SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

DRAFT

Final Project Report

Title: AN INVESTIGATION INTO THE ACCESSIBILITY OF THE SEISMICALLY ACTIVE FAULT PLANE IN WHICH TO PERFORM CONTROLLED FAULT SLIP

Author/s: O D Goldbach

Research Agency: CSIR: Division of Mining Technology

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SUMMARY

Continued research into the feasibility of pro-actively de-stressing seismically hazardous faults through the injection of propellant initiated gas is being questioned by the SIMRAC committee in terms of the practical implementation of such a technique in the field. Specifically, concerns exist about the accessibility of geological discontinuities targeted for de-stressing.

This report presents examples of possible field scenarios in which the proposed technique may be practically implemented in scattered, longwall and sequential grid mining environments.

CONTENTS

1 INTRODUCTION

The CSIR Division of Mining Technology has been actively investigating pro-active rockburst control techniques for a number of years (Lightfoot et. al, 1994, 1995, 1996a, 1996b). This has been necessary because rockbursts are responsible for an unacceptably high percentage of fatalities (approximately one fatality per tonne of gold produced), injuries and severe disruptions to production on South African Gold Mines.

Broadly speaking, rockbursts may be categorized into facebursts and rockbursts resulting from slip on existing geological discontinuities. Analysing the statistics reported in the Miningtek fatality database in terms of these two categories puts the relative fatality numbers into perspective (see figure 1).

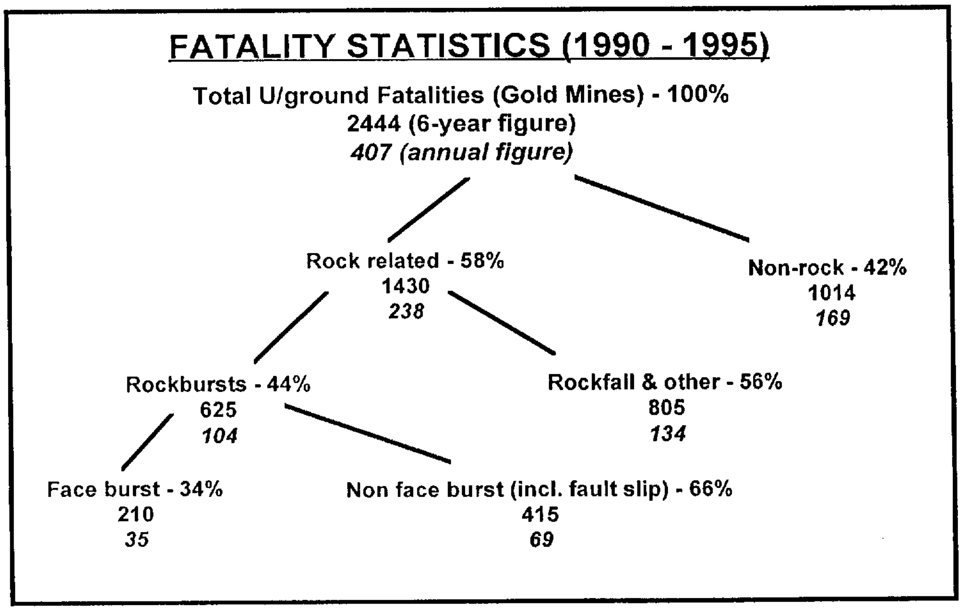


Figure 1: Underground fatality statistics on South African gold mines.

Figure 1 shows that approximately 104 fatalities occur per annum due to rockbursts on South African gold mines. Approximately 34 percent of these can be directly attributed to facebursting. Extracting fatality data due to slip on geological discontinuities is more difficult, as such structural evidence is not specifically recorded on the accident report form, unless slip was observed on fault exposures or was recorded by a seismic network. Therefore, one can infer that rockburst fatalities due to slip on geological discontinuities fall into the 'non face burst' category which comprises 66 percent of all rockburst fatalities. However, specific mention of structural involvement in the 'non face burst' category was made in 22 cases over the six year period 1990 to 1995.

Furthermore, an analysis by Lenhard (1988) of major seismic events (M>3) that occurred over a two year period in a deep level mine in the Carletonville district showed that the majority of seismic activity is directly related to the presence of geological structures (see figure 2).

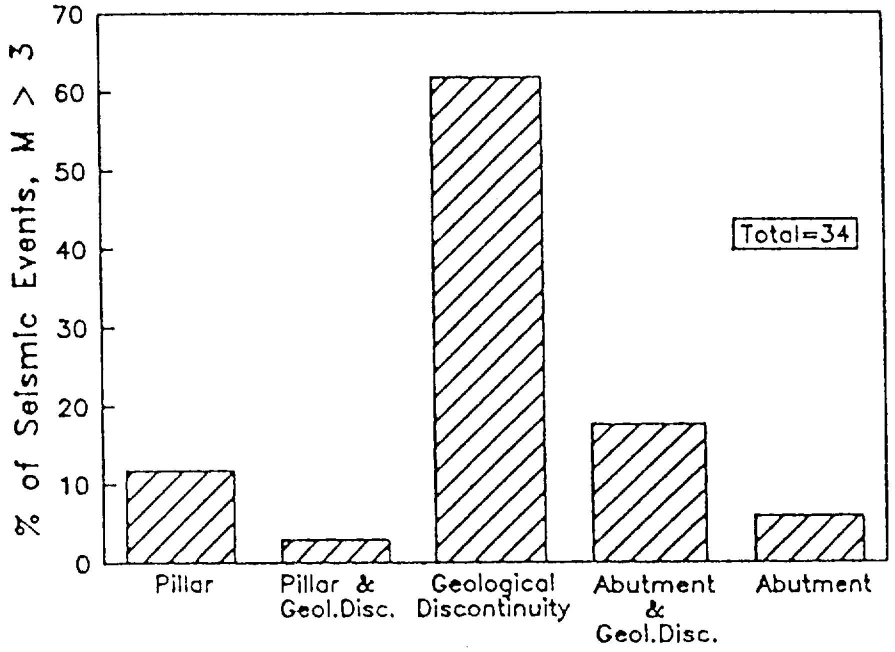


Figure 2: Large seismic events (M>3) for a two year period and where they occurred.

The hazard posed by violent slip on such structures should, therefore, not be underestimated. In fact, it is evident that fault slip (and poor hangingwall conditions close to geological structures) are a major concern on South African gold mines since many geological structures are bracketed with pillars, leaving behind strips of sterilized ore in the process.

The faceburst problem is being addressed by the face preconditioning method. Even though facebursts are typically small in magnitude (M<2) and result in local damage, their impact on fatality statistics is significant due to the relatively large concentration of workers in the face area of a stope. Rockbursts as a result of slip on geological discontinuities, on the other hand, can also result in many fatalities; such rockbursts are often the result of large magnitude seismic slip events (M>2) leading to widespread damage and consequent injuries and fatalities, even at relatively large distances from the source of slip. As a result, the control of slip on geological discontinuities needs to be addressed in an attempt to ameliorate the rockburst hazard posed by such structures.

The main objective of the Controlled Fault Slip (CFS) project is to develop a rockburst control method that will enable mines to operate in the vicinity of seismically hazardous geological features under reduced risk by decreasing the number and magnitude of damaging seismic slip events.

Until recently, research into CFS has been carried out by Miningtek as the SIMRAC funded GAP030 project (Lightfoot et. al, 1995). Pumping water onto faults in order to induce seismicity was the focus of that work. This approach was shown to be a possible, albeit unviable, way of generating slip events on faults. The induced seismic events were of insufficient magnitude to achieve the required goal, mainly because of the complex nature of natural fault surfaces and because water has been shown to be too viscous to pressurize a large enough area on the fault. Significantly less viscous fluids (by a factor of 10^4), such as high pressure gases pumped onto the fault through the burning of propellants, offer an alternative approach to achieving the goals of CFS. An important consequence of the lower viscosity of gases is that single injection points would be sufficient to pressurise a radius on a fault that is perhaps an order of magnitude larger than is achievable with water.

Although a lot has been learnt from reviewing the literature on the use of propellants in the petrochemical industry as a rock fracturing technique (its main application), the use of propellant gas to mobilize existing fractures has never been tried. Thus, a significant amount of fundamental work is required by way of analytical investigations through (non-trivial) numerical modelling, and by way of empirical studies through laboratory tests in order to establish a sound conceptual technique in a controlled environment. The extension of this work into a scaled-up field programme follows as a natural step.

Work has commenced on the empirical aspects, however, SIMRAC has expressed concerns about the feasibility of ultimately implementing the CFS technique in the field. Specifically, the accessibility of fault planes targeted for gas injection is being questioned. This study has therefore been conducted to address these practical concerns by investigating possible field applications of the CFS technique in various mining environments.

