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DESTRESS BLASTING AT CAMPBELL RED LAKE MINE

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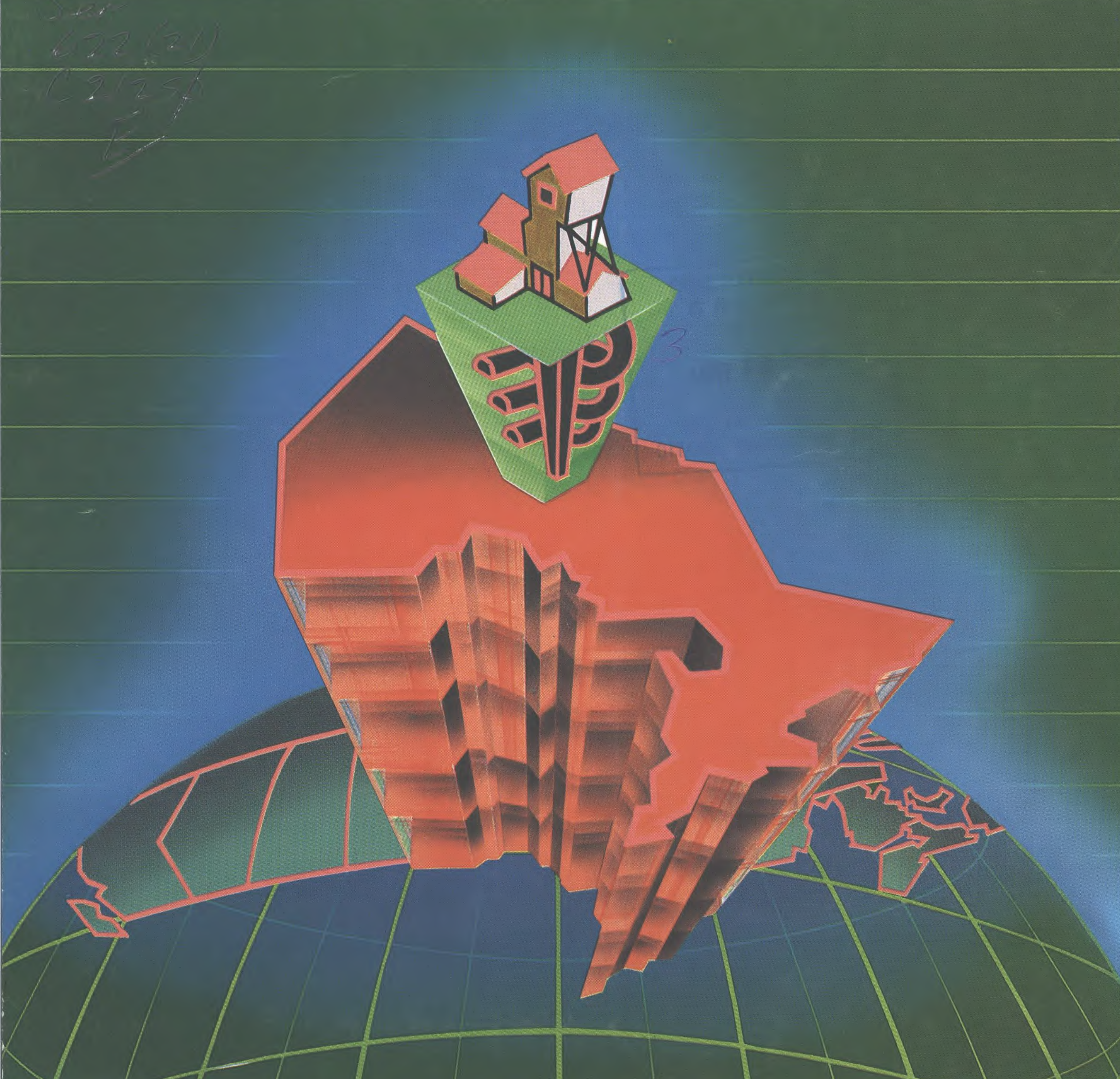

DESTRESS BLASTING
AT CAMPBELL RED LAKE MINE

A. MAKUCH, M. NEUMANN, D.G.F. HEDLEY AND W. BLAKE

ELLIOT LAKE LABORATORY

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DESTRESS BLASTING AT CAMPBELL RED LAKE MINE

PART 1: ROCK MECHANICS CONCEPTS OF DESTRESSING PILLARS

PART 2: PRACTICAL APPLICATIONS OF PILLAR DESTRESSING AT CAMPBELL MINE

PART 3: AN INSTRUMENTED DESTRESS BLAST OF THE 1604E CROWN PILLAR

by

T. Makuch*, M. Neumann**, D.G.F. Hedley+ and W. Blake++

ABSTRACT

Destress blasting is commonly used in rockburst-prone pillars in thin steeply-dipping orebodies. The purpose is to fracture the rock and reduce the stresses acting on the pillar. Since 1982, four destress blasts have been done in pillars at Campbell Red Lake Mine, with varying degrees of success. In general a common-sense approach was used in the design of the destress blast.

This report is divided into three parts. The first part explores the rock mechanics concepts of destressing. It attempts to identify the parameters which make for a successful destress blast. The main conclusion is that the major purpose of destressing is to reduce the potential energy of the rock mass. This is achieved by fracturing the pillar and allowing the hanging wall and footwall to converge.

The second part of the report describes the first three destress blasts in cut-and-fill crown pillars and shrinkage boxhole pillars. The reasons for destressing, the design, instrumentation used and post-blast observations are documented.

The fourth destress blast was extensively monitored and is described in the third part of the report. Computer modelling was also undertaken to compare with the in situ measurement of stress and convergence.

Key words: Rockbursts; Destressing; Monitoring.

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INTRODUCTION

Destress blasting has been used for a number of years to overcome problems of highly-stressed ground and rockbursts. It is generally considered that the blast fractures the rock, reducing its deformation modulus, and transfers stress to the adjacent rock structures.

Destress blasting was first systematically used in South African gold mines in the 1950's to create a fractured zone in front of a longwall face. It was reported (Roux, et al. 1957) to be successful in reducing the number and severity of rockburst incidents. Also, there was a reduction in the number of casualties and lost days' production, hanging wall conditions improved, and there was a significant decrease in the number of bursts occurring on shift. However, the practice was discontinued apparently due to difficulties in drilling relatively long holes and loading explosives in highly stressed ground. Later it was reported that the energy liberated in a destress blast was no greater than the energy in the explosive itself (Cook et al. 1966). Seismic recordings of rockbursts had indicated that two-thirds of the liberated energy was in the vertical shear wave component. Similar recordings of destress and conventional blasts indicated that most of the energy was in the radial compression wave and a negligible amount in the vertical shear wave.

In North American mines destressing is more widely practised and apparently more successful. Destressing of sill pillars is done on a regular basis in the mines in the Coeur d'Alene district of northern Idaho. Instrumented field trials have been reported by Blake (1972) and Board (1983). Normally, destressing takes place when the sill pillars have been reduced to 10-12 m thickness and are highly stressed. Another concept is rock preconditioning where drilling and blasting is done before stoping takes place, and hence the rock is under its lowest stress condition. It has been reported that preconditioning significantly reduced seismic activity during mining (Blake, 1982).

In Canadian mines destressing is normally practised in sill pillars in thin, steeply-dipping orebodies, such as those at Campbell Red Lake Mine, Dickenson Mine, Falconbridge Mine (Moruzi and Pasieka, 1964), and Kirkland Lake mines (Cook, 1983). Other applications of destressing techniques are in development openings including shafts and access openings (Garrood, 1982). Although destressing is practiced extensively in Canadian hardrock mines there is not much published material on the subject.

ROCK MECHANICS CONCEPTS OF DESTRESSING

Although destress blasting is successfully practiced in North American mines, there is very little theoretical background on what actually happens to the stress, displacement and energy during the blast. There is a general consensus that destressing softens the rock and reduces its effective elastic modulus. There are conflicting views on the importance of reducing stress and the stored strain energy within the destressed rock.

Conditions of stress and strain, before and after destressing, were investigated by Crouch (1974). He postulated subcritical, critical and supercritical degrees of destressing as illustrated in Figure 1. After destressing the final equilibrium stress-strain position is dependent on the intersection of the destress modulus line with the slope of the local mine stiffness. If this intersection lies within the stress-strain envelope (i.e., subcritical) the destress blast will be ineffective. However, if the intersection lies outside the envelope (i.e., supercritical) excess energy will be released and eventually equilibrium is achieved along the residual strength curve. Both

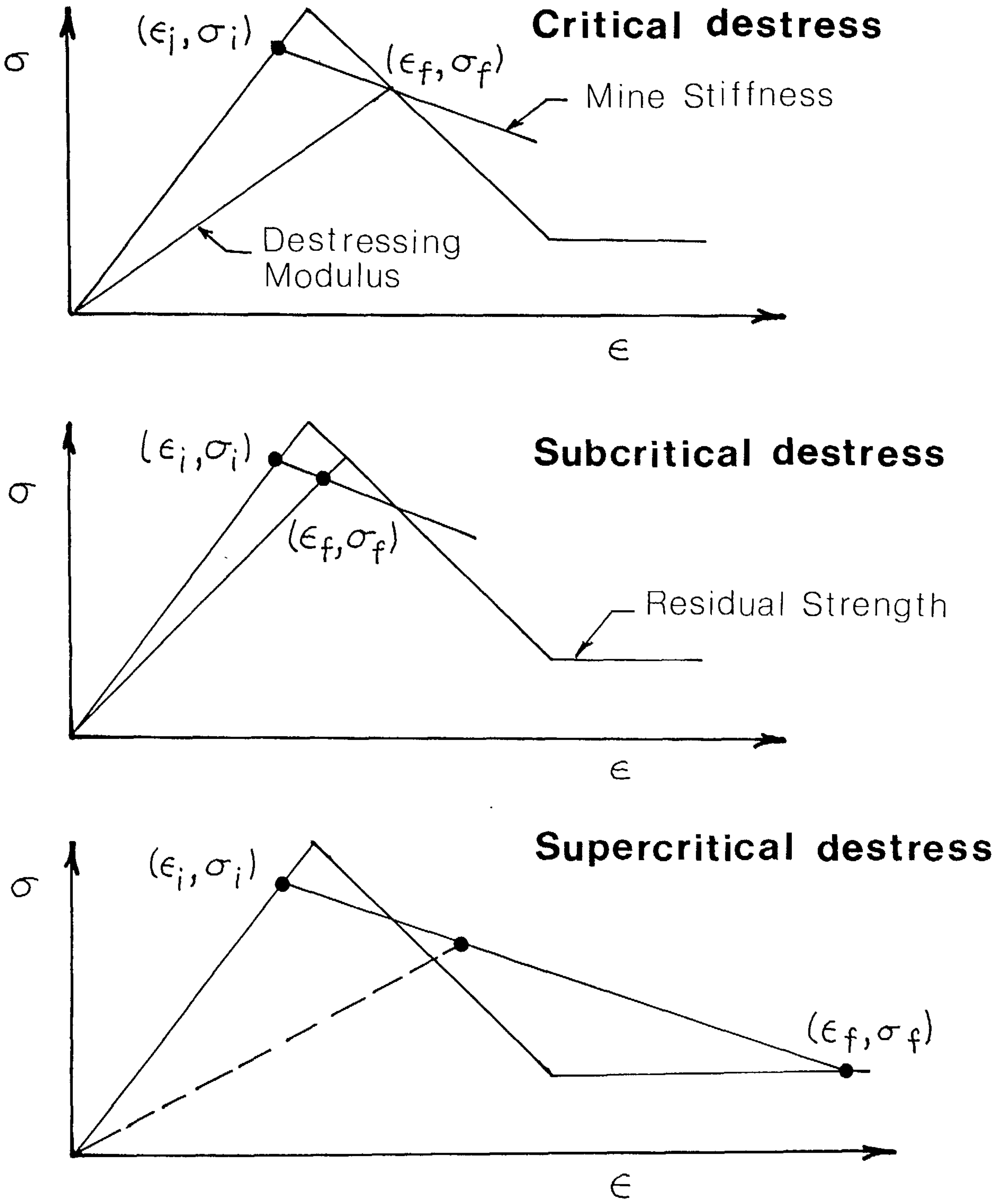

Fig. 1 - Different degrees of destressing (after Crouch, 1974).

Crouch (1974), and Blake (1972) state that destressing is most effective when the pillar is near its point of failure. Crouch (1974) also pointed out that the excess energy released in a destress blast, or a rockburst is derived from the change in potential energy of the rock mass, not the stored strain energy in the pillar.

