THE EXPLOSION AT MOURA NO. 4 MINE QUEENSLAND

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A view of the possible causes and development of the explosion

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Circulation

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Introduction

During my visit to Queensland, my views on the possible causes and development of the explosion at Moura No. 4 Mine began to develop.

This report summarises these views but I would emphasise two things:

1) The laboratory investigations were incomplete at the time of my visit so that any more recent data have not been taken into account.

2) The existing data base at that time was very extensive and I only have continuing access to a relatively small fraction of it.

I have not therefore been able to check the views expressed in this report against the complete data base.

I have divided the account into two sections, one on the main event, that is to say the part of the explosion that did the most damage, and the other on the initiating event, that is to say the events that led up to the main event.

I have discussed the main event first because it is better defined and because it helps to define the requirements for the initiating event, which is more speculative.

A plan of the area affected by the explosion is given at the end of the report.

The Main Event

The main event began when the blast from a relatively mild explosion travelling eastwards along the conveyor road interacted with the boot end of the conveyor.

This interaction broke the welds on the plates supporting the boot end roller and put a wiggle in the conveyor structure opposite No. 25 cut through and slightly to the east of No. 24 cut through. It also shook the conveyor belt violently, sending a travelling wave along the belt - at some stage this wave would have been reflected back, flipping the belt off the structure and looping it over the structure at the boot end.

The conveyor had been in use during the shift and had received its final shuttle car load of coal only a few minutes before the explosion. There were necessarily coal dust deposits on the belt. The violent disturbance of the conveyor belt therefore would have raised a substantial cloud of coal dust for as far as the belt disturbance propagated.

The explosion flame from the relatively mild explosion propagated into this coal dust cloud and the explosion developed rapidly in flame speed and over-pressure as a coal dust explosion, also travelling eastwards.

With the development of the coal dust explosion, the damage to the conveyor increased. The top belt failed near No. 24 cut through, the bottom belt near No. 23 cut through and disintegration of the conveyor structure began between Nos. 23 and 24 cut through.

The debris from the destroyed conveyor were displaced a good distance eastwards, with a tangle of conveyor belt finishing up opposite No. 22 cut through. A crest in the conveyor roadway at No. 23 cut through, where the roadway ceased to rise in the easterly direction and began to dip, may have also contributed to this increased damage, as the structure would have been more exposed to the blast wave as it traversed the crest.

A water trough barrier was located in the conveyor road in a zone about 20 m long immediately to the west of No. 23 cut through. The supports for this barrier and the components of the barrier were displaced in the easterly direction. There is little doubt that the barrier was responsible for stopping the coal dust explosion. Although the blast wave obviously continued in the easterly direction, the effects decreased in severity and there is no evidence that the explosion flame passed beyond the water barrier.

Given the amount of coal dust that must have been along the belt, there is every reason to suppose that the coal dust explosion would have travelled along the conveyor roadway to the portal, achieving extraordinary levels of violence, but for the successful operation of the water barrier.

As the coal dust explosion developed in the conveyor roadway, a zone of high pressure was created which sent pressure waves through cut-throughs into neighbouring roadways and back along the conveyor road in a westerly direction. The explosion flame itself would have penetrated into the cut-throughs to some extent.

Under these circumstances there is little doubt that the development of the explosion flame into neighbouring roadways was prevented by the high standard of stonedusting in the mine. Without adequate stonedusting, the coal dust explosion would have propagated into and along the neighbouring roadways.

As the high pressure gas from the explosion in the conveyor roadway expanded into the intake roadways on either side, a rapidly increasing static pressure was applied to the permanent seals in the cut-throughs between these intake roadways and the two return roadways causing the damage summarised in 4(c) of Report 3.

This summary indicates that for both the north and south return roadways, the maximum damage to the seals was associated with the region near CT 23 and 24. This is consistent with the coal dust explosion developing in power as it ran along the conveyor roadway and peaking in violence as the leading edge of the explosion flame began to run into the water from the barrier and progressive extinction occurred.

The summary also indicates that the seals into the north return suffered a higher damage category at corresponding cut-throughs than those into the south return. This is not a distance effect as the two sets of seals are approximately equidistant from the conveyor roadway.

There are two possible explanations for this asymmetry, which could apply independently of one another or simultaneously:

1) The mild blast wave from the initiating event could have travelled along the south return, but not the north return, thereby increasing the pressure on the return side of the seals, i.e. reducing the differential pressure, which is the effect that causes the damage.

2) The mild blast wave from the initiating event could have travelled along the transformer road (the intake between the conveyor and the south return) initiating northerly flows in the cut throughs to the conveyor road before the main explosion produced much stronger flows in the reverse direction. This effect would have slightly delayed the build up of pressure on the seals in this region and possibly the maximum pressure as a consequence.