After some initial comments on drilling experience in highly stressed ground and on in-situ fault identification, field examples of fault accessibility will be discussed for scattered, longwall and sequential grid mining environments.

2 DRILLING EXPERIENCE

Although the accessibility of fault planes targeted for propellant gas injection is the main concern raised by SIMRAC, a secondary concern exists about the possibility of being able to drill through highly stressed rock onto targeted fault planes.

The Rockburst Control project team has obtained considerable experience of drilling into high stress ground on both the fluid injection and preconditioning projects.

During the operation of field sites where water was pumped onto faults, the fluid injection experiment required multiple (up to four) wellbores to be drilled into faults targeted for injection (Lightfoot et. al, 1995). Between 60 m and 80 m long boreholes were successfully and accurately drilled through highly stressed rock into the faults. Sites included faults clamped by bracket pillars and faults situated in a shaft pillar remnant mining scenario. All holes were diamond drilled (BX size) and discs, as well as crushed rock fragments, were frequently retrieved from the core barrel. All holes were drilled into the loss area of normal throw faults where high stresses exist and where numerical modelling suggests that the potential for slip is large. Drilling rates varied from 2 m to 12 m per shift with an average of 4 to 5 metres per shift. Typically, drilling was initially quick and slowed down as the fault was approached. This reduction in drilling rate was due to the increased time required for handling longer rod strings as the hole length increased.

The preconditioning technique uses boreholes drilled either parallel or perpendicular to the stope face. Face parallel holes 15 m to 25 m long have been drilled into the stress peak ahead of a stope face at rates of 15 to 20 metres per shift. The hole size is NXCU and it is percussion drilled.

Based on experience, general comments made by drilling crews on both projects include the following:

- percussion drilling may be better than diamond drilling in high stress ground as the high stresses help to break the rock during the hammering action of the percussion bits. However, poorer accuracy is achieved with percussion drilling in terms of orientation, especially in horizontal holes, which may deflect significantly if the holes are longer than 25 metres.
- The problem of drilling in highly stressed ground is not so much the drilling itself, but keeping the holes open. Jumpers should be removed after each shift and holes should be cased once completed to maintain wall integrity.

The flexibility in deciding on optional drilling methods for CFS (percussion vs. diamond) is seen as an advantage. Field trials will establish which method is more suited to CFS. The possibility exists that an initial pilot hole may need to be diamond drilled when accessing a fault targeted for gas injection for the first time, and that subsequent holes drilled onto the same fault could be percussion drilled.

The fact that gas injection would not require closely spaced multiple wellbores to be drilled in order to achieve a large pressure radius (unlike with the water injection project) means that drilling time will be significantly reduced.

The facts presented here indicate that it is possible to drill onto faults through highly stressed rock. The only remaining drilling concern would be to drill into faults in a reasonable time frame and section 4 will address the criteria stipulated for achieving practical accessibility onto faults.

3 FAULT IDENTIFICATION

A further issue worth mentioning before fault accessibility is discussed in detail is the question of in-situ fault identification.

The reason for using diamond drilling in the water injection project was, firstly, for accuracy, as four wellbores were required to intersect the fault plane within 7 m of one another at the end of 80 m long holes. Secondly, the fault could be easily identified from the retrieved core as drilling progressed from footwall quartzites into hangingwall quartzites, straddling the fault.

A second possible method of fault identification would be to design a removable packer system which is installed close to the targeted fault plane in the hole to test whether the fault has been reached. Pressurizing the volume between the packer and the end of the hole with air would lead to a measurable pressure loss due to leak-off into the fault. Furthermore, the degree of pressure loss would give an indication of the effective aperture and gas acceptance of the fault. Details of such a design have not been investigated, but inflatable packers are available for this application. An inflatable packer is suitable for the low pressure (a few MPa) fault identification application proposed here as such a system could be easily moved and removed as the position of the fault is being tested for. The detailed design of a high pressure gas injection system comprising the propellant cartridge(s) and initiation device(s) also still needs to be developed, as such a system will need to be installed close to the position where the fault has been identified in the hole. Whether a similar inflatable packer is effective in sealing the borehole sufficiently under the high injection pressures (> 30 MPa) is one issue that needs to be investigated.

4 FAULT ACCESSIBILITY - FIELD EXAMPLES

In order to ensure that access to fault planes targeted for gas injection takes place in the most practical way, the following criteria were identified:

- Boreholes drilled into the structure (diamond or percussion) should be less than 40 m in length to ensure access in a reasonable time period - at an average drilling rate of 5 metres per shift such holes should be completed within two weeks.
- Up-holes are preferable to down-holes for ease of cleaning and for keeping the fault intersection dry.
- The size of boreholes has not been determined yet as the details of the propellant cartridge design need to be defined first. However, it is anticipated that holes will be less than 100 mm in diameter and that the propellant cartridge(s) will occupy a few metres of the borehole close to the fault intersection.
- Boreholes would be re-used for multiple gas injection for as long as access to the targeted fault remains open and for as long as the fault remains seismically active and requires de-stressing.

This section discusses various possibilities of gaining access to geological discontinuities (including both faults and dykes) in scattered, longwall and sequential grid mining environments. It should be pointed out that the sites presented in this report were identified by the relevant rock mechanics and seismic personnel on the mines as being potential hazards that they would like to have addressed by the propellant injection method. Various scenarios were then investigated as to how to best gain access to these identified structures by drilling into them.

4.1 Scattered Mining Environment

4.1.1 Vaal Reefs

The following mine personnel were consulted at Vaal Reefs:

Mr J. Oelofse - Section Head: North Mine
Mrs S. Trollope - Seismologist
Dr S. Glaser - Project Head: Seismics
Mr H. Esterhuizen - Rock Mechanics Officer: 5 Shaft
Mr J. Van Oord - Strata Control Officer: 5 Shaft

After a brief background introduction about propellant gas injection as a rockburst control method, the discussion revolved around some practical comments from the mine's point of view.

In structurally complex areas within a scattered mining environment, such as at fault/dyke intersections, the mine personnel expressed concern about stresses being transferred onto the dyke, if the intersecting fault is caused to slip as a result of gas injection.

Even though the gas injection method is being researched as a method aimed at inducing slip on any geological discontinuity (including faults and dykes), dykes were seen as probably being less suitable due to their burst potential. If the harder, more brittle (higher elastic modulus) material of dykes is more highly stressed than the surrounding quartzites, they are capable of storing more strain energy and would therefore have a potential to burst, rather than to slip. However, bursting will normally only occur under conditions of low confinement; at tens of metres into the solid, a dyke (or its contact with the country rock) will slip, rather than burst. The gas injection technique, therefore, has potential applications to faults and dykes.

Due to the abundance of seismically hazardous structures in a scattered mining layout, access to targeted slip planes was not perceived to be a problem from either off-reef or on-reef excavations. Seismic coverage, especially in the 5B block is very good, allowing the mine to identify seismic hot-spots to within 30 m in plan. However, a concern was expressed about the possible re-use of wellbores for multiple gas injection if the initial injection initiated slip at the fault/wellbore intersection. Miningtek feels that this should not be a problem, as the fault would still be exposed in the wellbore even after slip has taken place. Since gas would vent from an injection cartridge situated close to the fault intersection without straddling the fault, the gas would still be able to enter the fault. Casing of the wellbore upto the fault intersection should maintain integrity of the borehole walls, even after slip.

In a production scenario the mine identified pillar extraction and secondary ore recovery of island remnants left against geological structures as possible CFS applications. These will be presented below. A further application was suggested in a development scenario: apparently a number of fatalities occur when development is advanced through a dyke or fault. Access to such structures could easily be attained by drilling into the fault from the development end to inject the propellant gas.

5/68S 57E cross-cut (refer to figure 3)
In this pillar extraction example, the Ben Dyke can be accessed for gas injection by drilling 30 m long horizontal holes from the adjacent cross-cut or raise line. This can be done at various points as indicated by crosses on figure 3.

5/70 haulage E (refer to figure 4)
In this example the mine would like to extract two island remnants during a secondary ore recovery phase. The remnants lie between a set of faults. Access to the reef/fault intersections is not possible from 5/70 haulage E as the remnants lie approximately 120 m above this haulage (haulage elevation: -2616 m, reef elevation: -2500 m). In order to establish effective multi-point access to the faults one would have to drill wellbores from the planned raise/travelling way excavations required for the extraction of these blocks of ground.