These studies have looked at the before and after effects of destressing, and not what happens during the blast itself. When an explosive is detonated in a borehole a pressure, or shock wave, radiates outwards producing radial fractures around the hole. Expanding gases open and extend these fractures and physically displace (i.e., throw) the rock fragments. In a destress blast the explosive is confined and a free face is normally some distance away. Under these conditions the shock wave is the major source of rock fragmentation and most of the gases are probably vented through the borehole collar. Generally, the seismic energy in the shock wave is 5-10% of the total chemical energy in the explosive (Duvall and Stephenson, 1966).

In an elastic medium the increase in radial stress, $\Delta\sigma r$, can be expressed by:

$$\Delta\sigma r = P\left(\frac{r}{R}\right)^2 \qquad \text{Eq 1}$$

where, P = borehole pressure

r = borehole radius

R = distance from the borehole.

For commercial explosives the borehole pressure is in the range of 200 to 8000 MPa (Coates, 1981). Equation 1 indicates that the change in radial stress decreases rapidly away from the borehole. When R = 10r the change in stress is only 1% of the borehole pressure. For typical hardrocks the power coefficient is more likely to be 2.5 than 2, indicating greater attenuation of the shock wave.

The change in radial stress can also be expressed by:

$$\Delta\sigma r = \gamma\ Cp\ v \qquad \text{Eq 2}$$

where, γ = rock density

Cp = pressure wave velocity

v = particle velocity.

The velocity of crack propagation is only about 15 to 40% that of the pressure wave velocity (Coates, 1981). Hence, initially the pillar only experiences an increase in stress without a reduction in elastic modulus due to fracturing, which occurs later.

The imposition of a dynamic load due to explosives on top of a static load can now be looked at in terms of stress-displacement on a pillar as shown in Figure 2. Figure 2a) shows the pressure wave radiating from the destress boreholes. By the time these waves hit the hanging wall/footwall they have probably coalesced into a straight front. Figure 2b) shows the mechanical equivalent of a destress blast with a thin flat jack at mid-pillar height which can be instantaneously pressurized. This is not an exact duplication since the explosive pressure wave is transient. Figure 2c) shows the stress-displacement history of the hanging wall or footwall. The sequence of events during a destress blast are probably as follows:

a) Just before the blast the pillar is under static stress-displacement conditions at point A with an elastic modulus E_1.

b) After detonation the pressure wave radiates outwards and increases the stress on the hanging wall and footwall, similar to that obtained by pressurizing the flat jack. This internal pressure will force the hanging wall/footwall apart along the line AB which is the slope of the local mine stiffness curve.

c) Fracturing occurs after the pressure wave, similar to rupturing of the flat jack. There will probably be a sudden stress drop to point C after the pressure wave passes through, of magnitude probably equal to the

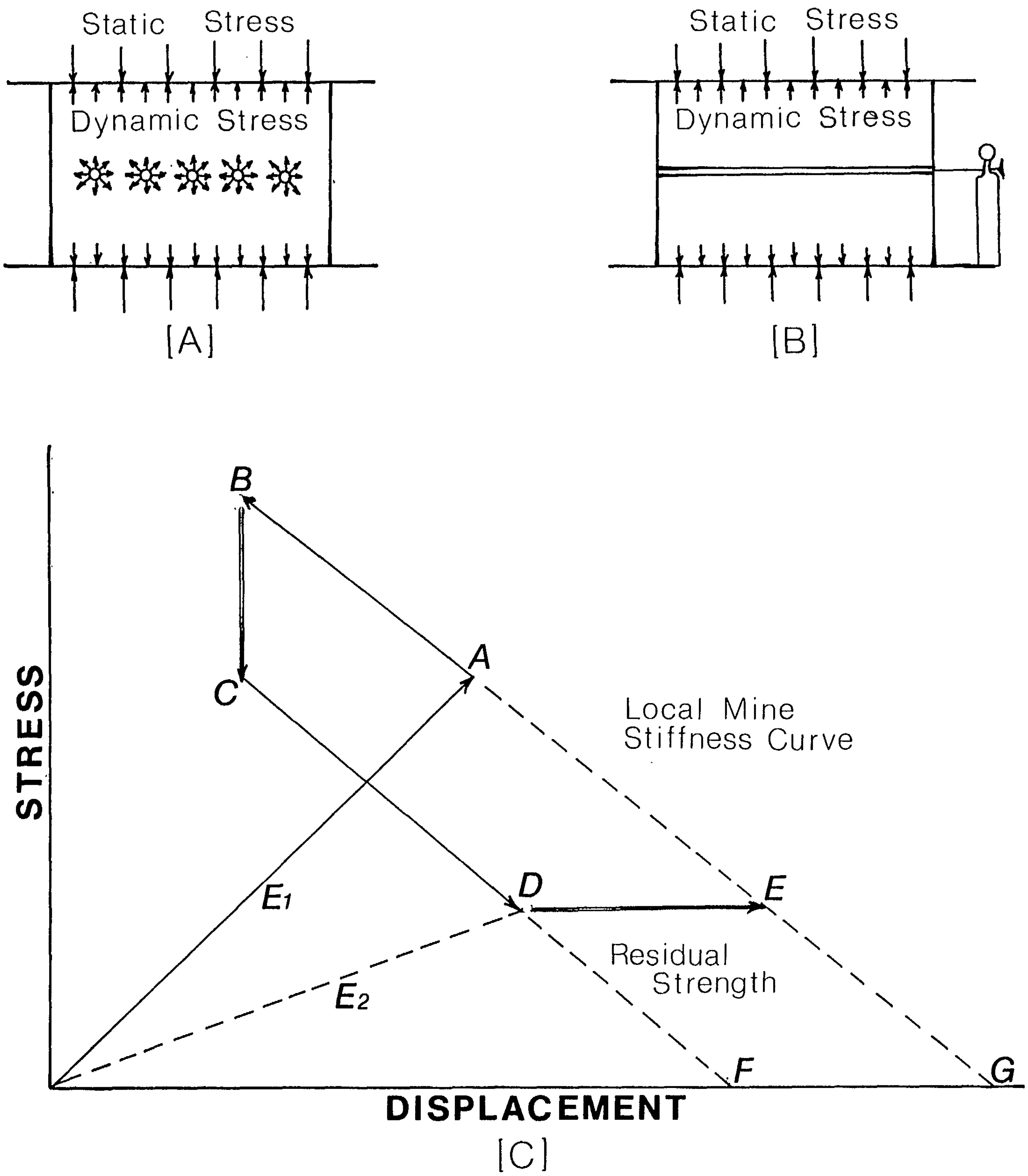

Fig. 2 - Stress-displacement history of a pillar during a destress blast.

increase in stress due to the explosive. This will be followed by a further stress reduction as the hanging wall/footwall converge. The pillar will have a reduced elastic modulus E_2 due to fracturing which is reached at point D.

d) Equilibrium has not yet been reached and displacement will continue along the residual strength curve until it intersects the local mine stiffness curve at point E.

e) If it were a production rather than a destress blast, then unloading would continue along line DF until zero stress is achieved. However, again, equilibrium is not reached until the hanging wall/footwall converge to point G which is the intersection with the local mine stiffness curve.

ENERGY EVALUATION

The energy components involved in the destress blast can now be examined. From Salamon (1974) the energy balance due to mining can be expressed by:

$$Wt + Um = Uc + Wr \qquad \text{Eq 3}$$

where, Wt = change in potential energy

Um = stored strain energy in mined material

Uc = increased strain energy in surrounding rock

Wr = released energy.

In the absence of any support, such as backfill, the released energy consists of the stored strain energy in the mined material, Um, and seismic energy Wk, which vibrates the rock mass. In a destress blast there will be additional energy components and Equation 3 becomes:

$$Wt + Um_1 + We = Uc + Um_2 + Wf + Wk \qquad \text{Eq 4}$$

where Um_1 = stored strain energy before destressing

Um_2 = stored strain energy after destressing

We = explosive energy

Wf = energy consumed in fracturing the rock.

These energy components are illustrated in Figure 3. The net change in potential energy is the area under the AE line as shown in Figure 3a). Explosive energy used to push back the hanging wall and footwall is the area under the AB line as in Figure 3b). There is an additional explosive energy, such as in heat and expanding gases, which is not accounted for and does not effect the energy balance. Stored strain energies before and after destressing are shown in Figure 3c) and represent the stress and elastic modulus at points A and E, respectively. The energy consumed in fracturing the rock is the area under the stress-displacement envelope minus the stored strain energy remaining in the fractured pillar as shown in Figure 3d). The seismic energy released is the area outside the stress-displacement envelope as shown in Figure 3e). It includes two components: that due to the explosive which pushed back the hanging wall/footwall, and that due to the change in potential energy of the rock mass.

DISCUSSION

Although this is a simplistic view of what happens during a destress blast a number of fundamental deductions can be made from the stress-displacement history in Figure 2 and the energy components in Figure 3.

a) The major function of destressing is to reduce the potential energy of the surrounding rock mass, which is the same conclusion reached by Crouch (1974). This is achieved by reducing the modulus and stress on the pillar. In Figures 2c) and 3a) the reduction in potential energy is from point A to point E. A further reduction in potential energy will occur when mining the destressed pillar until point G is reached. The closer point E is to point G the more effective is the destress blast, although

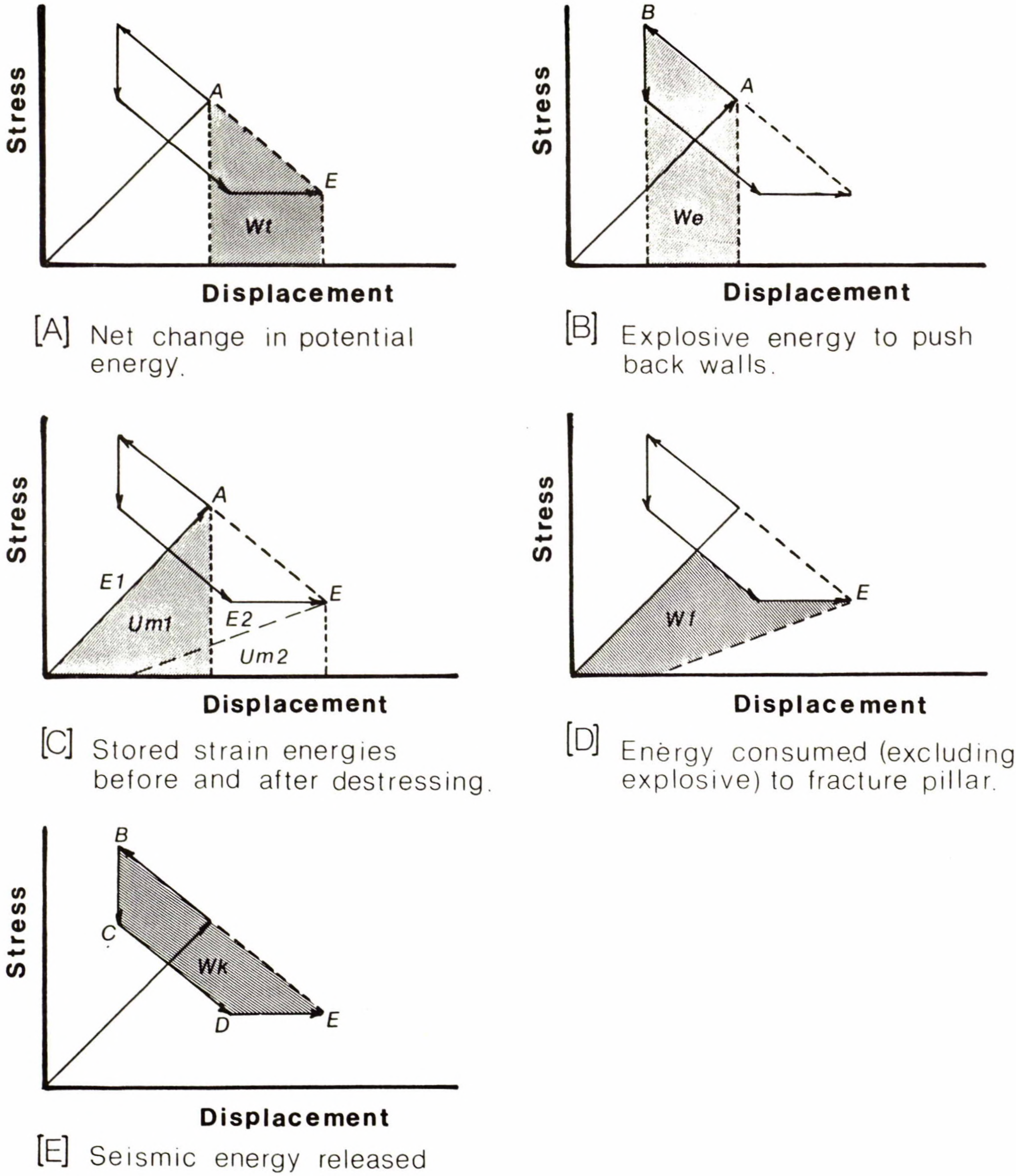

Fig. 3 - Energy components during a destress blast.

this must be balanced against the practical difficulties of mining extremely fractured ground.

b) Irrespective of whether the pillar is destressed then mined, or is removed by production blasts, or has failed due to a rockburst, the endpoint is always the same, namely point G in Figure 2c).

c) The stored strain energy in the pillar is used in the fracturing process and is not released as seismic energy.

d) The explosive as well as initiating the fracture process is used in pushing back the hanging wall/footwall.

e) The seismic energy released is partly due to the explosive and partly due to the change in potential energy. It is released during the latter part of the cycle.