Once the seals were destroyed, there would have been a flow of high pressure gas into the return roadways creating the blast wave that travelled along the return to the portal, damaging the fan ducting.

The flow from the explosion zone westwards along the intakes produced blast effects with a strong directional influence for instance, the bending of fire extinguisher brackets in the conveyor roadway towards the face areas and the displacement of a multi purpose vehicle originally loaded with timber at the No. 2 roadway/No. 25 cut through intersection.

The initial event may also have spread through the face areas; in any case, there would have been a complex set of pressure waves up and down all five roadways and through the cut-throughs, producing a very varied set of directional indicators. However, the strongest directional indicators are consistent with the above explanation.

As the pressure fluctuations died down after a few seconds, and with the ventilation system inoperative, the hot post explosion gases would have remained to produce some more prolonged heating effects.

The variation in volatile content of roadway dust samples is also consistent with the above explanation. In the conveyor road, samples taken between the face and cut through 23 have dry ash free volatile matter (DAFV) contents in the range 18-25%. To the east of cut through 23, DAFV values are in the range 23-31%. The rib samples in the belt road show a good linear relationship between DAFV and distance from the face.

Samples from the south return show somewhat similar trends; results from other roadways are more varied.

These data point to the involvement of coal dust in the explosion and to the main explosion occurring between the face areas and cut through 23. Obviously, coal dust is blown up and down the roadways by the blast waves, so that overall trends are probably more significant than individual values of DAFV.

The following estimates of explosion strength have been made, as described in Report 3:

4(a) The rise in static pressure in the conveyor road due to the explosion was about 1 Bar, with a corresponding dynamic pressure of about 0.3 Bar and a flame speed of about 150 m/s.

4(b) The rise in static pressure in CT 24 between the supply road and the conveyor road was between 0.4 and 0.8 Bar.

4(c) The rise in static pressure at the seals between intakes and returns varied from about 0.3 Bar at CT 24 to about 0.2 Bar at CT 22 and CT 27.

4(d) The shock wave pressure in the return roadway at the portal was about 0.18 Bar

Given their approximate nature and different methods of estimation, the estimates from 4(a), (b) and (c) are surprisingly self consistent. They are also consistent with the above qualitative description of the development of the main event.

They point to a maximum flame speed of about 150 m/s in the conveyor road and the creation of a volume of explosion gases at about 1 Bar overpressure. This volume expanded laterally into the adjacent intake roadways, creating a pressure rise of between 0.4 and 0.8 Bar, between the conveyor road and the supply road and a maximum pressure rise of about 0.3 Bar on the seals between intakes and returns.

The pressure wave in the return, once the seals had broken, had a maximum pressure of about 0.3 Bar. As it travelled along the roadway, this pressure wave steepened into a shock wave and despite numerous bends and junctions, the pressure rise at the shock wave was still about 0.18 Bar at the mine portal.

The Initiating Event

The requirements for the initiating event are a source of ignition in the presence of a flammable mixture of sufficient extent to give rise to the mild explosion in the conveyor road that triggered off the main event.

A very thorough examination of the mine and of the relevant electrical and mechanical equipment revealed nothing abnormal nor any signs of contraband. The electrical and mechanical equipment examined conformed to the required standards and gave no sign of having initiated an explosion. Clearly, some of the equipment was damaged in the explosion in such a way that it could not be thoroughly checked but there are no reasons to suspect any such equipment as a possible source of ignition. Flame lamps were in good order.

The mine had a continuously recording gas analysis system and this showed no signs of spontaneous combustion. The conveyor was relatively new and in good condition; it had been inspected along its entire length less than 2 hours before the explosion.

The mining operation had been stopped in a controlled way a few minutes before the explosion, probably because of indications that the roof in the goaf was about to fall. The miner and the shuttle cars were all parked and switched off.

Ventilation conditions on the panel were good with about 62 cubic metres per second of air circulating via 3 intakes and 2 returns (28 cubic metres per second in the North Return, 34 cubic metres per second in the South Return). Near the face, brattices had been erected to divert air off the transformer road intake to increase the air quantity flowing to the south return along CT 27. This had been done to improve the ventilation of the goaf area where the roof was about to fall. Since the roadway cross sections were about 6 m x 3 m, typical air velocities were about 1-1.2 m/s in the intakes and 1.5-2.0 m/s in the returns. The roads dipped at about 1 in 12 towards the face (west of CT 23).

The methane make on the panel was fairly steady at about 0.16 m^3/s giving typical methane concentrations in the return of 0.25%. The continuous monitoring system, with above ground equipment analysing samples drawn from the mine along tubes, recorded a normal methane content for the last sample to be analysed. (the explosion damaged a main underground cable which tripped out the surface supply as well).

