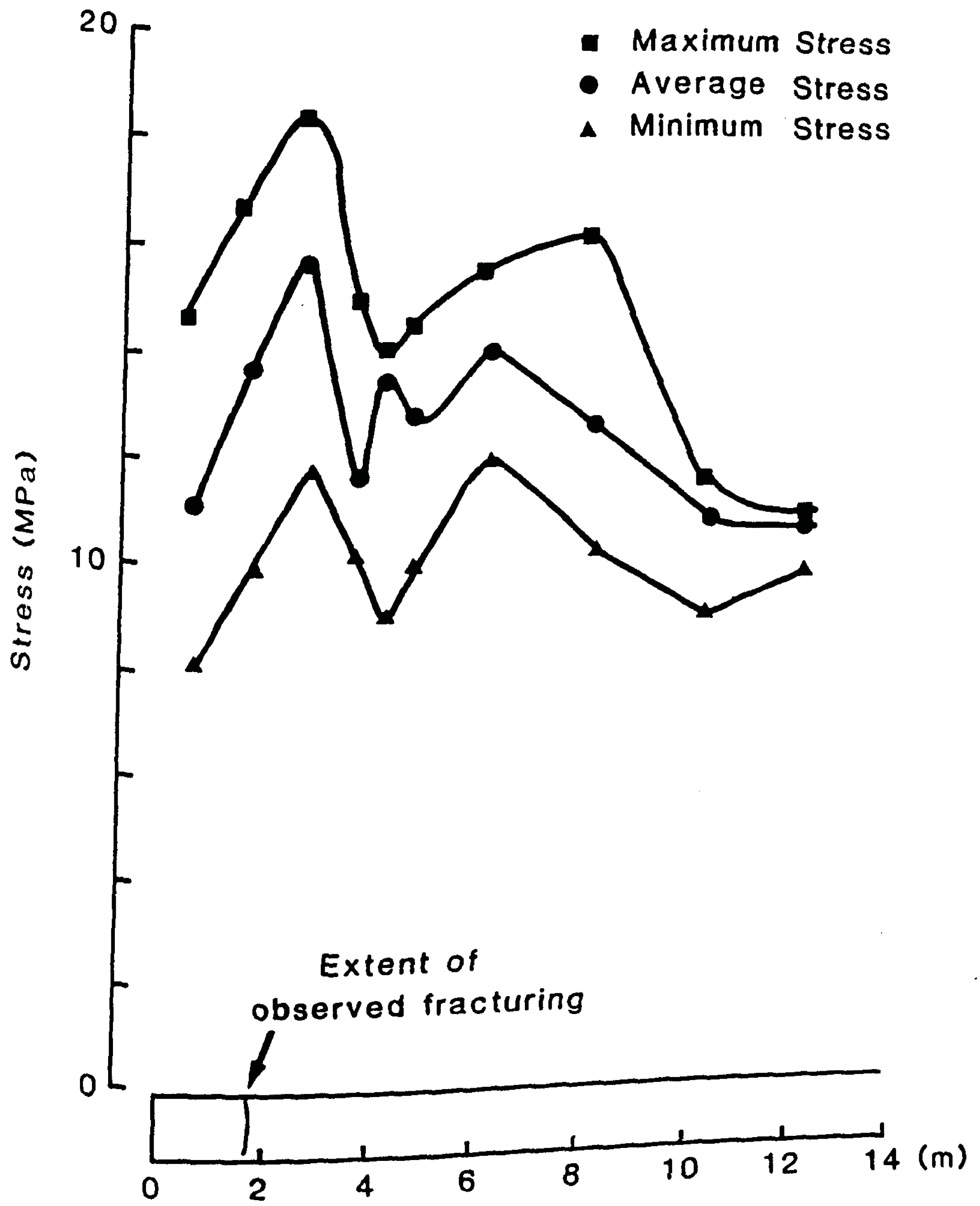



Figure 7.20 Maximum, average and minimum stress results across pillars at Piet Retief Colliery from the CSIR doorstopper strain cells.