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PART 2: PRACTICAL APPLICATIONS OF PILLAR DESTRESSING AT CAMPBELL MINE

INTRODUCTION

Campbell Red Lake Mine is a primary gold producer located in Balmertown, Red Lake District of northwestern Ontario. The mine was brought into production in 1949 at a rate of 350 tonnes per day and presently mining is down to the 900 metre horizon at a rate of slightly over 1100 tonnes per day. One central four-compartment shaft reaches a depth of 1315 m, with 27 levels at 45 m intervals. Most production is from overhand cut-and-fill stopes, using classified tailings and alluvial sand for fill. Cement is added for working floors and sill plugs. Most ore is encountered in steeply dipping replacement and fracture filled veins hosted by a strong brittle andesite. The replacement veins occur in flexures of the andesite-altered rock units and tend to be 2 to 12 m wide with narrow offshoot veins. Fracture filled veins are narrow quartz carbonate hosted totally by andesite in all zones except one.

Destress blasting has been used for a number of years to overcome problems of highly stressed ground and rockbursts. It is generally considered that the blast fractures the rock, reducing its deformation modulus and transfers the stress to adjacent rock structures.

Generally, at Campbell Mine, problems occur in the steeply dipping, hard and brittle structures when extraction has reduced the size of the supporting pillars to 20%. Three attempts have been made to destress cut-and-fill crown and sill pillars and one attempt in shrinkage boxhole pillars. This paper outlines each of the three destress blasts including the mining background, preparation, instrumentation, hole layouts, powder factors, and the post-blast activity. No attempt has been made to explain the theoretical aspects of destressing but rather to present why destressing was tried, the observations and results. A fourth destress blast which was extensively monitored is described in Part 3 of this report.

ROCKBURST HISTORY

Rockbursts or violent pillar failures were first recorded at Campbell Mine in the early 1960's, occurring in crown and boxhole pillars associated with shrinkage mining. Since 1983, at least 10 rockbursts of magnitude greater than 2.0, and one of 3.1, have been recorded.

Both pillar and strain energy types of bursts have been recognized at Campbell. Pillar bursts occur as violent failure of highly stressed underground rock pillars, while strain energy bursts are a result of high local stress concentrations adjacent to underground openings. Strain energy bursts are more frequent, occurring as rock bumps near production faces, and usually have only minor impact on mining activities. Pillar bursts, although less frequent, are usually more severe in magnitude and can have a greater impact on safety to underground personnel. Crown pillars at Campbell Mine become critically stressed and burst-prone when the pillar thickness approaches 6 m, or at about 80% extraction.

To alleviate the rockburst problem and allow safe and efficient recovery of crown pillars, destressing techniques have been adopted at the mine.

1102 E. 'B' CROWN PILLAR - DESTRESSED APRIL 1982

BACKGROUND

The 'A' ore zone at Campbell Red Lake Mine is a narrow fracture-filled vein extending from surface to a known depth of 900 m on the 20th level as is shown in Figure 4. This zone, being the 'Discovery' zone, was mined rapidly

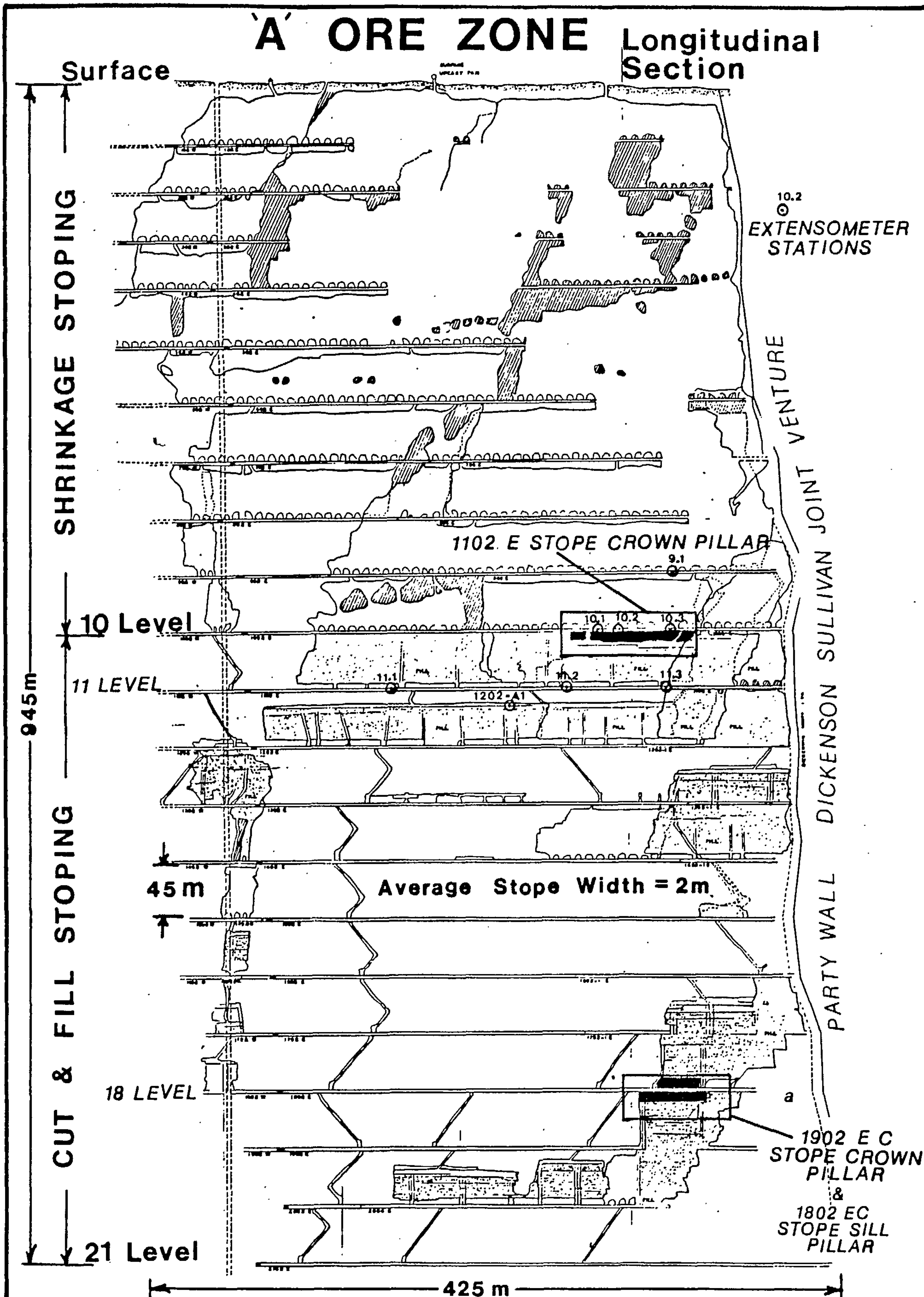

Fig. 4 - Longitudinal section of 'A' ore zone.

from surface to the 10th level using a boxhole shrinkage mining method. Mining was changed to cut-and-fill on the 11th and 12th levels while shrinkage mining and sill removal continued above. As the 1102 E. cut-and-fill stopes approached the 10th level, there was considerable activity and bursting of the boxhole pillars on the 10th level. Through slow mining of small sections, the stope was brought up to the 10th level for a length of 200 m. On the backfill, steel arches were placed for safe access to the eastern ore. Several attempts were made to mine the remaining portion of 1102E. stope, but each time, high stress problems forced work to stop. It was at this time that the decision to destress the pillar was made.

PREPARATION

On the 10th level the drift was heavily bolted and screened using chain link mesh, and a combination of mechanical, resin and split set bolts. At the chute openings between the boxholes, heavy timber and steel sets were placed to prevent muck from flowing through into the drift. Access to the stope was through two raises, one on each of the East and West ends of the block, and a manway from the stope to the 11th level. Using a stoper, extension steel and 45 mm wing bits, holes were drilled at a 1.8 m spacing from the stope to within 1.5 m of rail elevation as shown in Figure 5. The small isolated west section was drilled to break at the same time as the destress blast. All holes were loaded with ANFO and primed with '0' delay except the portion designed to break.

INSTRUMENTATION

Extensometer pins were cemented to the walls on the 9th, 10th and 11th levels to measure the wall closure. The layout on the 10th level is shown in Figure 5.

RESULTS

The blast was fired on a Friday, May 1st, and although it was felt on surface, no rockbursts were felt after the blast. On Monday morning, May 3, the area was inspected and the extensometer stations on the 10th level were measured. The stope could be accessed by both raises although the track had heaved and the fine ballast displaced. Considerable loose had been contained on the walls by the screen, and obvious wall closure was visually noted and measured in all sections except at extensometer station 10-2 below No. 38 boxhole pillar. In the stope, the back was loose and shattered around the destress holes, but otherwise in good condition. During the inspection period of over one hour there was not even one audible snap heard by anyone. It appeared that the destress attempt had been successful and mining could resume.

At 19:40 h that evening a rockburst was felt on surface. The procedure at that time, prior to having a microseismic system, was to try to physically locate the rockburst underground. On inspecting 1002 E. Dr. a burst was found to have occurred in No. 38 boxhole pillar where little closure had been measured previously, as illustrated in Figure 5. Large closure was now measured at station 10-2, and very little change was measured at the other stations.

OBSERVATIONS

Although the boxhole pillars on the 10th level were not visible because of timber, it has been documented that the boxhole pillars on 10th level had all burst. It may be that the rockburst occurred in the crown pillar with the effects being seen in the boxhole pillar.

It was clearly demonstrated that closure must be present for destressing to be successful.

Holes were drilled to within 1.5 m of rail elevation. The fact that solid rock may have been 0.3 to 1 m lower was overlooked and, as a result, excessive damage was done to the drift floor and track.