5/68 E3 58W cross-cut (refer to figure 5)
In this case, another two island remnants planned for secondary extraction abut against the Tribute Dyke. Wellbore access to this dyke may be possible from reef elevation in the old stopes adjacent to the remnants (if they are still open), or else holes can be drilled from the planned cross-cut/raise/travelling way infrastructure required for the extraction of these remnants. In all cases the boreholes would be much shorter than 40 metres.

4.1.2 Hartebeestfontein

The following mine personnel were consulted at Hartebeestfontein:

Mr K. Bosman - Regional Rock Mechanics Officer
Mr N. Els - Rock Mechanics Officer: South
Mr F. Weyers - Rock Mechanics Officer: North
Mr J. Campbell - Senior Strata Control Officer

Discussions here too indicated that the mine was concerned about how various intersecting structures would react in a complicated way if one structure was caused to slip through gas injection. However, enthusiasm was expressed about the possibility of implementing the technique on isolated hazardous structures.

It also became clear that access to hazardous structures identified by the mine was not difficult in the many shaft pillar examples discussed. In fact, multiple access was often possible from various levels within the infrastructure of a shaft pillar.

4 shaft pillar: 22-74 (refer to figure 6)

Two normal throw faults exist in the 4 shaft pillar that is planned for extraction from mid-1999 onwards: one has a throw of between 15 m and 18 m and the other varies between 2 m and 7 m. The mine's plan is to raise and strip along these faults. The mine expects these faults to pose a seismic hazard during the planned extraction and, therefore, these faults have been targeted for the application of CFS by gas injection.

Access to the 15 - 18 m throw fault can be attained from two existing cubbies on 31 haulage W. Reef/fault intersection is at -740 m and the elevation of 31 haulage W is at -709 m; therefore, down-holes approximately 30 m long can be drilled to gain access to the fault.

Similarly, the 2 - 7 m throw fault is accessible from two cross-cuts which are at an elevation of -710 m. Reef/fault intersection is at -705 m to -700 m; therefore, 5 m to 10 m long up-holes need to be drilled to gain access to the fault.

Alternatively, drilling into either of these two faults may be supplemented by on-reef drilling from the advancing panels of either short (less than 10 m in length), horizontal holes, or holes that are angled upwards into the region of positive excess shear stress (ESS).

4 shaft pillar: 21-74 DF4 - dyke/fault intersection (refer to figure 7)

Even though reasonable access is possible to these structures. It was felt that this field example was too structurally complex to be used as a research CFS application.

4 shaft pillar: 30 haulage E (refer to figure 8)

Five possible CFS access points exist from twin 30 haulages E, 29 haulage S and from 29 RAW S into a 10 m throw fault. This fault is expected to become seismically hazardous when the extraction of 4 shaft pillar commences in mid-1999. The haulage elevations vary from -620 m to -660 m; with the reef/fault intersection at -665 m this means that 5 m to 45 m long down-holes would be required to gain access to the fault.

4A sub-shaft pillar: 21-75 (refer to figures 9a and 9b)

Further extraction is planned for the 4A sub-shaft pillar. A large normal throw fault from adjacent Vaal Reefs splits into two 90 m throw faults on Hartebeestfontein. The mine is concerned about these two faults as the main fault on Vaal Reefs apparently has a significant seismic history; however, the seismicity stops at 4A sub-shaft on Hartebeestfontein. The reasons for this are unknown, but questions being asked are:

- Does the seismic gap occur as a result of the fault splitting in two?

- Does the seismic gap occur due to the presence of the 4A sub-shaft pillar?
- Does the pillar's clamping effect cause the fault to build up strain energy, i.e. is the observed seismic quiescence good or bad?

The overriding question, however, is what will happen to these faults once mining of the pillar commences? If seismicity needs to be pro-actively released, then these two faults were identified by the mine as possible sites to perform CFS by gas injection.

Access through drillhole intersections with these two faults was investigated and multi-point accessibility was shown to be possible. Five access sites were identified for each of the two faults (indicated by crosses on figures 9a and 9b) using horizontal holes, up-holes and down-holes ranging from less than 10 m to 40 m in length, and drilled from a travelling way, haulages or a return airway as shown on the plan.

6 shaft/7 shaft: 25-74 deep block (refer to figures 10a and 10b)
In the planned mining of the deep block the mine would like to strip against the 100 m to 120 m throw fault without leaving a pillar. Pro-active rockburst control through the incremental release of stored strain energy would have to performed on the fault during mining. Drillhole access to the fault for the purpose of gas injection is currently possible from various planned and existing cross-cuts, travelling ways and raises. In the case of travelling ways and raises, access is possible via horizontal holes from reef elevation and in the case of cross-cuts, access is possible via up-holes. In all cases, hole lengths would be less than 30 metres.

2A sub-shaft pillar: 20-72 (refer to figure 11)
The 27 Dyke and adjacent 20 m throw fault are expected to become seismically hazardous during the planned extraction of the 2A sub-shaft pillar. Various access points are possible onto these structures from haulages, cross-cuts and reef drives as indicated by the crosses shown on figure 11. In all cases hole lengths would be less than 25 metres.

