ARG/87/3

LONDONDERRY OCCUPATIONAL SAFETY CENTRE

MOURA INVESTIGATION: FINAL REPORT

POSSIBLE CAUSES AND EXPLOSION DEVELOPMENT

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Introduction

I was called upon by the Queensland Department of Mines in mid-August 1986, to assist them in their investigation: in particular to comment on the development of the explosion and if possible to identify the source of ignition.

In this report, an attempt is made to reconcile the incident with available evidence gathered by others and myself, and embraces the findings presented in my three previous reports.[1,2,3]

Background to the Explosion:

The explosion occurred at Moura No. 3 in the "Dip" section. This area was serviced by five headings going through a well defined shear zone between 22 and 23ct, known as the P2¼ fault or" Taj Mahal". This zone formed a swilley in the headings. The average incline outside of this zone was about 1 in 12.

Predrainage of the seam started in late 1983. The seam was allowed to stand for a year before extraction started in April, 1986. Total extraction of pillars commenced on 7th July, 1986. Inspection of goaf edge and monitoring the south return at No. 6 point between 13/14ct indicated less than 0.3% methane in air. The last inspection in the goaf took place by the deputy on the dog watch of 16th July. The carbon monoxide level was less than 3ppm and water was being pumped into the waste.

On the afternoon of 15th July, extraction of the south side fender was completed and the continuous miner was pulled back to 27ct to extract the next fender. The area was stonedusted and set up for the day shift the next day. The morning shift discussed how to remove the fender and decided to take 2-3m off the fender and put in extra roof bolts and props before complete extraction. A brattice was erected inbye of 27ct on No. 3 heading to direct flow round the goaf into the returns.

The undermanager was underground from 8.15am to 10.15am and reported no problems and no noise. Extraction of the fender started at approximately 10.20am. The transport driver who went underground reported no problems or noise as did two belt patrolmen who reported no problems with the belt. The supply man went to the face and took a trolley from 27ct to 26ct behind a shuttle shunt and left at 10.55am.

The explosion occurred at approximately 11.07am, on 16th July, 1986, killing 12 men. Eight others were underground in 3 south. These witnesses described hearing - "a lound bang" - "a low rumble" - "a double bang a few seconds apart", - and was accompanied by an increase in pressure on the ears. Of the two persons in the Dip 1 belt, one had popped ears and one was blown over. Neither reported a loud noise. These two were the nearest in roadway line. On the surface thick clouds of dust were observed coming from No. 4 entry and at first it was assumed to have been caused by a major fall rather than an explosion. It took about an hour and a half before high levels of carbon monoxide were discovered which showed that an explosion had

occurred and led to the withdrawal of all persons underground. Rescue was hampered by a fire which occurred in 24ct and had to be controlled before the bodies could be brought out and investigation of the explosion commence.

The continuous miner had been pulled back into heading no. 3. All switches were in the reset position. In this mine, it was normal practice to trip the earth leakage test button to cut power to the machine and then reset the switches ready to be turned on at the main switch. There was therefore no power to the miner at the time of the explosion.

Shuttle No. 30 was found in the normal shunt position in 26ct. The brakes were set with the lights on. All other controls were off. The cable to the car was live and had been damaged in the area of the anchor.

Shuttle No. 31 was found in heading no. 4 hard against the rib, an unnatural position. The brakes were on and the lights on. All other switches were off. There were no drag marks to indicate that the car had been moved by the explosion.

A body (Hull) was found under the cable reel compartment of Shuttle No. 31. Autopsy has shown that there was no injuries consistent with being run over. The blood CO level was 4.8% - one of the lowest - and the cause of death was asphixia.

The diesel mine rover was found inbye 26ct on no. 4 heading, against the rib. It was in 1st gear with the handbrake on, the bonnet blown off, tilted at 10° and the roof of the vehicle had been hooked onto a roof bolt. There was fuel in the tank, water in the scrubber. the left header tank contained water while the other was dry. The seats were extensively burnt. The mine rover had been parked in this heading since early in the shift and was still there when the supplyman came out of the mine at 10.55am.

The bodies were located around 26ct in headings 3 and 4. Autopsy has shown three causes of death, head injury, asphixia and incineration. The majority had very high CO levels in their blood.

A fire was found in 24ct between headings 2 and 3 after the explosion and hampered rescue attempts. Another small fire had occurred against the rib in heading 1A.

The shuttles had loaded coal onto the conveyor system some 3 minutes and 10 minutes before the explosion.

The explosion caused massive blast damage in the belt roadway moving the conveyor frame sideways at 24ct and breaking the frame at about 23ct moving the entire frame outby 22ct. The water barriers situated between 23ct and 24ct were blown out with the frames found about 20ct. Water in headings 1, 2 and 3 at the "Taj Mahal" had been moved up the dip as far as 19ct.

Source of Fuel

The mine contains methane and coal dust. Both could have been the source of fuel for first ignition. Analysis of dust samples collected after the explosion show that the volatile content of the dust has dropped from the expected value around 33%. (Figure 1). This is indicative of a coal dust explosion. It doesn't necessarily imply that coal dust was the first fuel ignited.