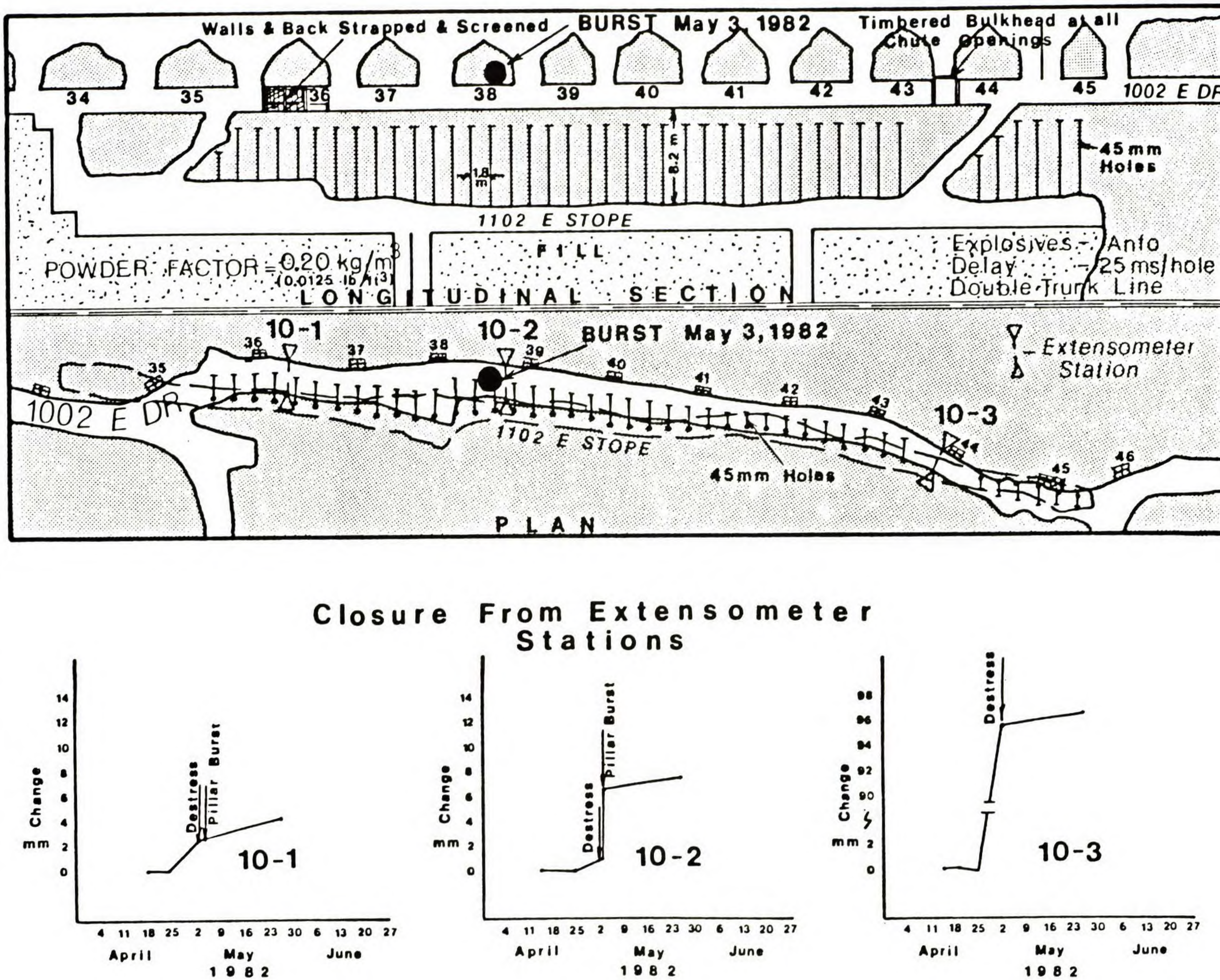

Fig. 5 - 1102E 'B' crown pillar destress: layout and closure results.

The stress relieved during destressing must be transferred to an abutment pillar strong enough to carry the added load. In this case the boxhole pillar was not able to carry the load shifted onto it, or unable to sustain the shock wave from the rockburst. Microseismic noise does not necessarily precede a rockburst. Many accounts of a quiet period or 'lock up' prior to a burst have been reported.

1421 W. BOXHOLE PILLARS - SEPTEMBER 10, 1982

BACKGROUND

The 1421 W. boxhole pillars are located in the 'F' zone, which is a narrow fracture filled type zone hosted by andesite. Mining in the 'F' zone was all boxhole shrinkage with chutes on 8 m centres and a sill of 4-6 m left in place, as illustrated in Figures 6 and 7.

No problems were encountered in this zone until mining commenced below the 12th level. The walls and boxhole pillars began to spall and cracks developed in the pillars adjacent to the chutes. Sill pillar thickness was increased to 8-9 m in stopes being mined in 1981 after a boxhole pillar burst on the 11th level. In early 1982, the 14th level mining was nearing completion on the eastern end, but only started on the west. The 15th level stopes were 50% mined in the east and started on the west. At this time it was noticed that six boxhole pillars in 1421 W. were deteriorating much more rapidly than those on either side of this section. These pillars are in a block fault area and it was believed that this resulted in a higher stress concentration to these particular pillars. Because this was the main access to the western 'F' zone stopes, it was decided to destress these pillars.

PREPARATION

A renovation crew was sent in to rockbolt using mechanical bolts. Resin bolts and screen were avoided because major renovations would be

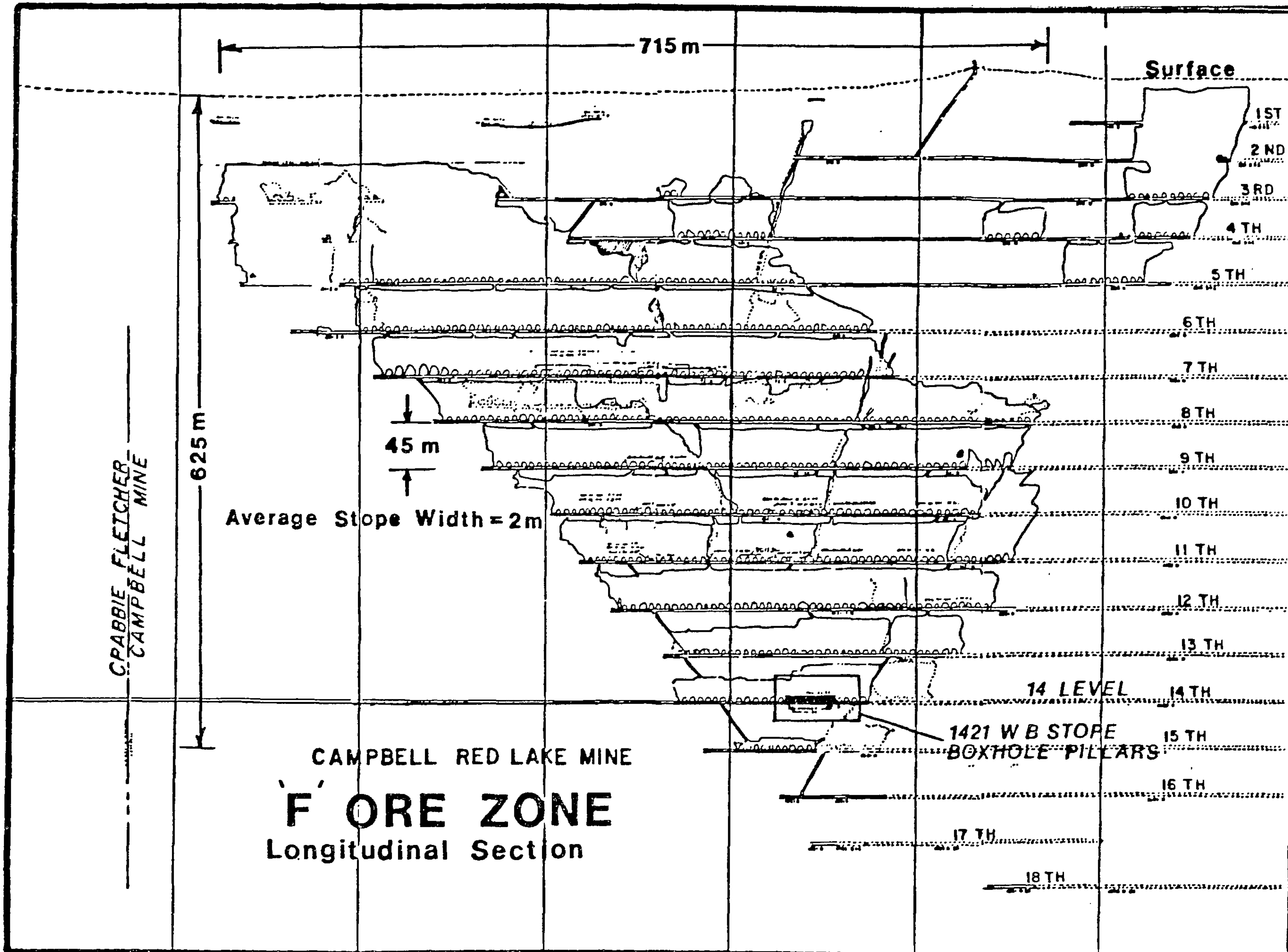

Fig. 6 - Longitudinal section of 'F' ore zone.

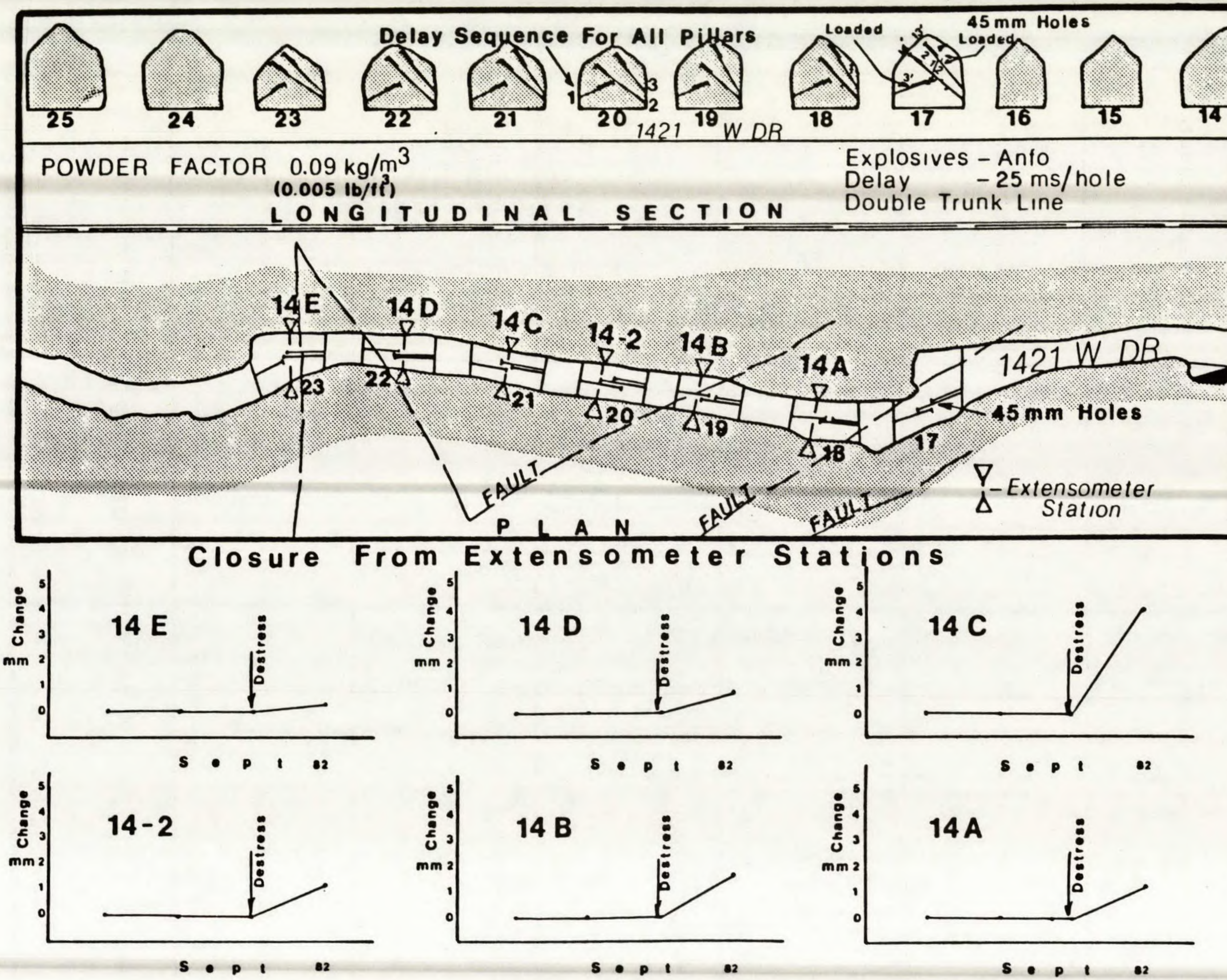

Fig. 7 - 1421W boxhole pillar destress: layout and closure results.

required after the blast. A destress pattern, as shown in Figure 7, was laid out so that the 'core' and the upper portion of the boxhole pillar would be hit the hardest, and hopefully the drift back portion would not be blasted down. The holes were loaded with Anfo and fired with Nonels and double 'B' line.

INSTRUMENTATION

Six tape extensometer stations were installed in the walls 1.2 m above rail elevation.

RESULTS

Following the blast there was no seismic activity felt on surface. The area was inspected a week later and, with the exception of the smaller pillar where the stope manway was located, there was little damage. Boxhole pillars on either side of the destress section showed very little added pressure and it was felt that the large pillar below had taken the load.

Several days after the inspection, there were a number of rockbursts on the 10th and 11th levels of 'F' zone. It was decided to stop all mining in the zone at this time and no access was allowed back into the destress area. In December 1983, severe bursting occurred in the upper levels of the 'F' zone, and several boxhole pillars on 14th level burst, including one which had been destressed. (Bursts located by the microseismic system.)