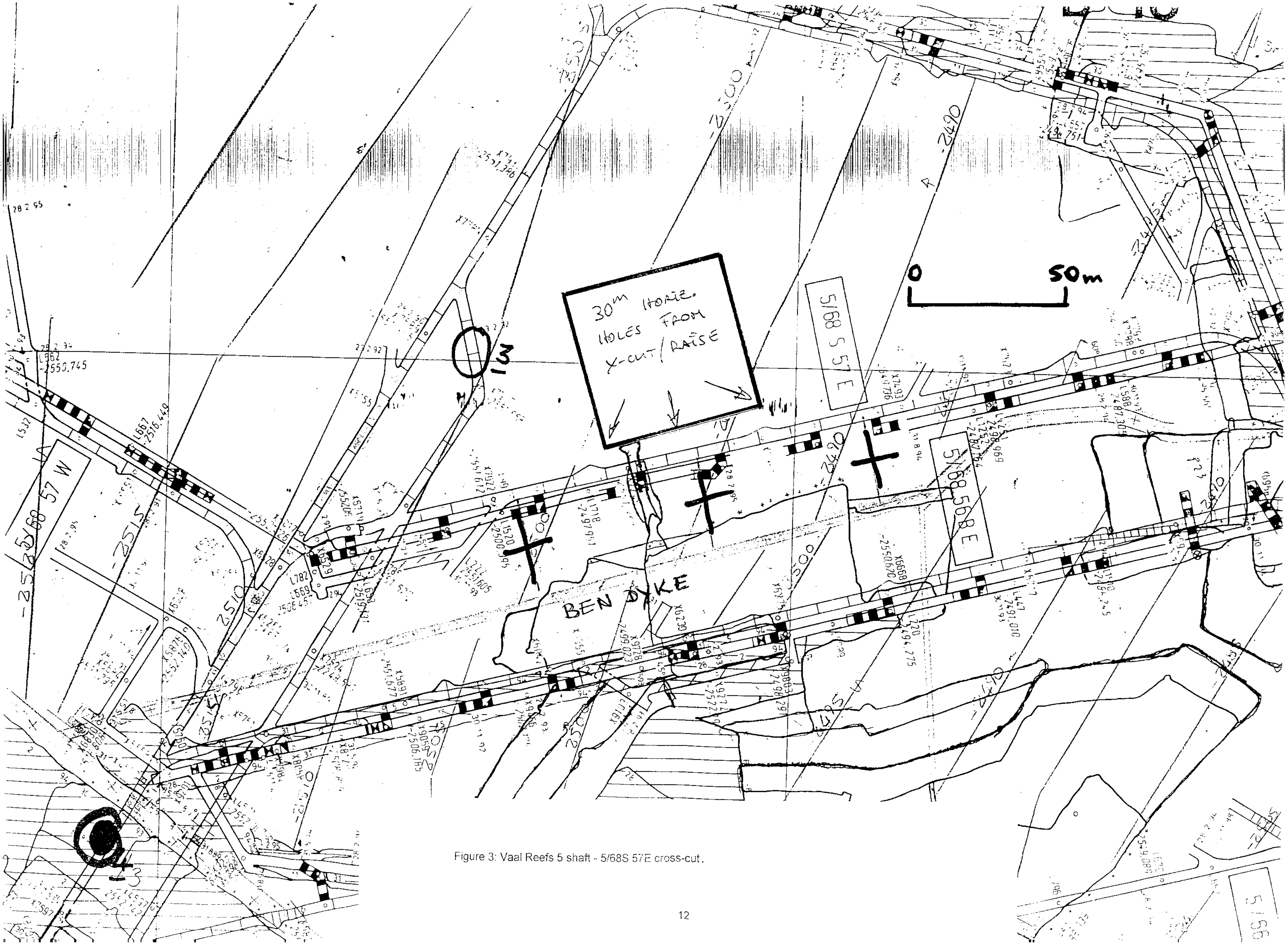
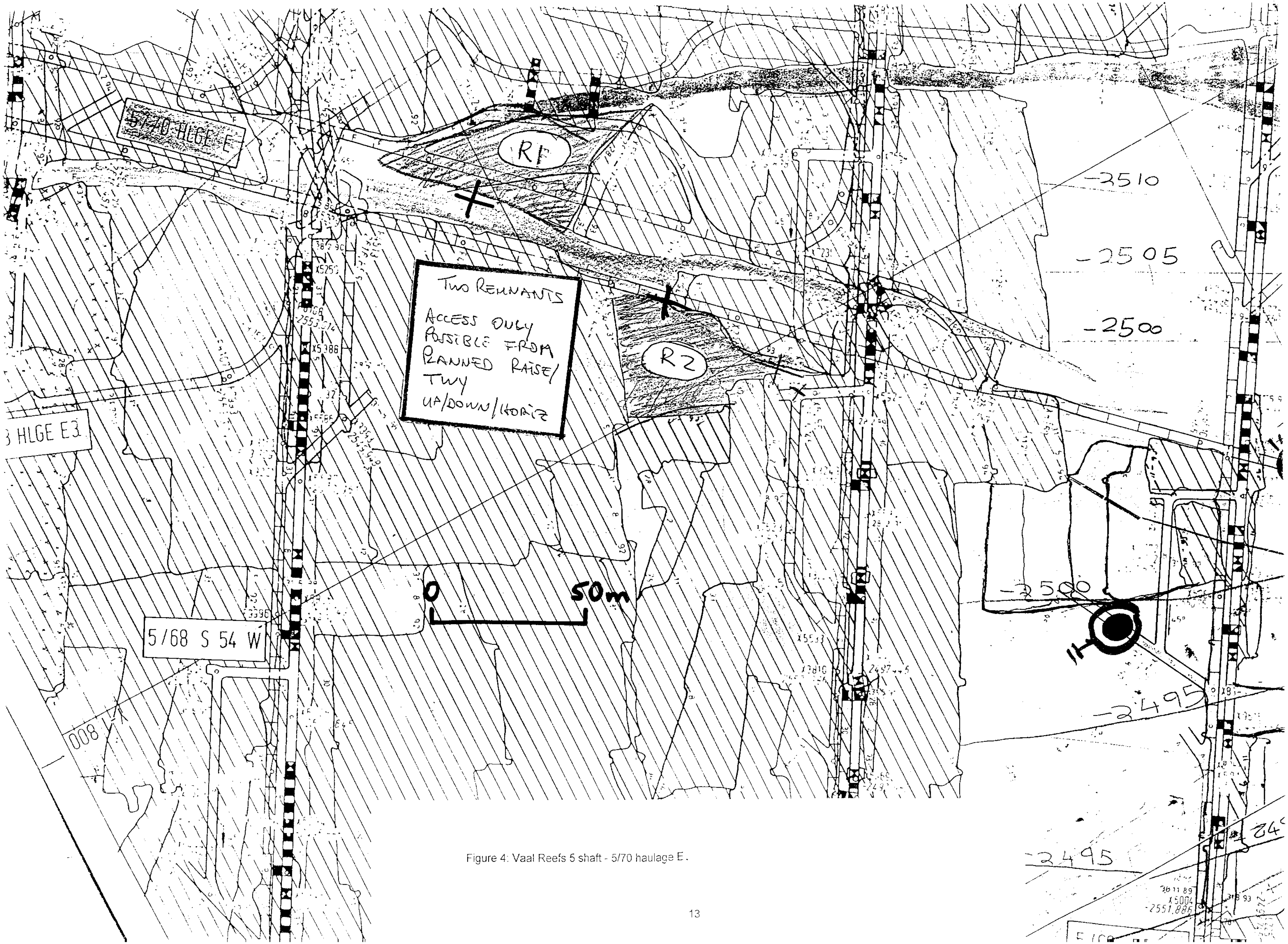


Figure 3: Vaal Reefs 5 shaft - 5/68S 57E cross-cut.



TWO REMNANTS

ACCESS ONLY POSSIBLE FROM PLANNED RAISE/TWY UP/DOWN/HORIZ

Figure 4: Vaal Reefs 5 shaft - 5/70 haulage E.

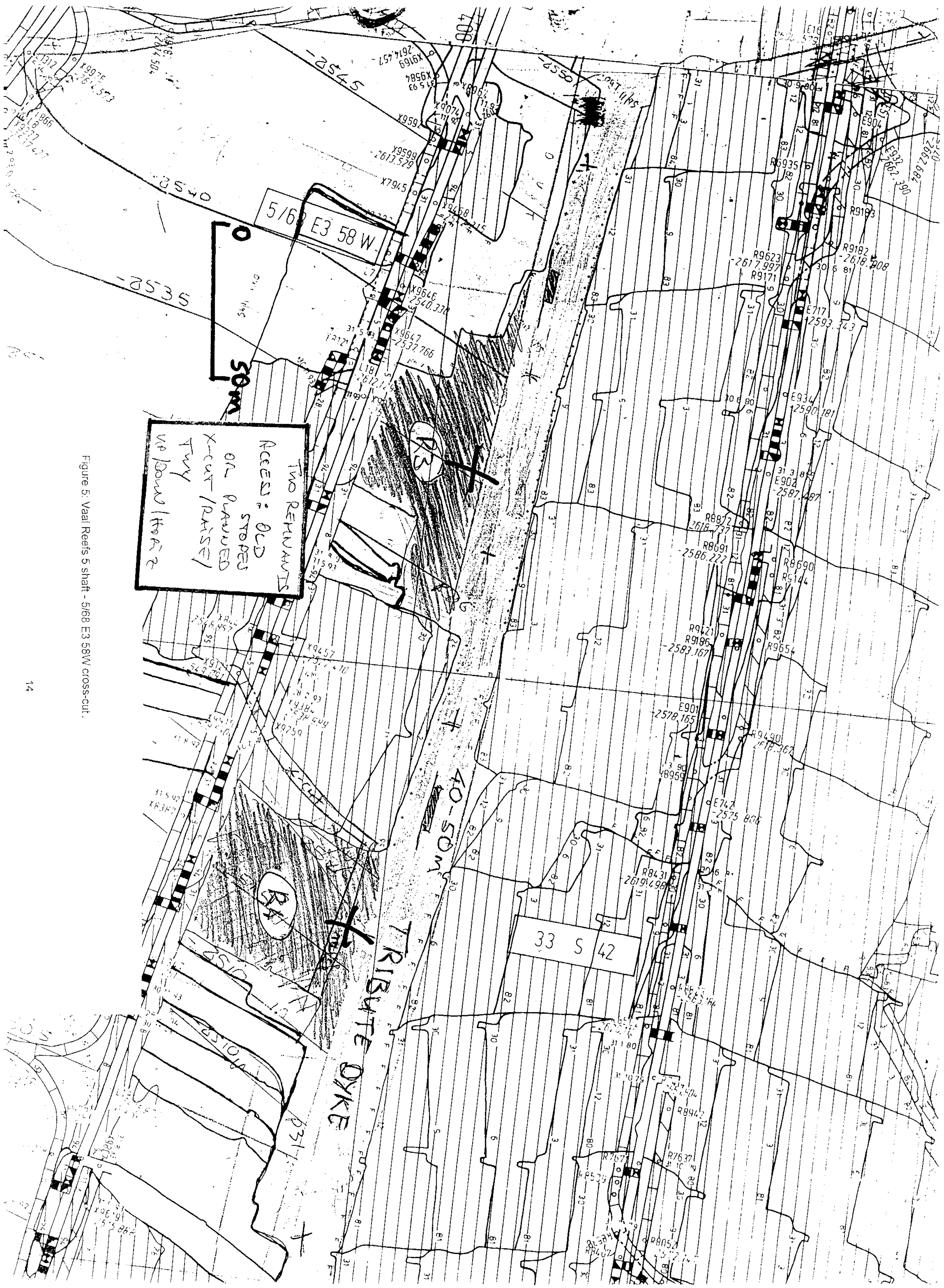


Figure 5. Vaal Reefs 5 shaft - 5/68 E3 58W cross-cut.