Gas was present in the goaf and continually outgassed into the return. Prior to the explosion, the level of methane in the return was less than 0.3% and there were no high peaks during the previous 15 days. Hargreaves[1] has calculated that the total gas release into the goaf area was about $0.05 m^3 s^{-1}$. This is too low a rate to cause an explosive atmosphere without some other mechanism increasing the flow into the mine ventilation system.

The concentration of either gas or dust has to be above the lower flammable limit (LEL) before an explosion can be initiated. Figure 2 shows the extent of flame during the explosion. The red (triple hatch) area corresponds to the area found from the examination of dust and plastic materials recovered after the explosion. No samples of dust could be recovered from the yellow (double hatch) area on safety criteria. It is therefore not known how far flame extended into the goaf.

Estimates of minimum quantity of gas (LEL), based on Figure 2, that could cause this area of flame is between $280 m^3$ and $900 m^3$, assuming no participation from any coal dust. The latter figure is based on revised estimates of the goaf volume given to me by the Queensland Department of Mines. As coal dust was involved in this explosion (Figure 1), then not as much gas would be needed for ignition.

The equivalent quantity for a pure dust explosion is between 2,240kg and 7,200kg of dust. An additional mechanism (as with gas acting as the first ignited fuel) is also required to get dust airborne in sufficient quantities to form an explosible atmosphere that can be subsequently ignited.

Other fuels do exist in the mine associated with particular apparatus such as hydraulic oils in the hydraulics of mine machinery. These sources are only relevant when a fault occurs with the associated apparatus.

Sources of Ignition

There are many potential sources of ignition present in the mine environment. Possible sources of ignition for this explosion include:

i) Preceding mine fire
ii) Electrical Arcing
iii) Frictional heating along the conveyor system
iv) Heated surfaces on vehicles
v) Faulty apparatus
vi) Battery faults

vii) Contraband and prohibited articles
viii) Incendive ignition
ix) Static electricity

Many of these ignition sources can be excluded as the causal source of ignition in this explosion following examination and investigation of apparatus present in the mine at the time of the explosion by the Queensland Department of Mines and by the company.

(i) Preceding Mine Fire: A fire can act as a fuel, due to partially combusted components, and as a source of ignition from the hot gases and radiation from the flame. There was no evidence of a fire existing prior to the explosion. The monitoring system at the mine analysed for methane and carbon monoxide. There had been no change in the carbon dioxide reading of 2-3 ppm over the preceding seven days. This low reading indicates that there was no flaming combustion in the mine and the static reading indicates that there was no incipient spontaneous combustion occurring.

(ii) Electrical Arcing: Arcing can arise from faults occurring in the electrical circuits in various apparatus and from damage to trailing cables. The continuous miner was isolated back to the transformer and only the cables to the shuttle cars were live. Investigation has shown that no arcing had occurred along the cables even though the cables sustained damage as a result of the explosion. Flame proof apparatus containing electrical circuits had the correct gaps and there were no signs of arcing from the circuits enclosed within these flameproof enclosures. All intrinsically safe circuits were found to be satisfactory.

(iii) Friction Heating: This can occur by collapse of a bearing on the return idlers or by foreign objects being jammed against the moving conveyor. Two patrols of the belt system prior to the explosion found no indication of the collapsed bearing, or foreign objects, likely to act as a source of friction.

(iv) Heated Surfaces: Hot surfaces on vehicles are normally kept below a level to cause ignition of coal dust, which for certain coals can be as low as 180°C. Water is normally employed as the coolant for these surfaces. The diesel mine rover was found with water in the scrubber system and this would cool the exhaust system. Furthermore, there was no evidence that the rover had been moved from the position where it was parked some 2 hrs before.

(v) Faulty Apparatus: There are a number of pieces of equipment underground that can develop electrical and other faults on becoming damaged through continual use: for example, the flame safety lamp, cap lamps and bateries, methanometers etc. No evidence has been found to suggest that any such pieces of equipment were faulty and could cause ignition of gas or dust.

(vi) Batteries: Certain heavy duty batteries evolve hydrogen. This can be ignited if a fault occurs at the terminals of the battery. No batteries of this type were in the mine. There were no faults on other types of batteries.

(viii) Incendive Ignition: Three types of incendive or frictional ignition can cause an explosion: rock rubbing against rock, rock against metal and certain metals impinging on other metals. If a roof fall occurred, then rock rubbing against rock or striking a roof bolt or plate could cause frictional ignition. This source cannot be excluded as a potential source of ignition. An Entonox (N_2O/O_2 gas mixture used for first aid) cylinder made of aluminium was found in 26 ct. This is one of the commonest metals that can cause frictional ignition on contact with rusty iron or steel. This is also a potential source of ignition.

(ix) Static Electricity: Discharge of static can cause ignition of gas and dust. Problems usually occur when a fast gas or dust flow passes over unearthed plastic surfaces that have a high resistivity. In this case a roof fall could have caused such a flow over brattice cloth. Normally such cloth would have a resistance of less than 10^8 ohms. Consequently build up of sufficient surface charge would not be enough to discharge from the surface. At the time of writing this report, I have received no information on the type of brattice cloth used or the results of surface resistance tests being undertaken by the Department of Mines. This must also remain as a potential igniton source.