OBSERVATIONS

Subsequent computer modelling of the 'F' zone geometry indicated high stress levels were present in these boxholes prior to the destressing. Also, the boxhole pillar stress is more dependent on extraction above, than the size of pillar below the level. This was demonstrated in another similar zone where solid ground existed below the 15th level and a boxhole pillar burst on the same level.

The influence of the faults on boxhole pillar stress in this area was not studied further, although it is felt that higher than normal stress was present because of them. Closure was present at all stations indicating that some destressing was accomplished. However, the subsequent burst proves that at least one of these boxhole pillars had remained intact.

1902 E. CROWN - 1802 SILL PILLAR - JANUARY 20, 1984

BACKGROUND

This pillar destress was in the 'A' zone near the party wall with Dickenson Mines, as shown in Figure 4. Because of bursting experience in this zone on the upper levels Campbell Red Lake Mine adopted a stair step mining geometry suggested by Prof. Morrison in 1961. Mining was started at the lower eastern extremity of the ore and mined by cut-and-fill in small 40 m blocks. Four small sections against the party wall had been mined through the level with only minor difficulties. The length of these stopes made mining very slow, and therefore, the stope length was extended to 80 m. When 1902 E. 'C' stope was within 6 m of the level, the decision to destress was made. This was based on the reports of 'Working Ground', visual inspections and, for the first time, an increase in recorded microseismic activity.

PREPARATION

On the 18th level the drift was renovated using 1.8 m and 2.4 m resin rebar on walls and back, and welded mesh screen. Initially, all holes were to be drilled 54 mm in diameter from the 18th level using a longhole machine. The plan was changed and spacing adjusted so the same designed powder factor remained when 44 mm upholes were drilled from the 18th level and from inside 1902 E. stope, as shown in Figure 8. Since mining was to be done from the 18th level using a benching method, the stope was closed off and tight filled.

INSTRUMENTATION

a) A tight array of geophones was placed around the pillars to record

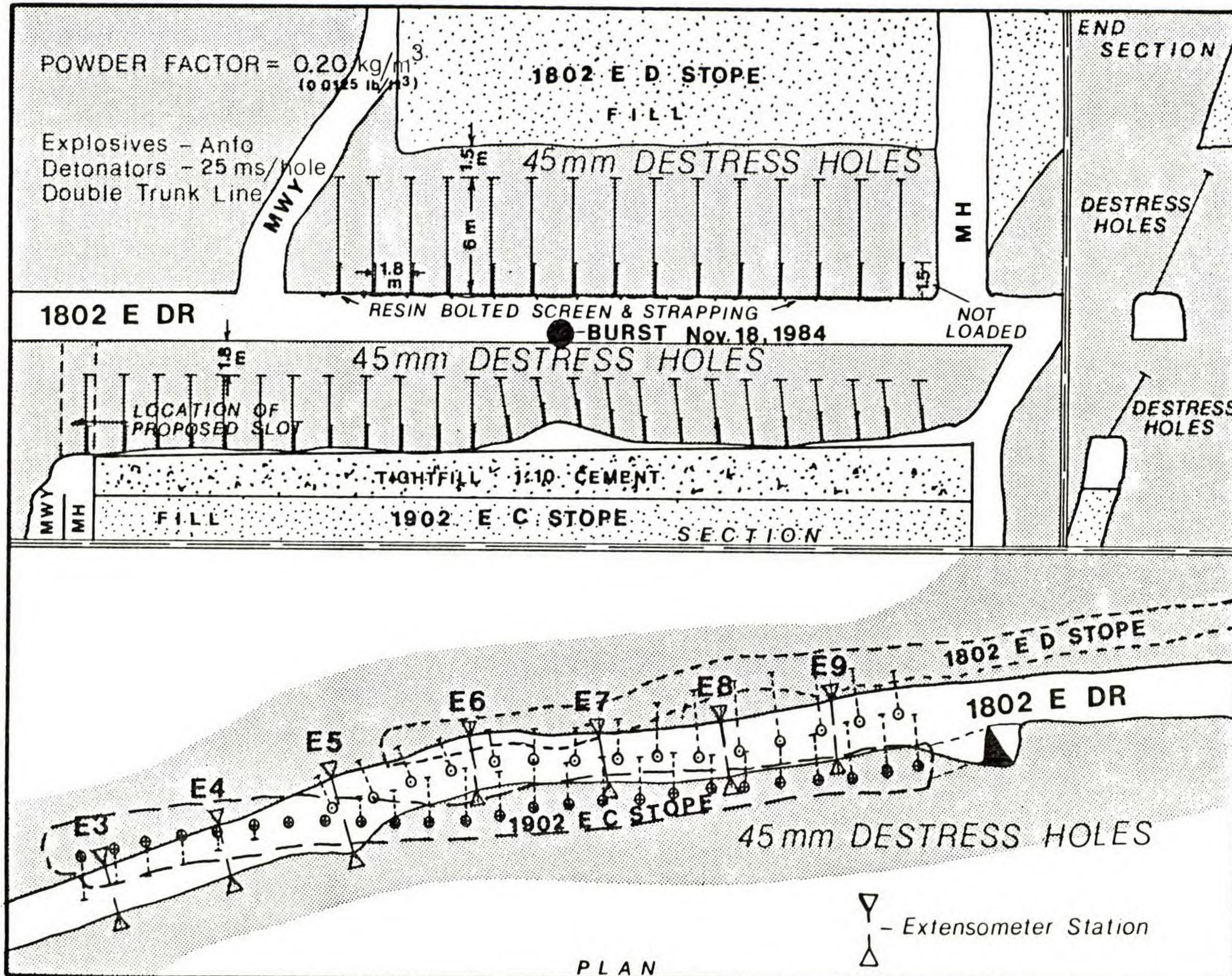

Fig. 8 - 1902E 'C' crown - 1802E 'C' sill pillars: destress layout.

activity prior to and after the blast.

b) A cassette tape recorder was used to record the blast from the closest geophone.

c) An Electro-Lab portable microseismic monitor was used for counting small local events.

d) Tape extensometer points were placed along the drift on the 18th level to measure closure.

e) An oscillographic recorder was used to record seismic waveform.

RESULTS

The destress blast was recorded on the microseismic system followed by many small events and audible noises for approximately 1/2 min. A rockburst then occurred in the upper pillar knocking out the closest geophone. Microseismic activity decreased over the next few hours as the pillars stabilized.

Inspection on the 18th level showed significant damage to the back and over 30 cm of muck covered the drift floor. Because of this, and no entry possible into the stope, the condition of the pillar below could not be determined. The walls were in fairly good condition and measurement of the extensometer pins was possible.

Renovation consisted of rebolting and screening with chain link screen. The original resin bolts did an excellent job in holding the cracked ground.

A slot was driven over the existing millhole on the west end and benching commenced. It was soon evident that the pillar below was very cracked and broken up making drilling difficult. After a production blast a small rockburst occurred in the pillar directly above the 18th level, damaging the screen. This was repaired and the remainder mined without further incidents. Although destressed, the upper pillar was not mined as only unconsolidated fill is in place above it.

OBSERVATIONS

Destressing would never be attempted now at Campbell Red Lake Mine without a central microseismic system. Because microseismic events can be located and the activity heard from a remote location, a better understanding of the rock behaviour is possible. The microseismic data also gives an indication of a safe time to inspect the area.

This was thought to be the most successful destress attempt undertaken. The fact that two small bursts occurred in the pillars after destress and production blasts indicated that a major rockburst was likely if some of the energy had not been released by destressing.

A portable Electro-Lab, single channel microseismic unit was used before and after the destress blast to count the small events in the proximity of the pillars. These events were not large enough to be picked up by the central system, but gave an indication of local activity. The system consists of a battery powered event counter with an adjustable timer, memory, and adjustable threshold setting. Procedure was for the miner to set the system to turn on automatically and record events for 2 hours during the quiet time between shifts. Upon returning he would note the number of counts and record them for the Rock Mechanics Engineer. This system not only gave the miners some added confidence, it made them feel more involved in the project.

CONCLUSIONS

Destressing pillars is a very slow and costly procedure with results that are not entirely predictable. To better assess the results, an effort is being made to instrument these destress blasts using all the technology available.

Destressing is not a new method in burst prone ground. Each mine seems to adopt a method using trial and error to achieve results which appear consistent. The general feeling at Campbell Red Lake Mine on destressing can be best summed up by quoting a literature survey report done in 1980 by Dimitrios C. Frantzos (5).

"It is impossible to weigh, but unfair to ignore, the psychological effect of long hole destressing. Especially when it is supported by a long period of apparent success. One must accept the term 'apparent success' because, although the decision to de-stress is not lightly taken, there can be no definite assurance that it was a correct decision. Once de-stressed there can be no evidence that the working place would have burst if it had not been de-stressed."

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PART 3: AN INSTRUMENTED DESTRESS BLAST OF THE 1604 E CROWN PILLAR

INTRODUCTION

The 1604 EW stope is part of the 'A-1' ore zone at Campbell. Mining in this zone is from the 13th to 18th levels (550 to 800 m horizons) as shown on the longitudinal section in Figure 9. Stoping is carried out at 45 m level intervals, and the stopes are fairly narrow, 1.8 m wide, following the ore vein system along a strike length of 150-180 m.

The stope was started in 1975 by taking down the backs on 16 level to a height of 3 m. Manway-millholes were placed at 35 m intervals, and cemented backfill was poured to form a sill plug. Overhand cut-and-fill stoping was used to mine the ore full length at 2.5 m lifts to within 10 m of 15 level. At the same time, similar stoping was being carried out in the 1504 EW stope to 14 level.

When the stope back approached to within 10 m of 15 level, it was felt that the centre section of the pillar should be destressed and mined first. Along the centre section of the stope, two offshoot veins in the footwall from the main vein had been mined with the stope. The main vein was referred to as the 'A' vein, while the footwall offshoot veins were referred to as the 'B' and 'C' veins. Past destressing at Campbell has been to drill destress holes in the plane of the ore. Because of the overlapping veins, the destress blastholes were drilled in the 'C' vein to shadow both the 'A' and 'B' veins. A portion of the main 'A' vein from the 'C' vein intersection of the stope raise had to be destressed in the traditional method, as shown in Figure 10.

A longhole machine was used to drill 4.5 cm holes at 1.4 m centres along with the angled holes drilled west from the end of the 'C' vein. A powder factor of 0.704 kg/m^3 was used for the destress, as opposed to 2.1

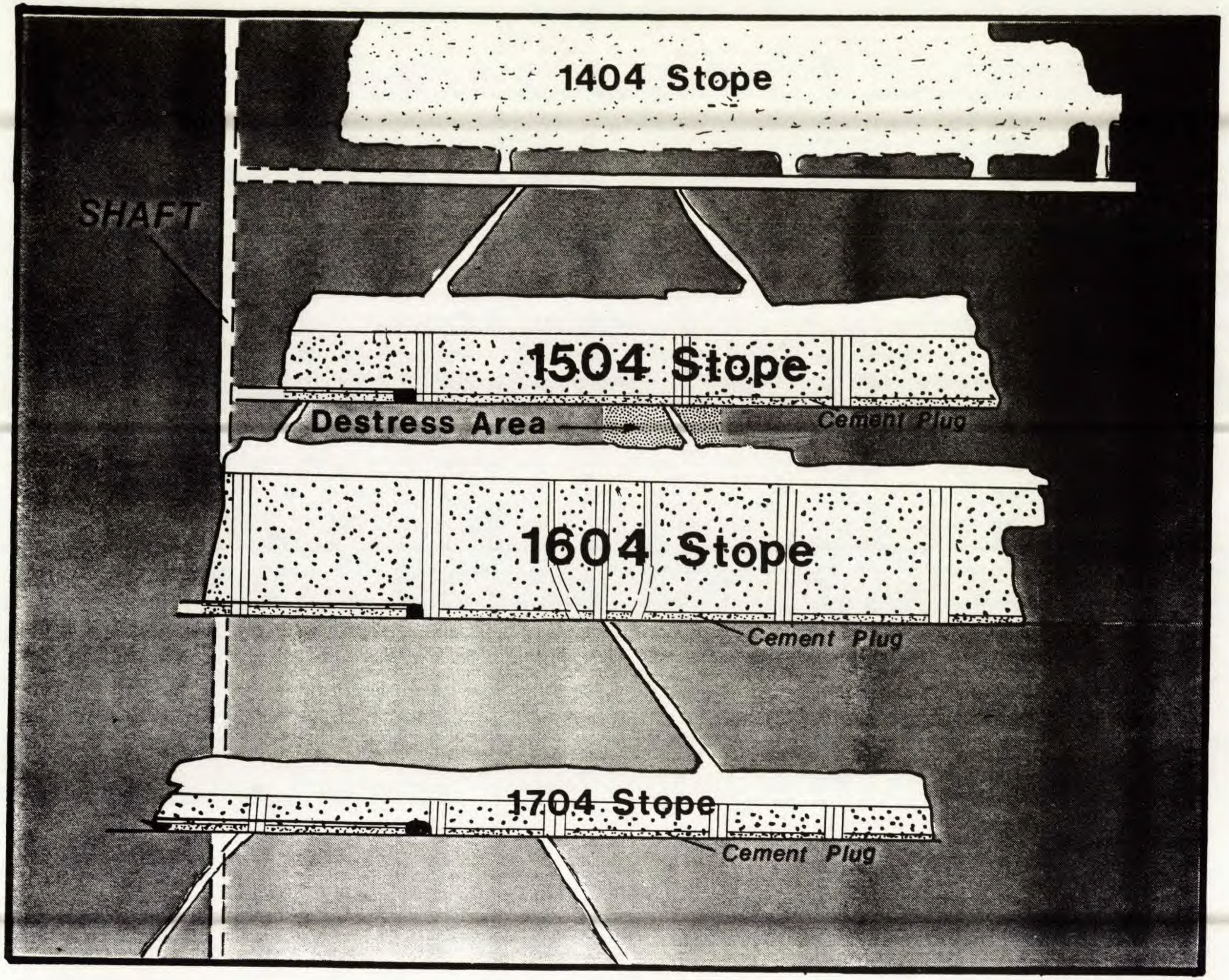

Fig. 9 - Longitudinal section of 'A-1' ore zone.