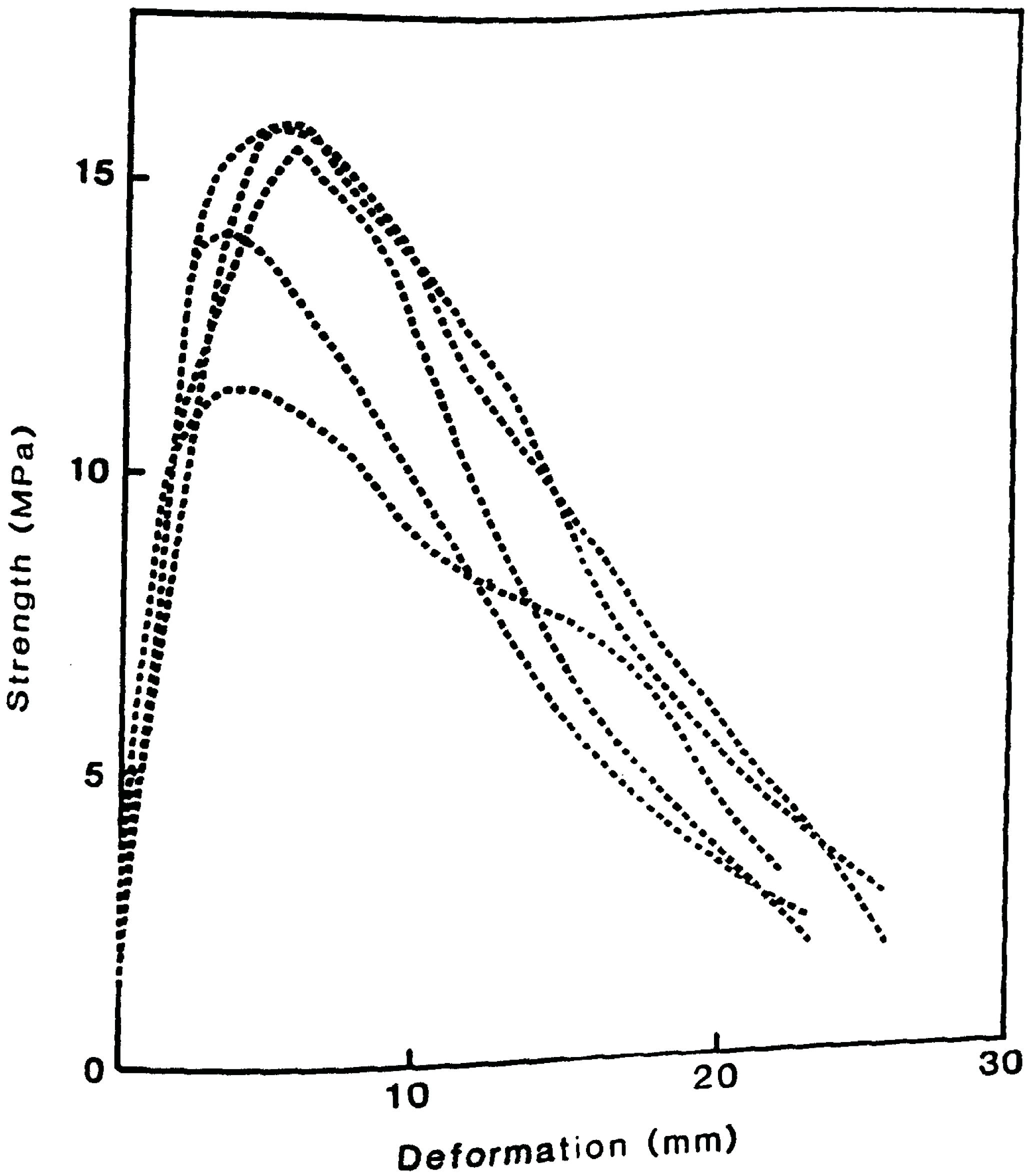



Figure 7.21 Strength-deformation curves of five *in situ* compression tests, after Wagner (1974).