Three potential ignition sources could have caused the explosion but consideration must be given to other evidence to help distinguish between alternative sources of ignition.

Explosion Development

Figure 3 shows the estimated pressures developed by the explosion.

The contours were obtained from the distances that bricks were moved from the stoppings between No's 4 and 5 headings and between No's 1 and 2 headings assuming that the dynamic pressure lasted for about 0.2s. The pressure was greater towards the south (a larger time would lead to lower pressures but the trend would remain the same) around No's 1,2, and 3 headings and 24ct. This is consistent with the explosion being more confined in this area due to water in No's 1,2, and 3 headings in the swilley between 22ct and 23ct. The higher presures are consistent with an acceleration of the explosion in this area most likely by the belt roadway where partial blockage increases the rate of turbulence and hence the rate of energy release.

Figure 4 shows the major airflows during the explosion obtained from observation of dust deposition and scouring of roof bolts, plates and props. The observed pattern fits with a main flow moving outward and a second flow moving inward towards the north west of the mine. This is also consistent with a high pressure zone on the south side of the mine trying to relieve the pressure to the north, reversing the flow north west and going with the outward flow to the north east. The water in headings 1,2, and 3 acted as a water barrier, quenching the explosion. This is shown by the more rapid decay of pressure on the south side of the mine outbye of 22ct. To the north the decay was slower due to less water on that side of the mine.

One consequence of the confinement of pressure and subsequent relief to the north would be to increase the length of time that dynamic pressure and heat was acting on objects, compared with a single explosion moving only in one direction. This is seen on figure 3 by the overprediction of pressures associated with the water being pushed outward along headings No's 1,2, and 3 and associated with movement of prep-seal doors and tyres along heading No 4. Increasing the time to about 1 second instead of 0.2 seconds decreases the estimated pressures to about those estimated from the stopping data.

Figure 5 shows the heat damage caused to various objects in the mine. The main heat damage occurred around 26ct in No's 3 and 4 headings and along the belt roadway (No 3 heading) as far as 24ct. This pattern of damage is consistent with increased residence time of the flame due to reversal of the airflow in this region.

The dry ash free volatile content of coal dust obtained from samples after the explosion (figure 1) show most combustion occurring along the belt roadway and in the vicinity of 26ct in No 4 heading. This is also consistent with an increased residence time of flame in these areas.

CONCLUSION:

The estimated pressures during the explosion, the observed flow patterns, the heat damage to surfaces and the volatile content of dust surfaces are all consistent with an initiation inbye 25ct, moving outward probably along the belt roadway, being accelerated and confined by the water in the swilley on the north side of the

mine. The explosion tried to vent itself to the north, pushing westward down the belt roadway and No.4 heading into the goaf increasing the damage in this area. The explosion generated sufficient force to push water in the swilley outbye 22ct which helped to quench the explosion, more so on the south side than the north side. The explosion was finally vented through the swilley on all headings.

Accident Scenarios

If it is assumed that there was no roof fall prior to the explosion then the fuel could only have come from a preceding fire, which acted as a source of fuel (and possibly an ignition point) or from another source such as a hydraulic fluid break. No evidence supports this argument. Only methane or dust could have acted as the first fuel ignited as no preceding fire occurred and equipment that contained alternative sources of fuels were intact. Furthermore, the make of gas from the goaf was too small to produce a local flammable mixture other than at the roof line at goaf cavities. If a gas ignition occurred first it must have been preceded or accompanied by a roof fall.

There is evidence to support such a roof fall. On the morning of the explosion the deputy and undermanager discussed the possibility of a fall during the shift. The continuous miner had been pulled back and isolated as if a fall was imminent and anticipated.

The consequences of a fall in the goaf are that:

(a) The brattice cloth controlling the ventilation at the face could have been torn down by the wind blast. This would short circuit the intake at 26ct and leave the goaf with virtually no ventilation.

(b) Gas that had accumulated in cavities in the roof could be flushed out by the wind blast of the fall. This could form either localized flammable pockets of gas or a methane layer moving along the roof up the dip toward 26ct before being dispersed by the ventilation.

(c) Coal dust would have been raised into the atmosphere by the fall, principally along the face and belt roadway where stone dusting cannot normally keep up with dust produced from the coal winning.

The conditions for ignition by incendive rock or by electrostatic discharge could have been created by such a fall in the goaf. In the former case rock rubbing against rock while falling through a flammable gas mixture will ignite the gas, only if the rock is of an incendive type. The sample that I received was tested by two methods: x-ray diffraction (XRD) and petrological section. The latter method is used to classify incendivity of mine rock in N.S.W. and Queensland. The sample had a quartz content of 25% when analysed by XRD but only about 6% when studied by petrological section [5]. The petrological report suggests that the local quartz content could only go as high as 30%. Tests

that I carried out on the sample [2] show that it is not incendive. A sample taken by Dr. A.F. Roberts was analysed by XRD, giving a quartz content of 69%. This latter sample was able to ignite methane in a grindstone test which is difficult even for Darley Dale sandstone, a well known incendive rock obtained in the UK. This sample is clearly incendive. It must be concluded that bands of high quartz content exist in the goaf area.