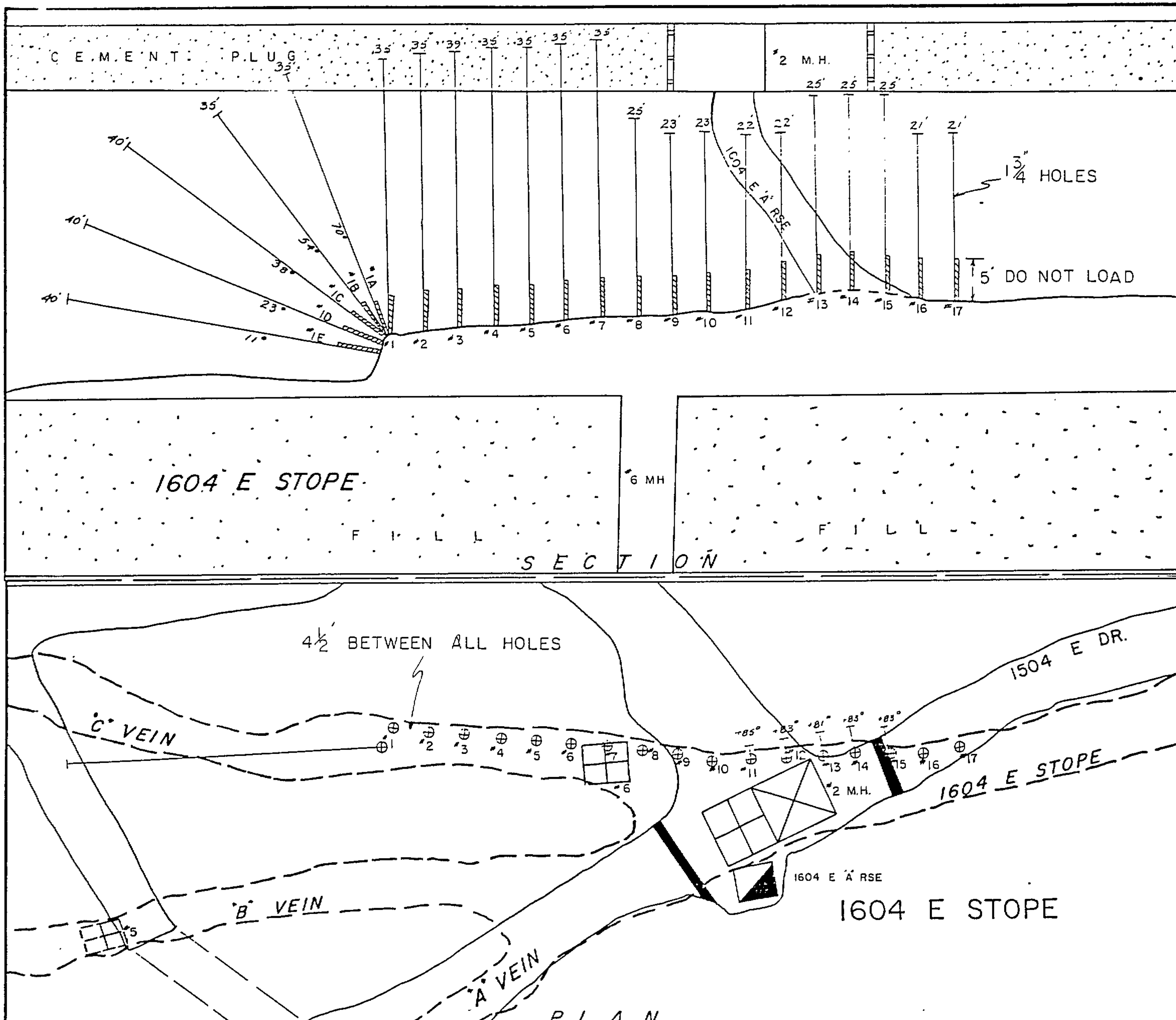

Fig. 10 - Layout of destress blast in 1604E stope.

kg/m^3 for normal production blasting. All of the destress holes were loaded with ANFO to 1.5 m of the collar, double primed with '0' delay NONELS and fired with double PRIMACORD.

POST DESTRESS PLANNED SEQUENCE OF EXTRACTION FOR 1604 E CROWN PILLAR

A sub-drift from 1504 drift was driven above the millhole in the 'B' vein and a slot driven up to intersect it prior to the destress. Another slot was driven in the 'A' vein above No. 3 manway-millhole and up to the cement plug on 15 level. Following the destress blast, a series of 9 m high x 2.5 m long breasts are to be taken on the 'B' vein until the vein intersects the 'A' vein. This 'B' vein should be in the 'shadow' of the destressed 'C' vein and continue up past the 15 level to where the vein was found and mined in the 1504 E stope (see Figure 10). Before the 'B' vein is mined past the level, a sub-drift will be driven to intersect the slot in the 'A' vein. When the 'B' vein mining is complete, mining in the 'A' vein, starting at the slot over No. 3 manway-millhole will proceed in similar fashion with 30 ft high breasts. When mining is complete past a millhole, that section will be tight filled. In this way a maximum of 120 ft of stope is left open at one time.

INSTRUMENTATION

To measure the effects of the destress blast on the in-situ rock properties and stress in the 1604 E crown pillar, instrumentation was installed throughout the destress area to measure:

- rock noise or microseismic activity associated with stress redistribution within the pillar area;
- rock stress change within the 'A' vein crown pillar;
- peak particle velocity of the destress blast and any accompanying seismic events;
- stope closure;

- load transfer to the backfill in the stope.

Campbell Red Lake Mine operate a 48-channel Electro-Lab MP-250 microseismic monitoring system. The MP-250 is a microprocessor-based system designed for detection and source location of underground rock noise activity. The principle of the system is to measure the difference of arrival times of a seismic signal to successive geophones in an underground array. Then, by knowing the location of each geophone along with the seismic velocity, an estimate of the source location for seismic events can be determined. The layout of the geophone array, projected onto the 15 level is shown in Figure 11.

For monitoring of the 1604 E crown pillar destress blast, 9 geophones were installed throughout the 'A-1' zone as a local geophone array. This helped to improve both the rock noise detection and source location capabilities in the destress area.

A Gould DASA 9000 8-channel waveform recording system was also used to monitor the destress blast. The signals from 8 of the underground geophones were input in parallel to both the Gould and MP-250 systems. In this way, the Gould was used to supplement the data from the MP-250 along with providing accurate 'P' and 'S' wave velocities, improve the source location accuracy and for checking the geophone installations.

For peak particle velocity measurements, three Instantel DS-377 blast vibration monitors were installed at selected distances from the destress blast, as shown in Figure 11.

Seven vibrating wire stressmeters were installed in EX diamond drill holes in the 'A' vein crown pillar. Along with the stressmeters, 12 tape extensometer stations were installed within the 'A' vein to measure hanging wall/footwall convergence. Finally, a pneumatic flat pressure cell was installed in the previous fill pour to measure any resulting load transfer to

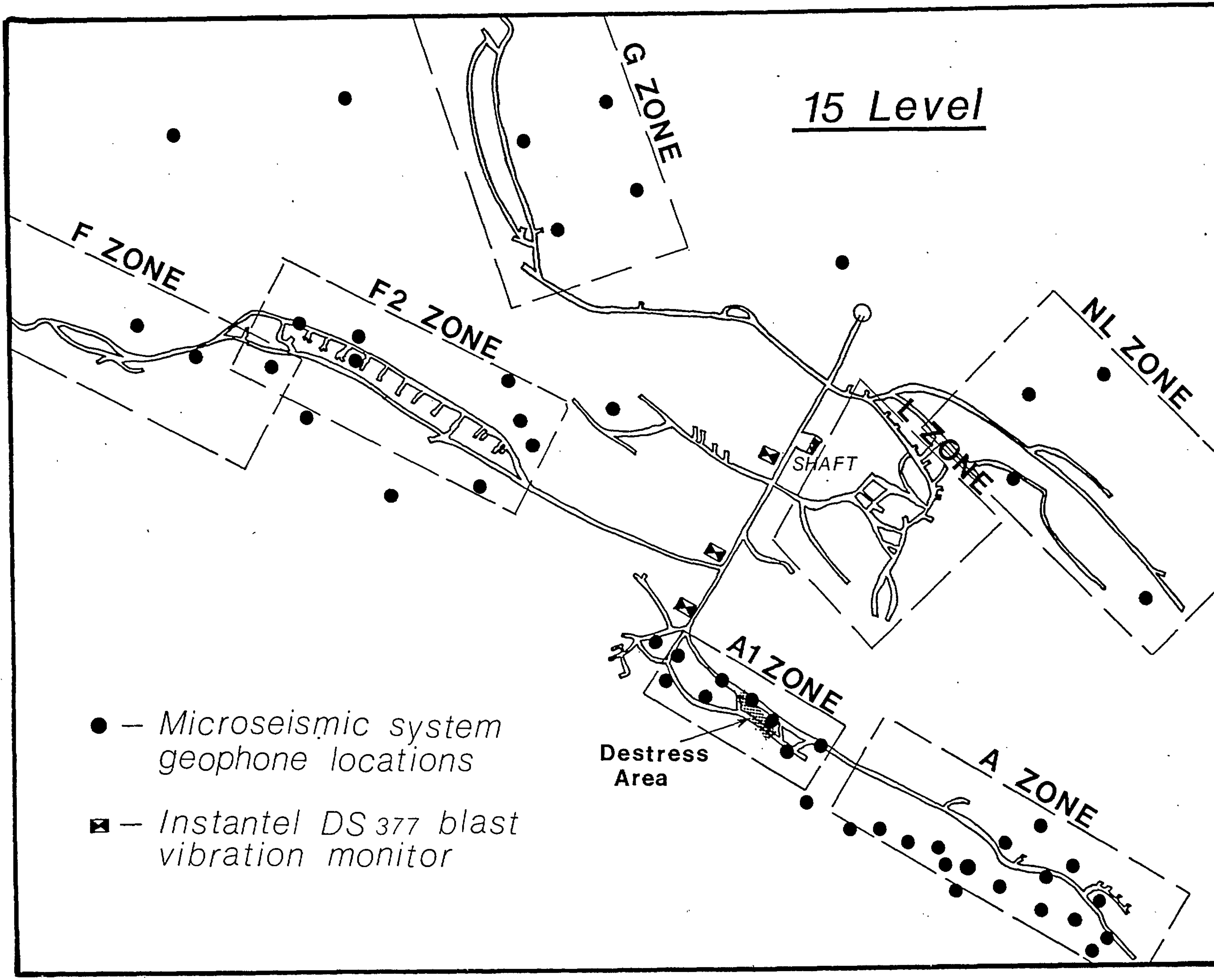

Fig. 11 - Layout of geophone array at Campbell Mine.

the backfill. The locations of the stressmeters, extensometers and fill pressure cell are shown in Figure 12.