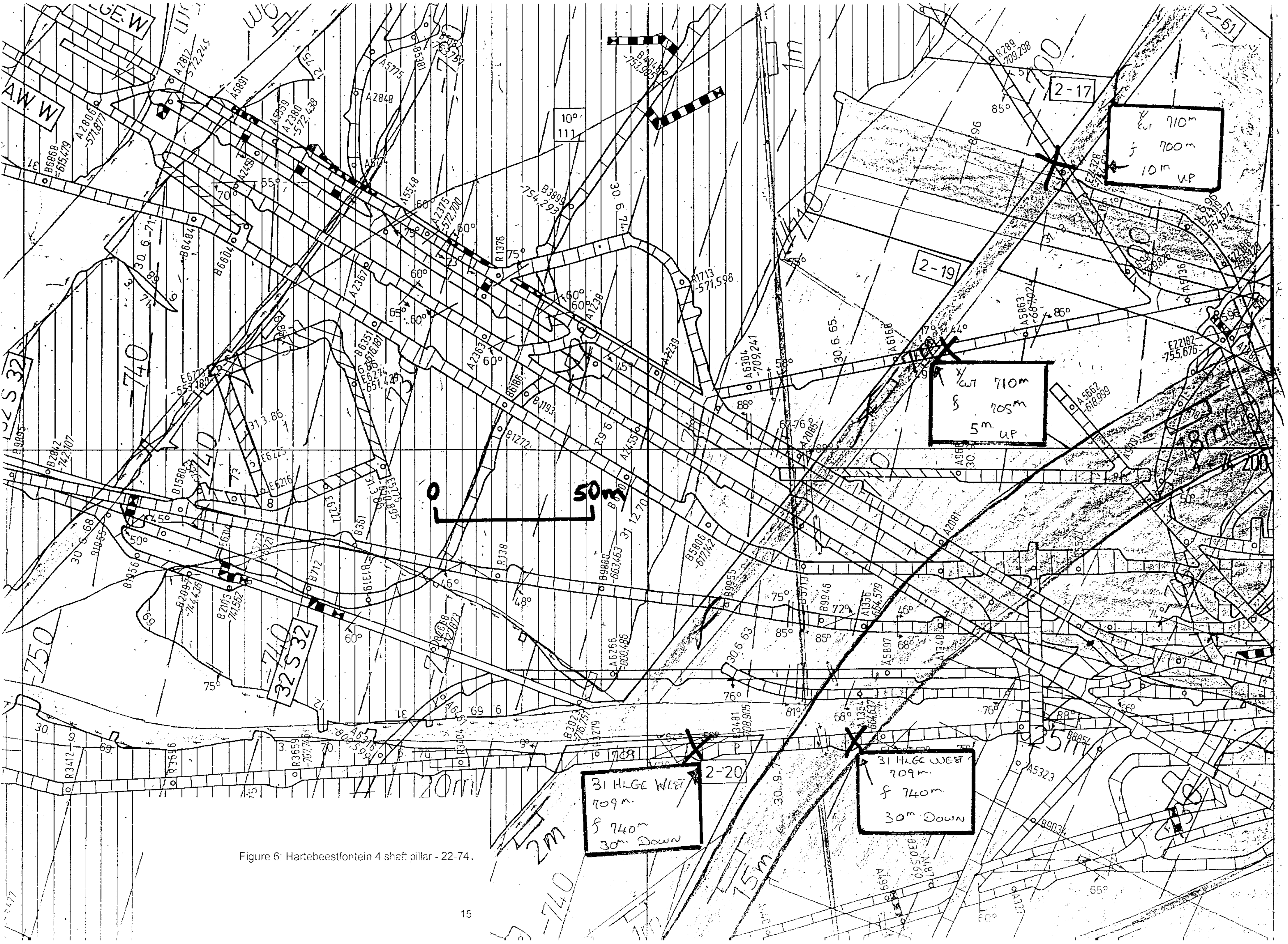


Figure 6: Hartebeestfontein 4 shaft pillar - 22-74.

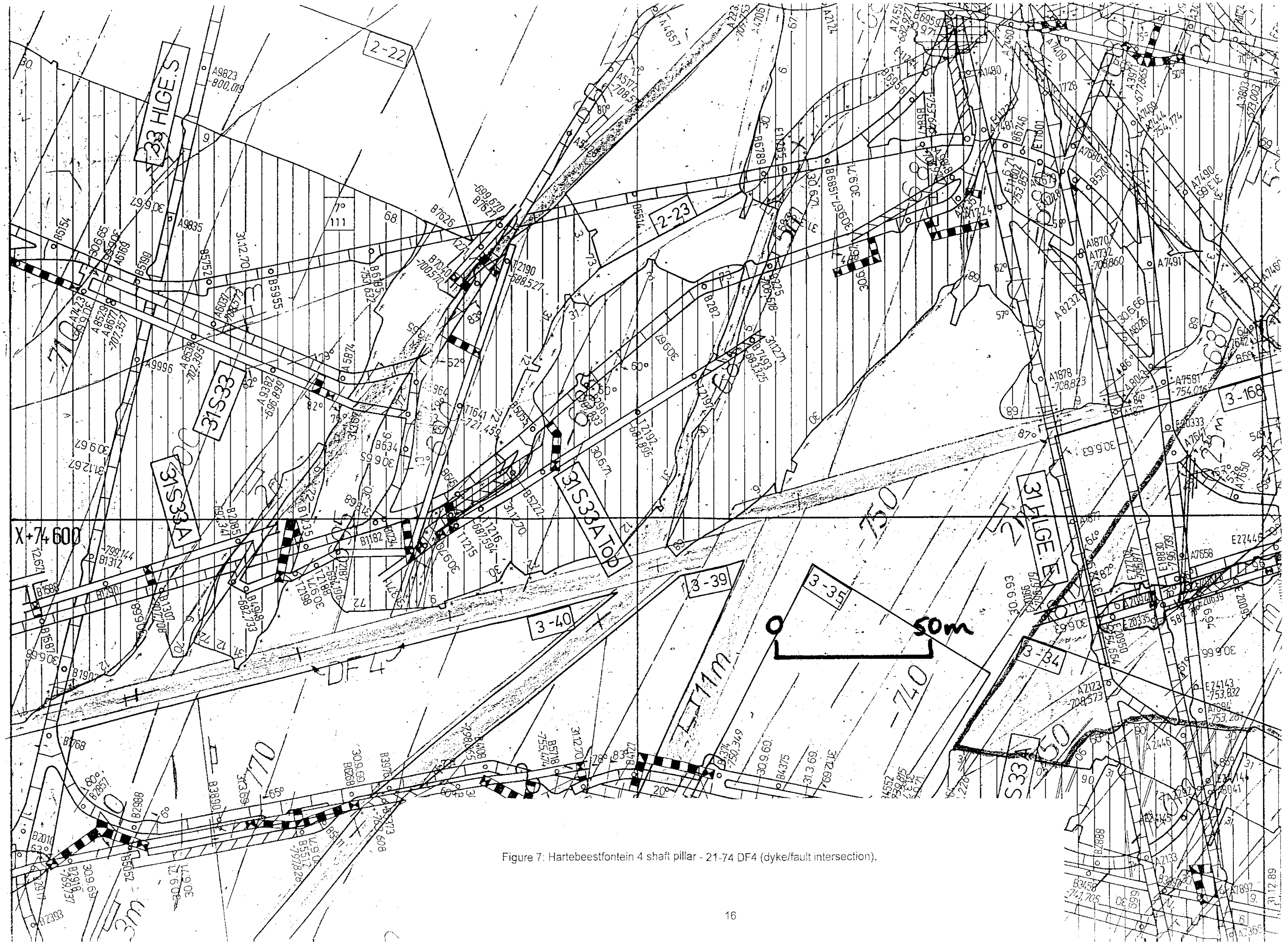


Figure 7: Hartebeestfontein 4 shaft pillar - 21-74 DF4 (dyke/fault intersection).