In the latter case (electrostatic ignition) a high velocity, dust laden airflow over a brattice cloth can lead to build up of charge on this plastic surface. The brattice would have to have had a surface resistance in excess of 10^{11} ohms where surface decay of electrostatic charge would be of the order of milliseconds and unlikely to lead to an ignition. If the brattice is of an approved type the surface resistance will be below 10^{8} ohms and static is unlikely to be an ignition source.

A roof fall could also have created a flammable dust atmosphere that could have been ignited by the entonox cylinder, striking with some force a steel or iron object. For this to occur, however, several additional assumptions have to be made. The cylinder head has to be removed suddenly. Once the head had been removed, the cylinder would act like a rocket. If no roof fall had occurred, dust could be raised by the jet from the rocket. If a roof fall had occurred, the flammable atmosphere would already exist. The rocket on impact with roof bolts, butterfly plates and other steel objects would cause frictional sparking. The cylinder was discharging the equivalent of a 70% oxygen atmosphere. This would lower the flammability limits and make ignition more likely[2].

The problem with this scenario is accounting for how the cylinder head was removed. Hull was found under the cable reel compartment of shuttle No 31 as though pinned by a backward moving vehicle. This accident caused problems with his breathing. If this occurred then it is logical to assume that someone would fetch the entonox bottle from the crib room where it is normally located. In panic or because of poor visibility due to a roof fall, the person carrying the entonox cylinder struck an object sufficiently violently to remove the head of the cylinder.

Experiments undertaken by Queensland Department of Mines suggest that a person could not remove the cylinder head with a single violent blow, taking between 6 to 10 violent blows to remove the cylinder head. Furthermore, metallurgical examination of the cylinder head suggested one violent blow had taken off the head. This is inconsistent with the above scenario.

The pressure in the vicinity of 26ct would be about 200 KPa at the upper limit and about 50KPa at the lower limit (figure 3). These limits correspond to air velocities of 280 m/s and 100 m/s respectively: enough to knock a man over. These velocities are also enough to move an 18 tonne shuttle about 2cm sideways: certainly enough to lift the vehicle up on its wheel base. Hull could have been trapped under the shuttle as a result of the explosion. Furthermore, air velocities in excess of 100m/s can

easily project the entonox bottle against objects with sufficient force to remove the head in one blow. It is more likely that the entonox cylinder was destroyed as a result of the explosion rather than the cause.

Conclusion:

The development of the explosion is consistent with ignition in the goaf area by incendive rocks. It has to be assummed though that gas had accumulated in cavities in the roof of the goaf and a preceding roof fall flushed out gas, developed a flammable mixture before another fall caused ignition. Alternatively electrostatic ignition cannot be ruled out until further evidence as to the suface resistance of the brattice cloth used in the mine is available. Here it is assumed that the roof fall was sufficiently violent to create a high velocity airflow over the brattice. The presence of gas need not be involved if sufficient dust was stirred up. However. the presence of gas would facilitate ignition by sparking.

Other scenarios either require several more assumptions about what occurred, which can be accounted for in other ways or there is evidence that a particular scenario could not have occurred.

Recommendations

(1) The presence of aluminum cylinders is cause for concern as they are made from a metal capable of incendive sparking. It is recommended that steel cylinders are used for entonox in first aid cases.

(2) There is a wide discrepency between the quartz content analysed by XRD and by petrological section, with the latter giving the lower value. More research is needed to resolve this discrepancy as there is the danger that mines are wrongly diagnosed as non incendive. It is usually assumed that quartz is the cause of incendive sparking in rocks. This is based on work done in the U.K. The parameters that actually determine the incendivity are the hardness, melting point and thermal capacity of the rock. The harder the rock, the higher the melting point and greater the thermal capacity, the greater is the incendivity. Quartz is the only type of rock that occurs in any quantity in U.K. coal measures with the correct properties. Other rock types such as pyrites will be atternative candidates in Australian coal measures. A complete assessment of such rocks should be undertaken.

(3) Moura had a large free standing goaf. What are the consequences of large free standing goaves to explosion development, particularly in multi entry systems? More research is needed to determine this and whether dispersion of gas safely in goaves can be accomplished by reducing the free standing volume.

(4) The swilley at Moura which contained water acted like a large water barrier and effectively isolated the explosion to one part of the mine. Could this type of roadway be adapted for isolation barriers in gassy mines. Work is required to assess the practicability of such schemes and assess their reliability and effectiveness.

References

(1) A.R. Green. "Moura Investigation: Interim Report No. 1" ARG/86/5. LOSC Oct 86.

(2) A.R. Green. "Moura Investigation: Interim Report No. 2" ARG/87/1. LOSC. Jan 87.

(3) A.R. Green. "Moura Investigation: Interim Report No. 3, Estimates of Explosion Pressure". ARG/87/2. LOSC. Jan 87.

(4) A.J. Hargraves. "Revised Final Report to T.D.M. Moura, Jan 87.

(5) L.M. Barran "Lithic Sandstone from the Moura Coal Field, Queensland". Unpublished Petrological Report 86/8.