COMPUTER MODELLING

To help predict the effects of the destress blast on pillar stress and stope closure, both the NFOLD displacement discontinuity and finite element models were used to simulate the destressing.

Boundary conditions for this model simulation of the 'A-1' zone mining geometry included:

Horizontal/Vertical stress	= 1.7
Elastic Modulus of rock	= 80.0 GPa
Poisson's Ratio of rock	= 0.21
Fill Modulus	= 7.0 MPa

Figure 13a shows the input mining pattern for the NFOLD model. Stope geometry in the model includes the 'A-1' zone from the 550 to 730 m horizons. Mining widths are 2 m, with three parallel layers dipping at 75^{o}. The 'A' vein layer is the main stoped area, the 'B' and 'C' vein layers are into the footwall 7.5 and 12 m, respectively, (see Figure 13b).

A total of three mining runs were conducted to simulate the destressing, including:

1. Present mining geometry - elastic conditions.
2. Destress simulation by reducing the rock modulus by 25% in the destress area.
3. Destress simulation by reducing the rock modulus by 50% in the destress area.

Figure 14 is a contour plot showing normal stresses in this mining area. Average crown pillar stress is approximately 90-100 MPa. In the centre portion of the 'A' vein, the footwall 'B' and 'C' vein mining shadows the crown pillar resulting in a 5-10% reduction in pillar stress. From this, we

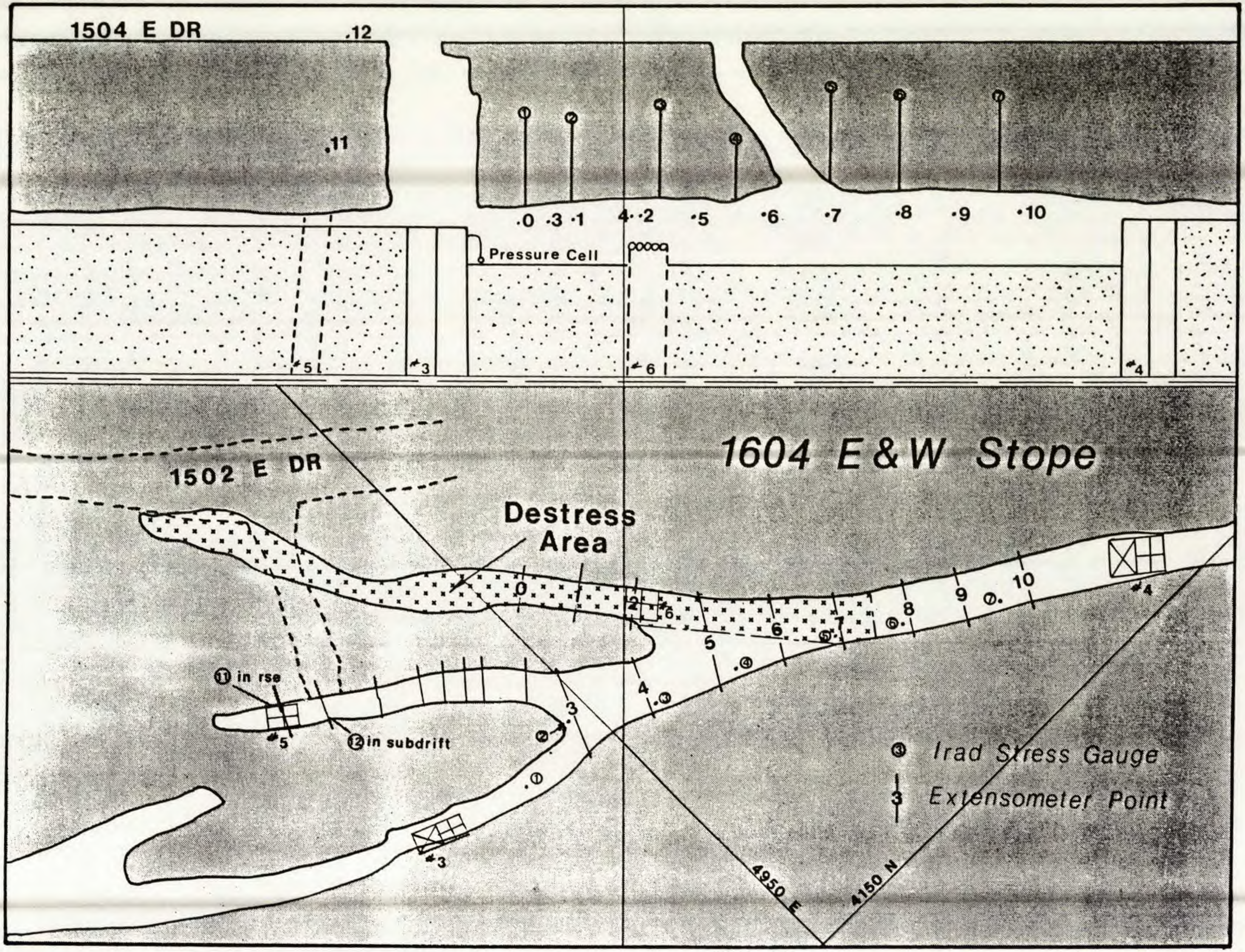

Fig. 12 - Location of instrumentation around 1604 stope.

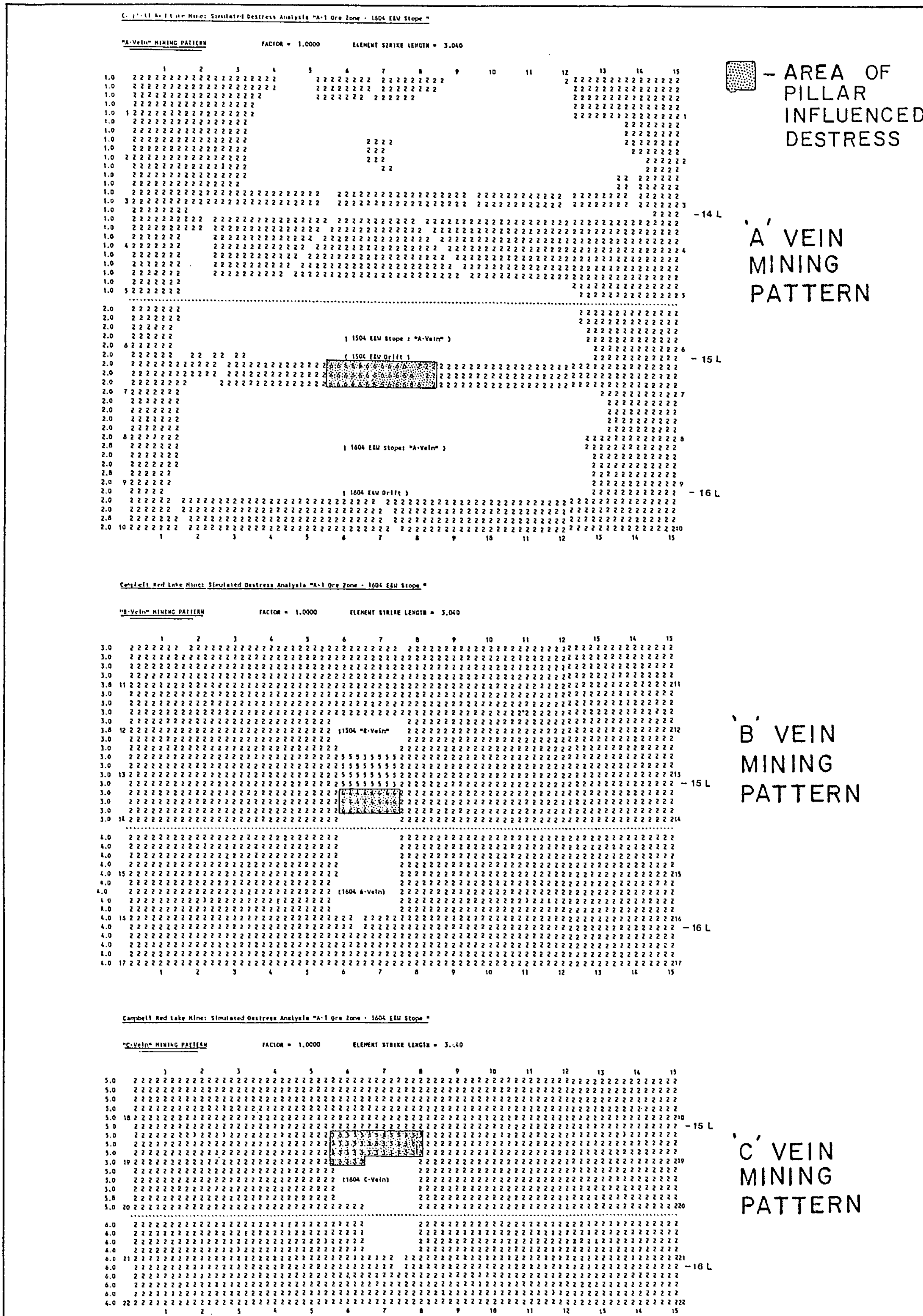

Fig. 13a - Mining layout of A, B and C vein in computer model.

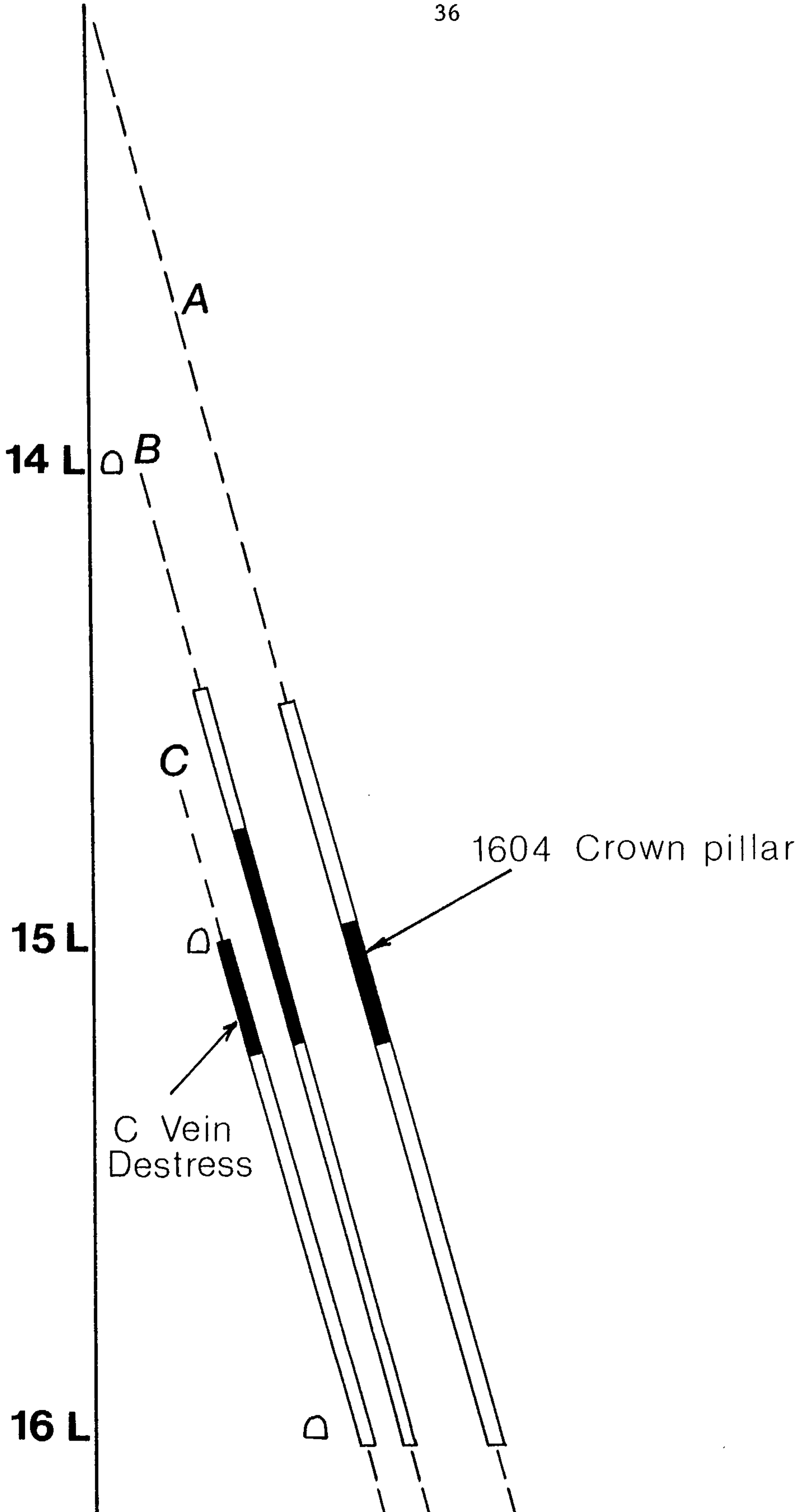

Fig. 13b - Cross-section showing A, B and C veins.