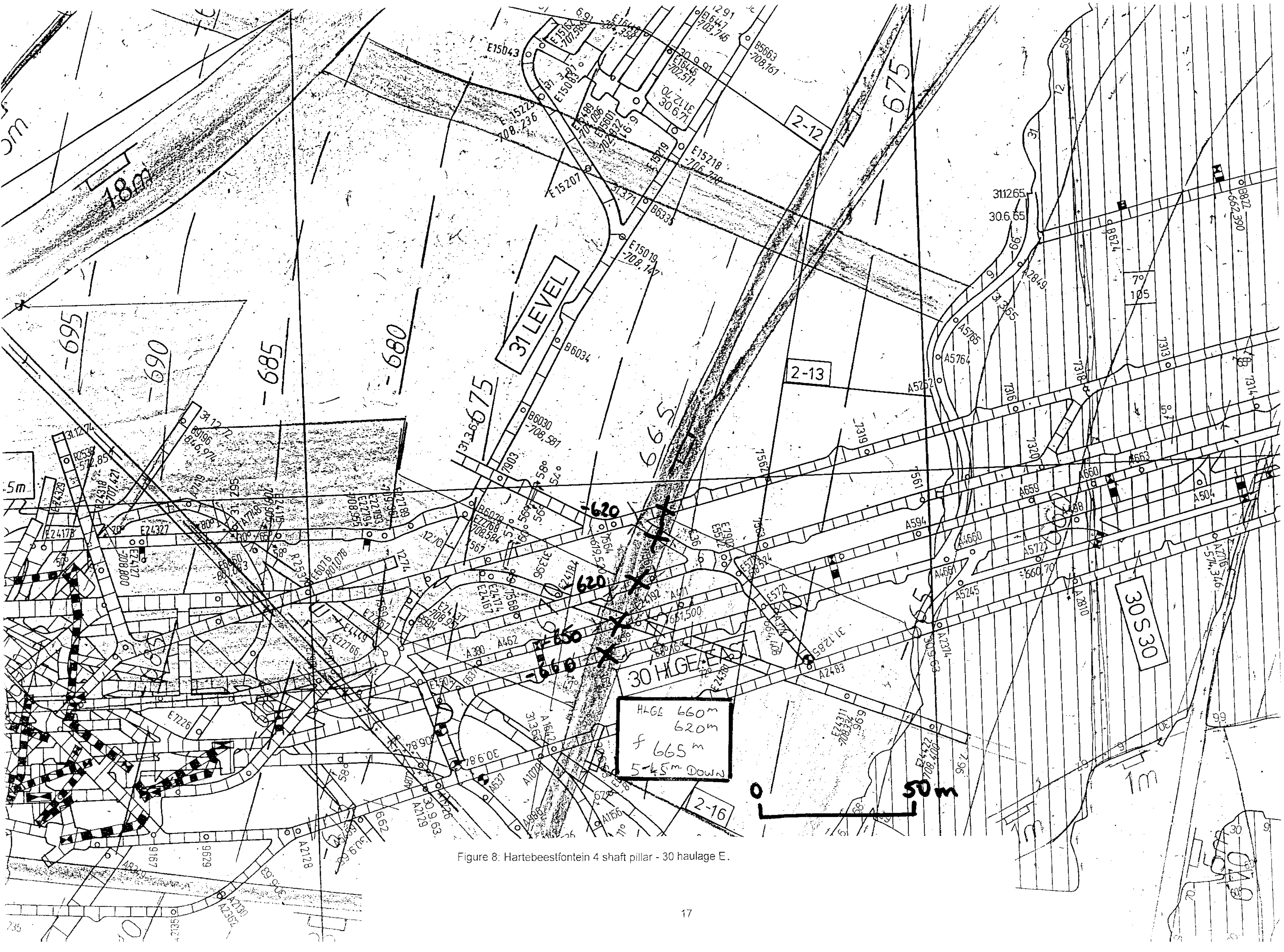


Figure 8: Hartebeestfontein 4 shaft pillar - 30 haulage E.

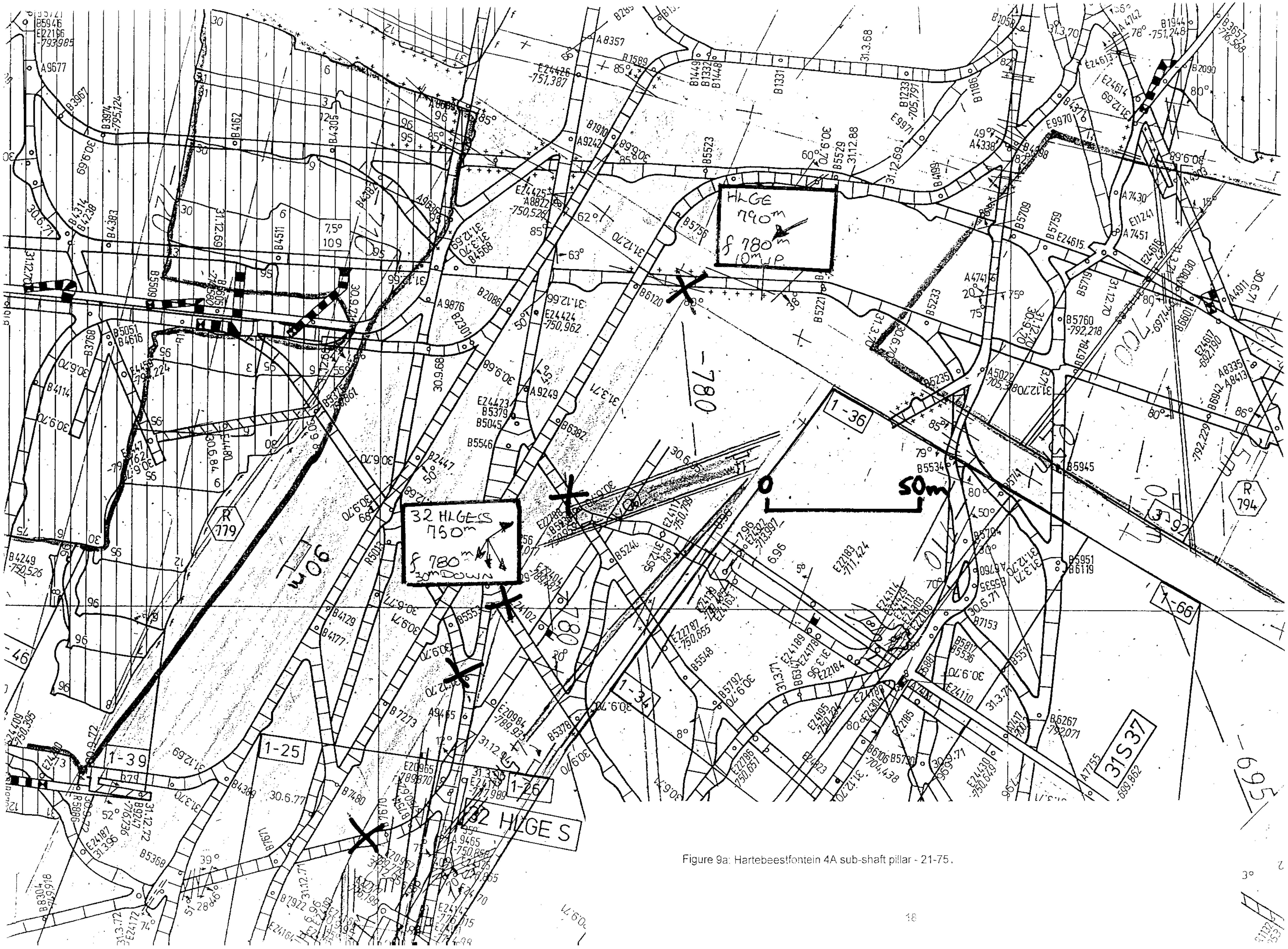


Figure 9a: Hartebeestfontein 4A sub-shaft pillar - 21-75.