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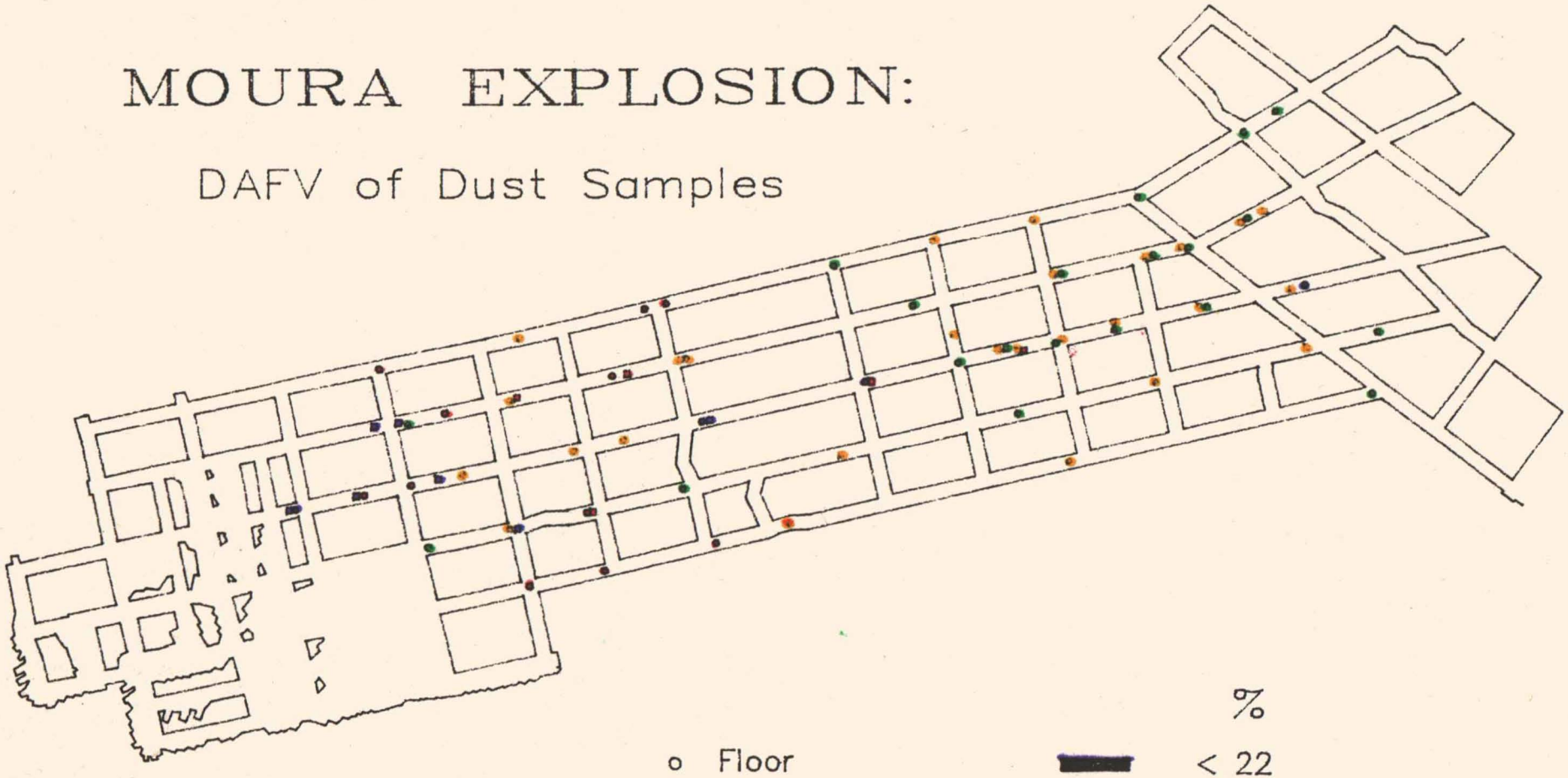
MOURA EXPLOSION:

DAFV of Dust Samples



o Floor

□ Roof and Rib

%
< 22
22–24
24–26
26–28
> 28

Figure 1.