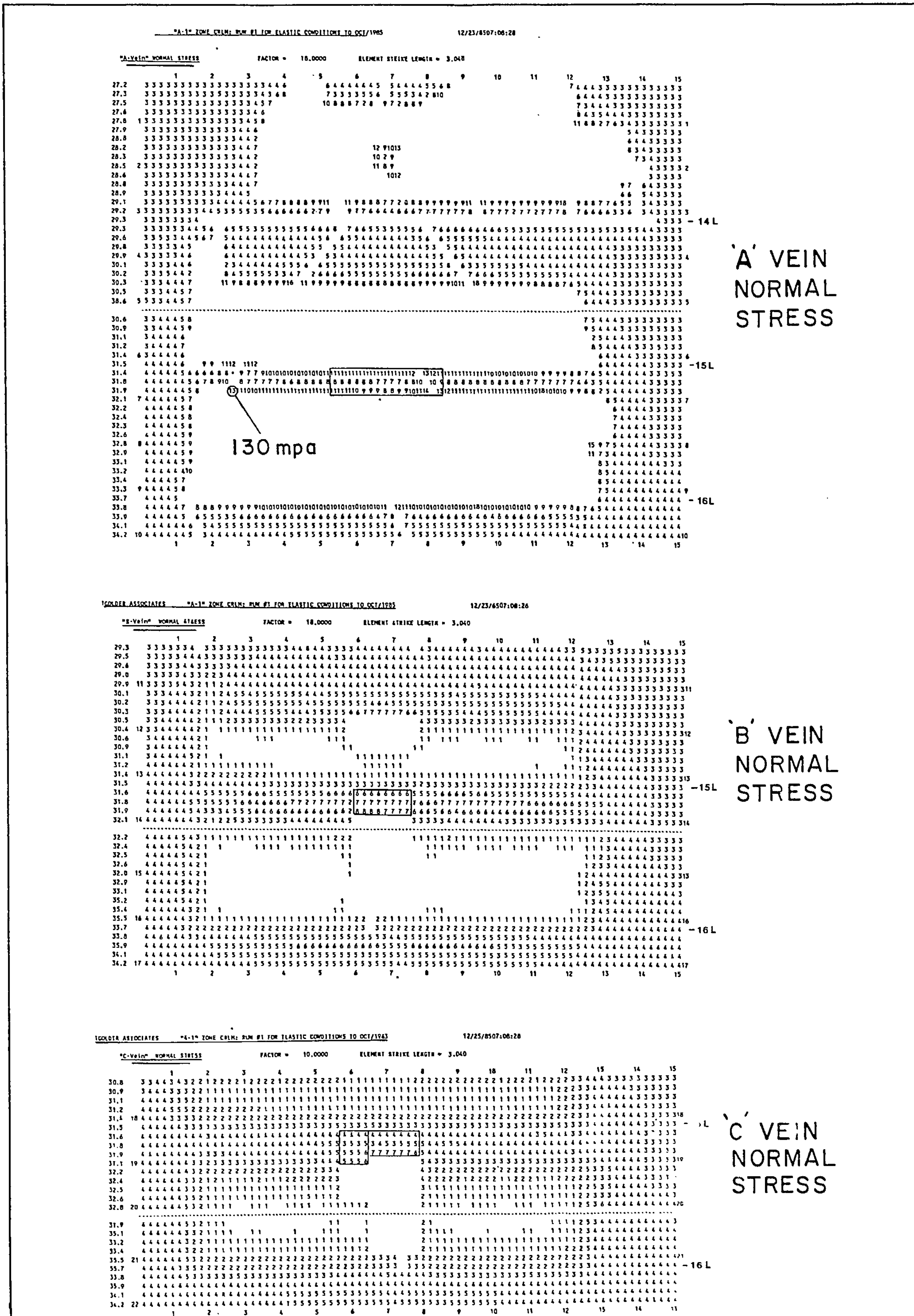

Fig.14 - Distribution of normal stress for elastic conditions.

see that the stress in the 1604 crown pillar was at critical levels, indicating the need for remedial mining methods or destressing.

FIELD RESULTS

Table 1 shows the actual closure and stress measurements compared with predicted results from the numerical modelling.

Table 1 - Measured and predicted changes in stress and closure

Station	Measured Change	Predicted Change 25% Modulus Reduction	Predicted Change 50% Modulus Reduction
EX-2	-2.89 mm	-0.67 mm	-2.06 mm
EX-4	-0.51 mm	+0.13 mm	+0.45 mm
EX-5	-1.41 mm	-1.03 mm	-1.90 mm
Stress-3	-0.77 MPa	-0.70 MPa	-2.10 MPa
Stress-5	-5.50 MPa	-1.80 MPa	-5.60 MPa
Stress-6	+5.60 MPa	+1.80 MPa	+7.60 MPa

A test blast was set off in the same area, prior to the destress blast, to determine seismic velocities. Using the Gould waveform display it was possible to accurately pick P-wave and S-wave arrival times, giving velocities of:

P velocity, 6327 m/sec , S velocity, 3743 m/sec

with a scatter of about 2%. The Electro-Lab MP-250 system gave a slightly lower P-wave velocity of 6215 m/sec. These values give a dynamic elastic modulus of 95 GPa and a Poisson's ratio of 0.23, which are 10 to 20% higher than the static values used in the NFOLD model.

Only two of the three blast vibration monitors recorded the blast. The actual peak particle velocities for the blast were within 20% of the predicted values.

Table 2 - Blast vibration measurements

Station	Distance From Blast	Peak Particle Velocity Measured	Predicted	
IS-1	104 m	32 mm/s	25 mm/s	(80% of predicted)
IS-2	81 m	46 mm/s	38 mm/s	(83% of predicted)
IS-3	45 m	Not recorded	99 mm/s	

Theoretical peak particle velocities were determined from Ambrassey's and Hendron's formula for spherical charges:

$$\hat{v} = 2080\left(\frac{R}{W^{1/3}}\right)^{-1.6} \qquad \text{Eq 3}$$

where, R = distance from the blast in metres, W is the weight charge per delay of explosive in kilograms, and $\hat{v}$ is the peak particle velocity in mm/sec.

The fill pressure cell was installed in the 'A' vein in order to monitor any increase when mining resumed in the 'A' vein. Consequently, it was not expected and did not react to the destess blast.

Following the destress blast, 8 seismic events were recorded over the microseismic monitoring system. Also, during the first 10 min after the blast, low energy microseismic activity could be heard over the monitor on a geophone located about 20 m away from the destress on 15 level. Figure 15 shows the location of these events, which are all around the destressed area.

DISCUSSION

After the amount of preparation and effort for instrumenting this destress attempt, the lack of significant microseismic activity and rock bursting was not expected compared to other destress blasts at Campbell Mine. The stope was easily accessible from the 16th level manway, and most of the instrumentation was still operational. Three of the destress holes at the

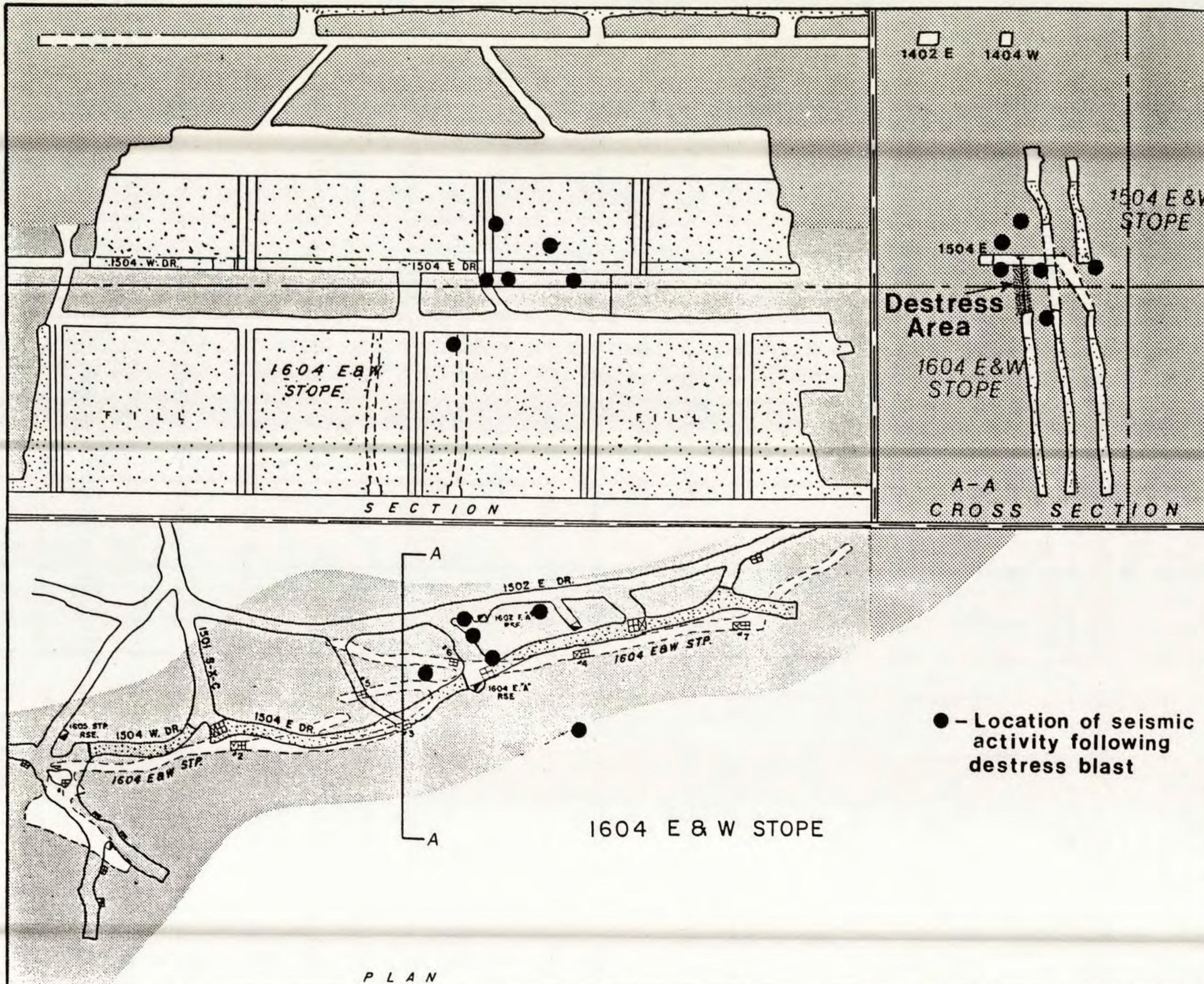

Fig. 15 - Location of seismic events after destress blast.

west end of the 'C' vein had misfired, but otherwise the blast was successful.

The seismic activity which was recorded was all within the 1604 stope crown pillar area, along the east abutment of the destress blast. This was a good indication of the effectiveness of the destress blast in transferring some of the load off the crown pillar.

From the computer modelling results, pillar stress within the 'C' vein was not at critical levels. Therefore, the influence of the destress on changes in pillar stress and stope closure was less than if the destress blast had been entirely within the more highly stressed 'A' vein crown pillar.

All the data from the stress meters, extensometer points and the blast vibration monitors agreed reasonably well with the theoretical results from the computer modelling. Using this information, the blast appears to have lowered the modulus of the pillar by 25-50%.

Mining was started in the 'B' vein with a 3 m long breast, the full height of the crown to the 15 level horizon. No ground problems were encountered, and the 'B' vein mining has been completed. Mining will continue above the 15th level taking 3 m lifts with uppers until the 1504 E stope horizon is reached. When this is completed the 'A' vein crown will be mined taking the full 9 m high pillar in 3 m long breasts. Problems with the ground in this pillar are anticipated as the mining progresses past the 'C' and 'B' vein shadow. At this time, the pillar will be destressed in advance of the face by drilling extra holes extending 3 m ahead of the end of the breast.

ACKNOWLEDGEMENTS

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