A relatively small cavity in the roof of the goaf more or less opposite the end of the conveyor road could have housed an accumulation of methane, though the base of it was ventilated and no abnormal concentrations had been detected there. However a modest flow of methane from the cavity would only have given rise to a small roof layer in the goaf as ventilation conditions would have prevented a large layer spreading into the working areas.

Thus, there were no obvious sources of ignition nor of methane to build into explanations of the initiating event.

Alternative hypotheses for the initiating event have been put forward, each based on observations of the situation after the explosion - the Entonox hypothesis and the Roof Fall hypothesis - as follows:

Entonox hypothesis 'Entonox' is a 50/50 mixture of oxygen and nitrous oxide used as an analgesic in emergency situations, as an alternative to morphia. A cylinder of Entonox was provided in the First Aid bench fairly close to the locus of the explosion. After the explosion, the cylinder, gauge and face mask of the unit were found widely separated; the cylinder, which was of aluminium, had impact marks and the high pressure fitting to the cylinder had fractured allowing the contents to escape.

The hypothesis is that, prior to the explosion, Kevin Hull was trapped beneath a shuttle car. Following the accident to Kevin Hull, someone had gone to fetch the Entonox cylinder for use in this emergency. In haste, that person had fallen or collided with something with sufficient force to fracture the fitting on the cylinder, thus releasing its contents.

This had three consequences:

1) the jet of discharging gas served to generate an airborne cloud of coal dust,
2) this cloud was oxygen enriched,
3) the discharge caused the cylinder to rocket and an impact between the aluminium cylinder and a steel roof belt (for example) gave rise to thermite sparks which ignited the dust cloud.

Qualitatively, the hypothesis has credibility. It ingeniously provides all the necessary elements for the initiating event.

Quantitatively, it has two major hurdles to surmount. The first of these is whether the fracture to the fitting could have resulted from human activity or whether the impact necessary could have come only from the unit being violently thrown against something by the blast wave of the explosion. Clearly, if the fracture is not credible in terms of human activity, then the hypothesis as stated above is rejected. Laboratory tests are in hand to examine this matter further.

The second hurdle is the size of the event that could result from discharge of the cylinder contents. The high pressure gas mixture was stored in a 3 litre container at 300 psi, equivalent to about 600 litres at atmospheric pressure. For the sake of argument, consider that the mixture was pure oxygen (a more severe situation than the actual one), giving the mass of the contents as 0.8 kg. This mass of oxygen would be sufficient to burn 0.3 kg of coal, giving rise to a flame volume of about 30 cubic metres, assuming that the burning occcurred as a single rapid event in which flames spread through a preformed fuel/air cloud e.g. as a fireball.

The roadway cross sections at Moura were approximately 6 m x 3 m so that this volume of flame would be sufficient to fill the cross section for only about 2 m. To me, it seems very unlikely that a fireball of this size in this cross section of roadway would generate a pressure pulse of sufficient size to give rise to a self sustaining coal dust explosion. Generally a pressure rise of about 0.1 bar or greater is required by an initiating event to cause such an explosion.

<u>Roof Fall hypothesis</u> It is known that an area of roof between CT 26 and CT 27 south of the transformer road (No. 2) was in an unstable condition before the explosion. This part of the roof was sagging, according to one witness, but thirty minutes before the explosion, it was still in place; after the explosion, this part of the roof had fallen. However there is good evidence that this roof fall had occurred before the explosion because the cavity so formed was blackened by combustion products and objects had been thrown into the cavity by the blast.

The roof fall hypothesis therefore is that the roof began to move shortly before the explosion, causing the termination of mining operations, withdrawal of the miner etc.

Because the roof was sagging, an unventilated cavity existed above the detached strata. Methane accumulated in this cavity, possibly from the seam above.

The rock forming the roof, was a strong quartzitic rock capable of giving rise to incendive sparks.

When the roof fell, methane was released into the goaf area. The falling rocks gave rise to incendive sparks either through the impact of rock on rock or through impact between roof bolts and rocks. The methane ignited and a methane/air flame spread out of the goaf into the neighbouring roadways, in particular the south return, the transformer road and the conveyor road. The air blast from the roof fall raised dust from the miner and the shuttle cars. The methane explosion flame in the conveyor road ignited the cloud so formed, leading to the main event.

The observed asymmetry in the blast effects of the main event is consistent with this hypothesis.

Entonox/Roof fall hypothesis One could combine parts of the two previous hypotheses to say that the air blast from the roof fall raised coal dust from the miner and the shuttle cars and caused the damage to the Entonox cylinder; the ignition of the oxygen enriched dust cloud, although leading to a flame that was relatively small in volume, was sufficient to ignite the coal dust/air cloud created by the air blast.