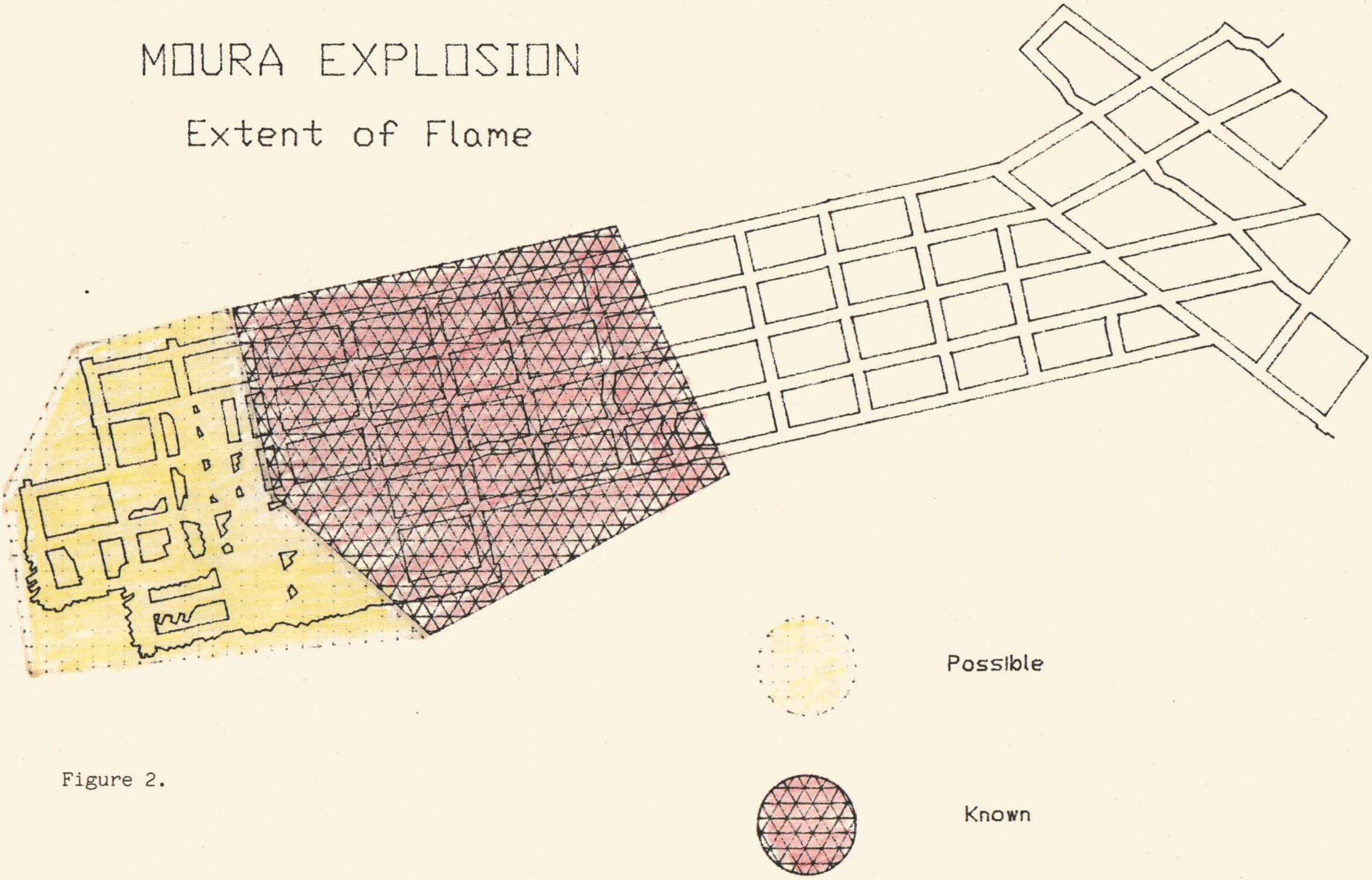
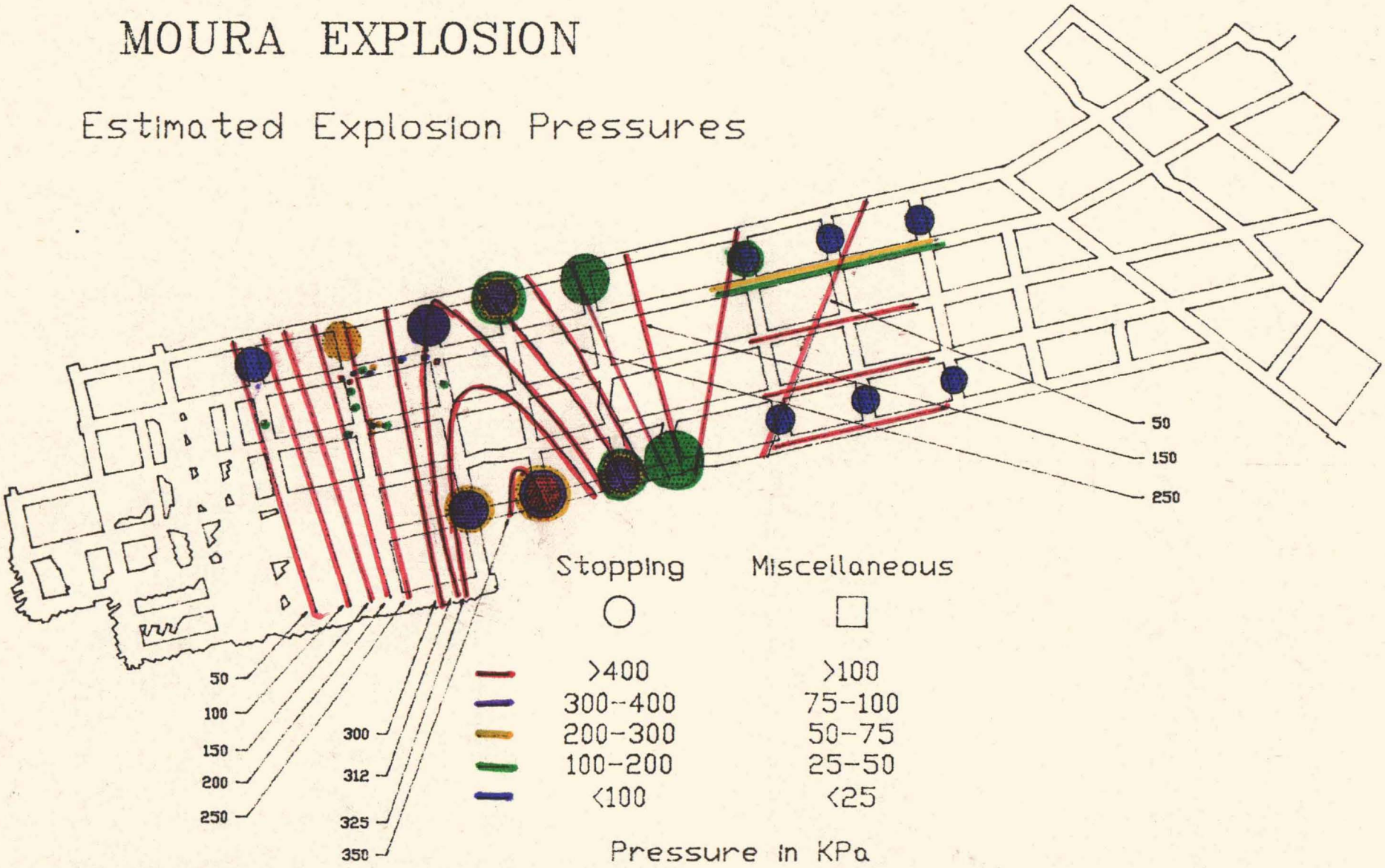