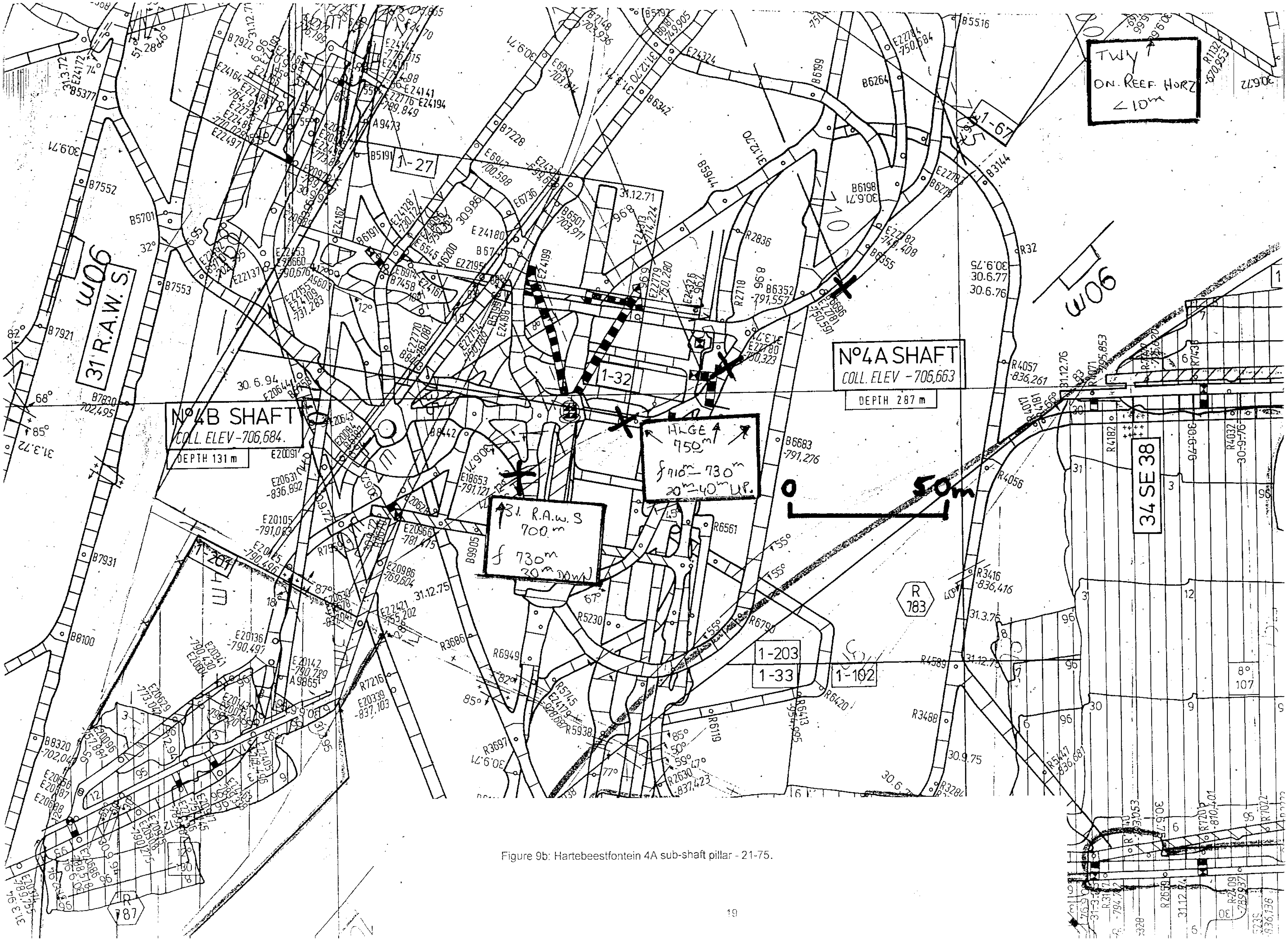
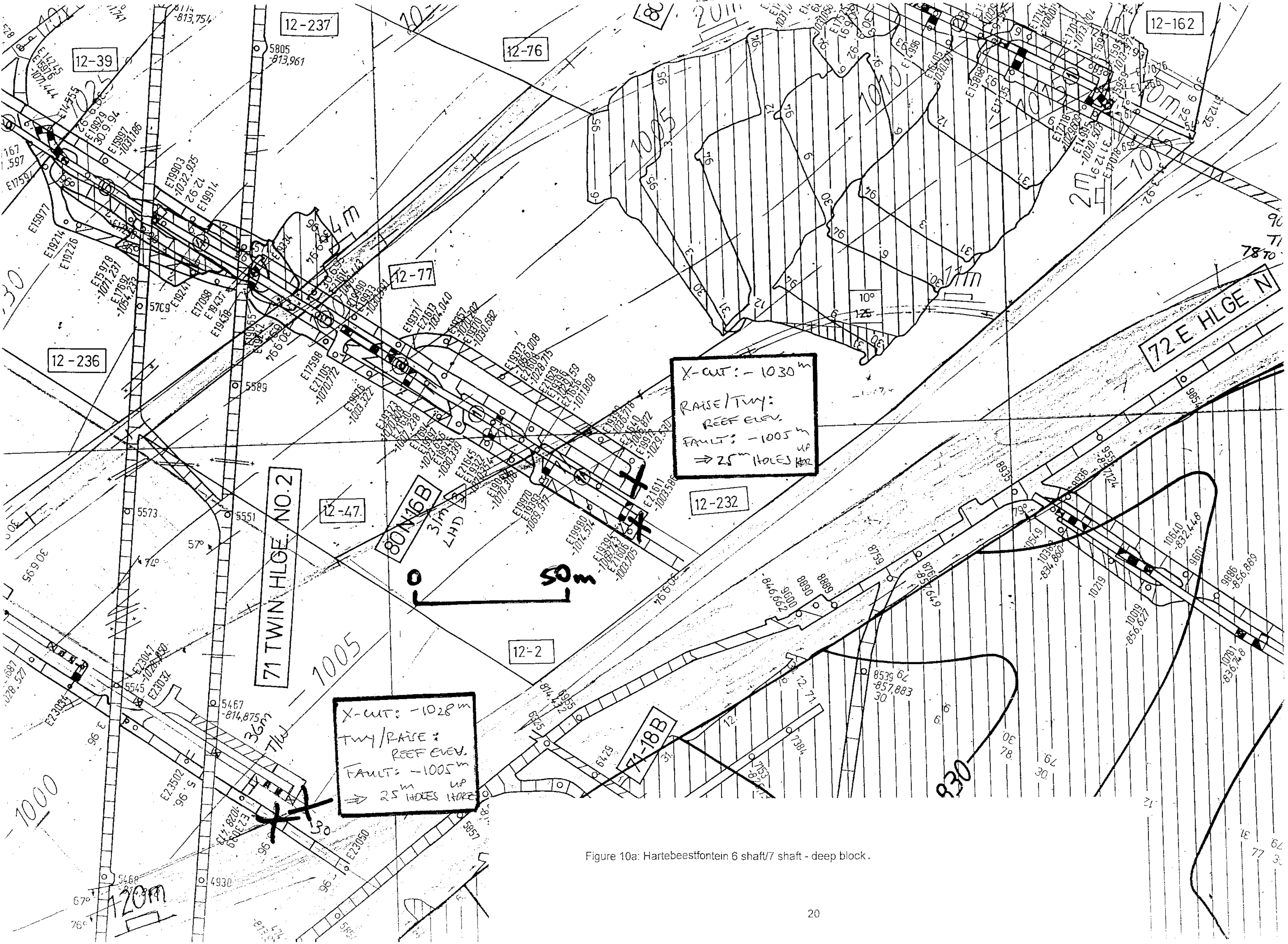


Figure 9b: Hartebeestfontein 4A sub-shaft pillar - 21-75.



X-CUT: -1030m
RAISE/TWY: REEF ELEV.
FAULT: -1005m
⇒ 25m HOLES UP HORZ

X-CUT: -1028m
TWY/RAISE: REEF ELEV.
FAULT: -1005m
⇒ 25m HOLES UP HORZ

Figure 10a: Hartebeestfontein 6 shaft/7 shaft - deep block.