Summary

Each of these hypotheses has weak features and the ones involving the Entonox cylinder rely on a very unusual chain of events.

If asked to choose the most likely, I would opt for the roof fall hypothesis, as being entirely within the range of circumstances encountered in previous mine explosions. As such, it does not have any particularly novel features but it does rely on the existence of a methane accumulation. The likelihood of such an accumulation developing above the sagging roof is a matter of mining or geological judgement. The possibility of a 'pure' coal dust explosion (i.e. one without the involvement of an initiating methane explosion) exists because the air blast from the roof fall would itself raise coal dust in the conveyor road but there is no apparent source of ignition in this area (except for the Entonox cylinder).

The damage pattern is reasonably consistent with the roof fall hypothesis, which could have given rise to the observed asymmetry in damage to the seals on the north and south side of the workings.

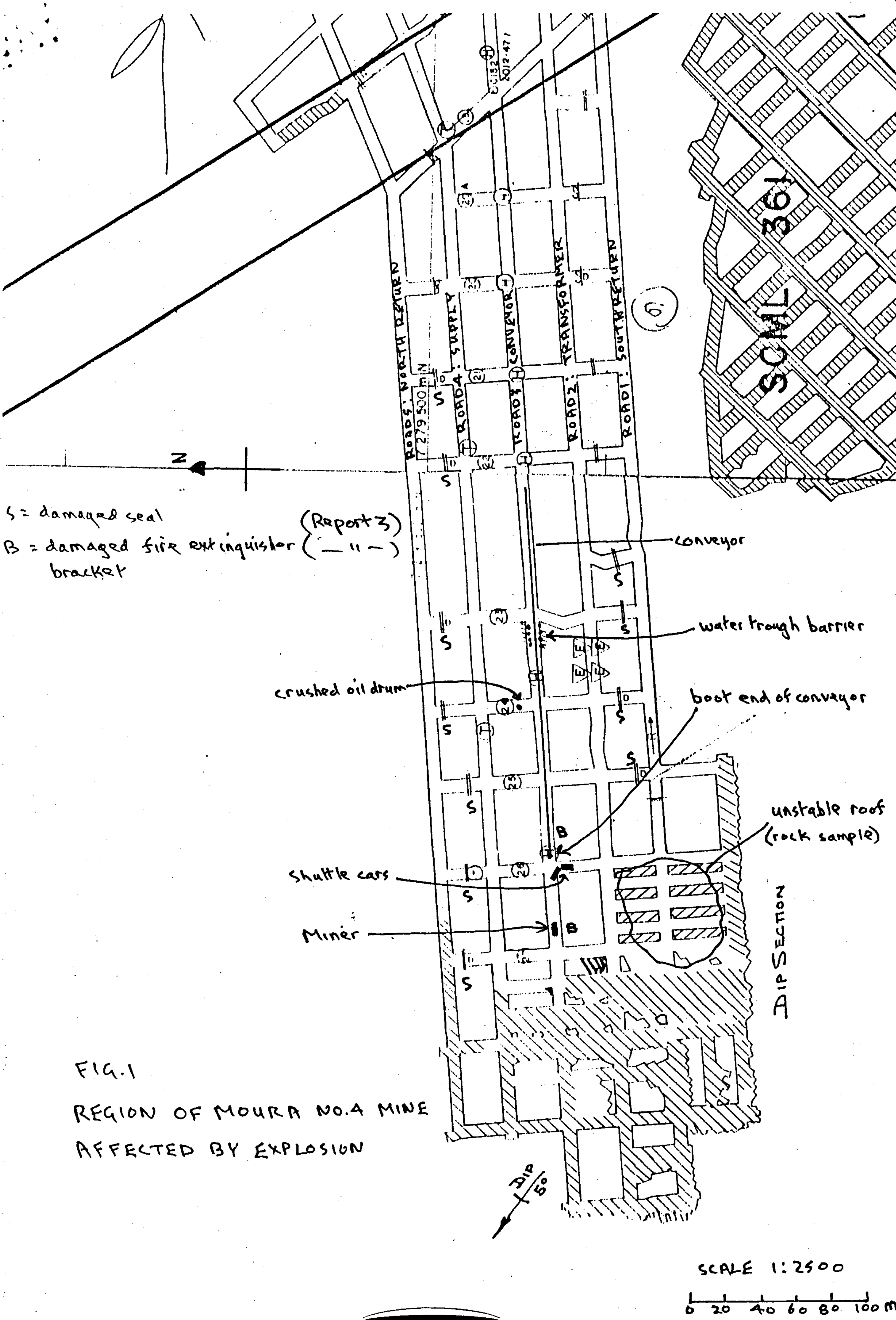

FIG. 1

REGION OF MOURA NO. 4 MINE AFFECTED BY EXPLOSION