Figure 2.

Figure 3.


MOURA EXPLOSION
Estimated Explosion Pressures
50
150
250
50
100
150
200
250
300
312
325
350
Stopping
Miscellaneous
>400
300--400
200-300
100-200
<100
>100
75-100
50-75
25-50
<25
Pressure in KPa

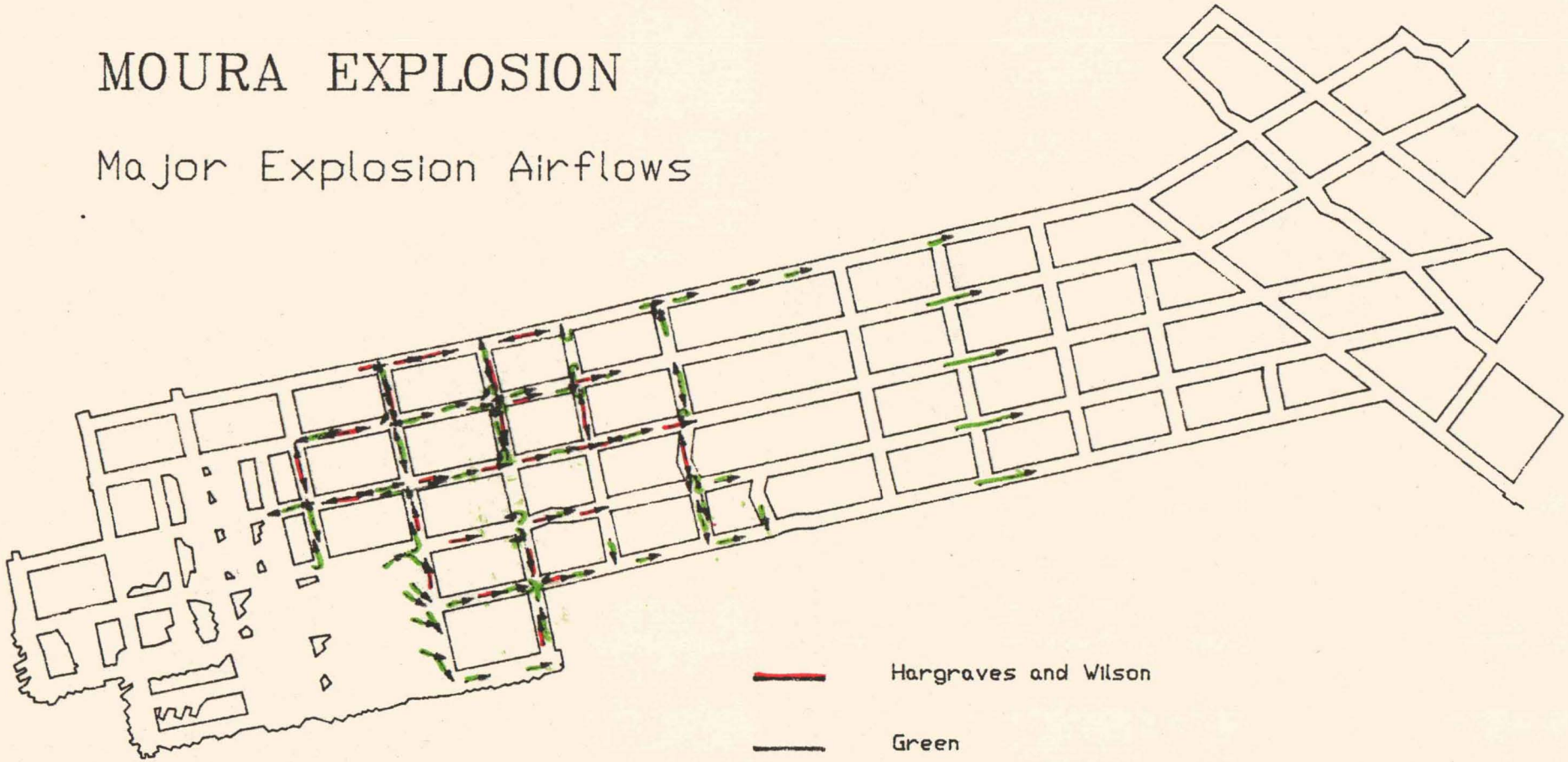
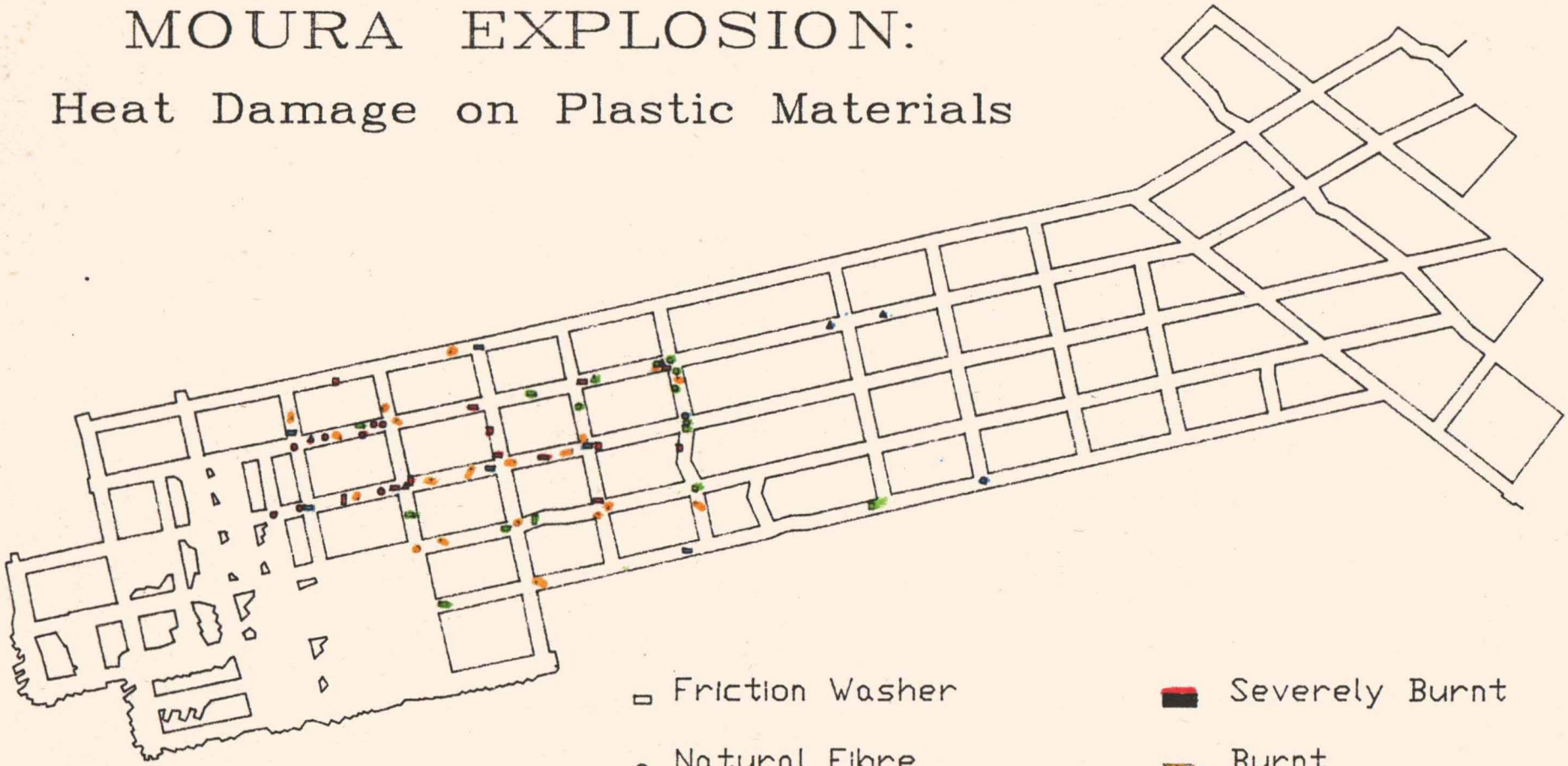

MOURA EXPLOSION
Major Explosion Airflows
Hargraves and Wilson
Green

Figure 4.

MOURA EXPLOSION:

Heat Damage on Plastic Materials



- Friction Washer
- Natural Fibre
- Polypropylene String
- Cable Tie
- Miscellaneous

- Severely Burnt
- Burnt
- Heated
- Slightly Heated

Figure 5.