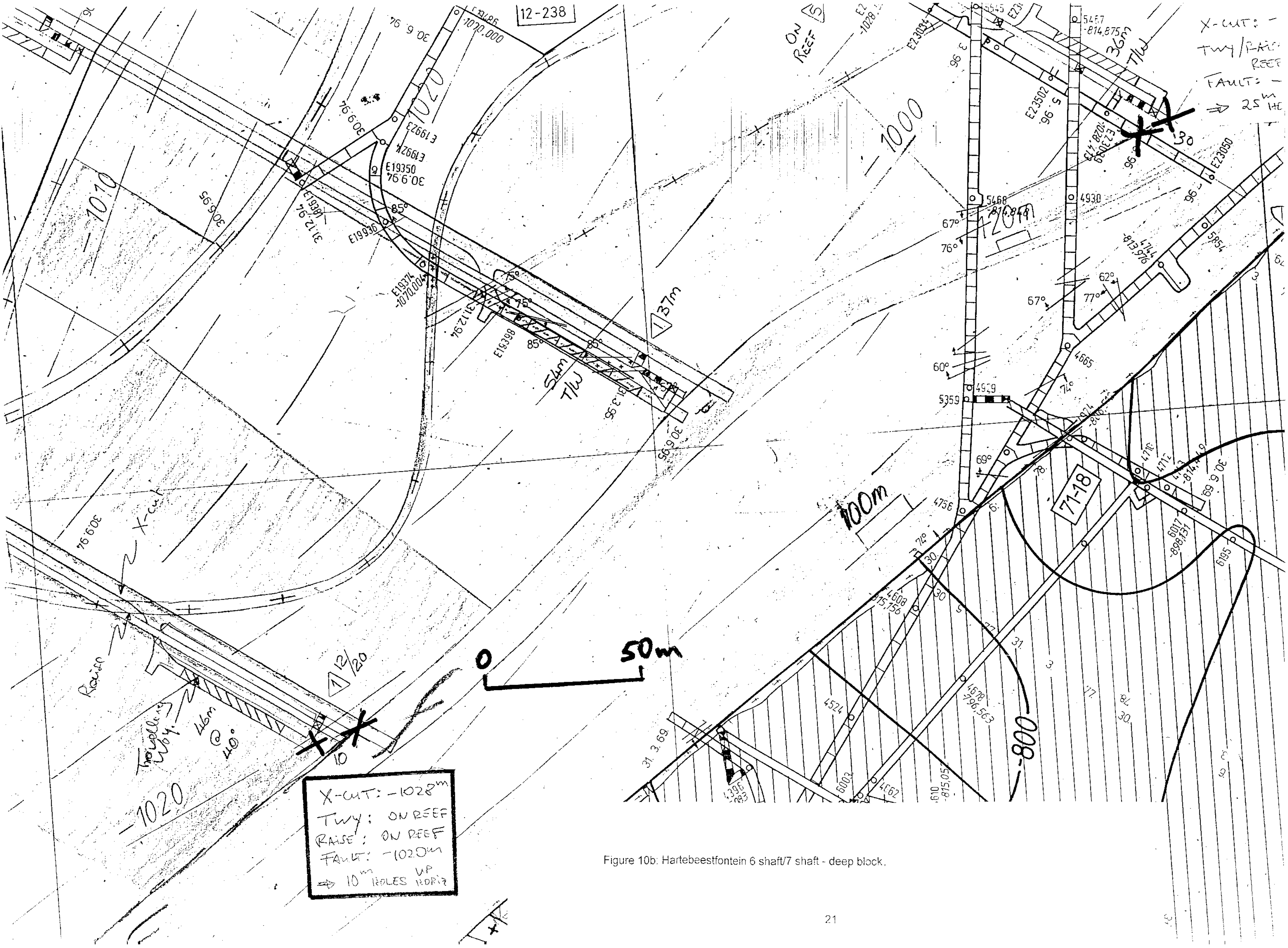


Figure 10b: Hartebeestfontein 6 shaft/7 shaft - deep block.

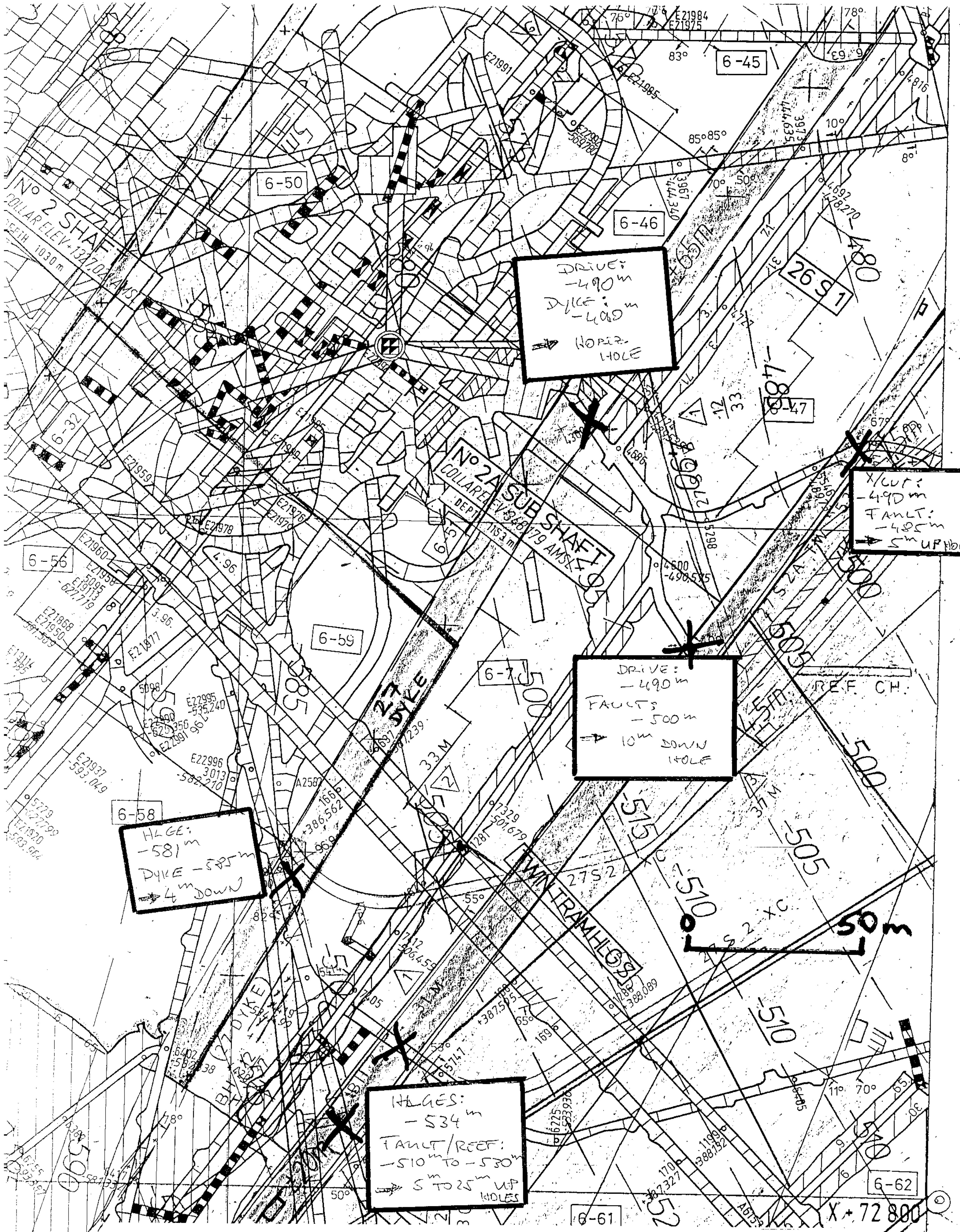


Figure 11: Hartebeestfontein 2A sub-shaft pillar - 20-72.

4.2 Longwall Mining Environment

4.2.1 Western Deep Levels (E and W)

The following mine personnel were consulted at Western Deep Levels:

Dr T. Hagan - Regional Head: Rock Mechanics
Mr S. Murphy - Section Head: Rock Mechanics (E Mine)
Mr R. Van Eck - Section Head: Rock Mechanics (W Mine)

It was interesting to note how the nature of the discussions around the CFS technique was different at Western Deep Levels compared to a scattered mining layout. I will discuss a few specific comments made by the mine personnel in this regard before presenting specific accessibility cases.

The mine personnel questioned whether one would be able to drill holes quickly enough to perform gas injection on structures identified as being seismically hazardous. This is because seismic observations have indicated a rapid stress build-up which may be released in a large seismic event within a week (too quickly to drill CFS holes and de-stress). However, the observed patterns of repeated build-up and release of seismic energy on the same structure will actually help in performing gas injection as effectively as possible, as the seismic trends can be used to "predict" when the next seismic cycle commences. Once the boreholes have been drilled, injection of the gas can be timed to de-stress the fault before the next rockburst is expected.

Furthermore, access to seismically active structures is not as easy in a longwall mining environment as it is in a scattered mining layout, as damaging seismicity often occurs 70 m to 100 m away from the nearest development or stoping. An example was given by the mine where a longwall approaching a structure may experience a rockburst due to slip on the structure up to 100 m away. On the other hand, a panel may only bump when it mines through the structure. Drilling into a fault from reef elevation was also not considered to be ideal as seismicity on faults often occurs 70 m in the footwall (see example later).

The seismic energy index was considered to be a suitable parameter to use in identifying geological structures which become hazardous.

The mine also indicated that development in virgin ground may be a possible CFS application. Seismic outbursting is sometimes experienced as one develops through a dyke. Further discussion with my colleagues at Miningtek have cautioned against this application of CFS as the seismic mechanism in such a development scenario is not well understood. Seismic moment tensor analyses suggest that a significant volumetric component occurs at the source, in addition to a deviatoric component, and the gas injection technique may initially only be suitable for slip-type events.

Finally, secondary extraction of bracket pillars was not practical on Western Deep Levels and pro-active de-stressing using gas injection for this purpose was, therefore, not an application in their longwall mining scenario. In fact, most bracket pillars operate in a dual role as stability pillars, which are not mined.

West Mine (refer to figure 12)
On West Mine, the rock mechanics personnel identified the Carbon Leader Reef (2 sub- and tertiary) shaft pillar as an area where they would like to apply the gas injection technique. As can be seen from figure 12, the pillar is transected by numerous dykes which may become seismically hazardous during the planned pillar extraction programme. Since seismicity on dykes is more complex and less well understood than seismic events occurring on faults, this scenario is probably not an ideal application for CFS (at least not initially). Access to the dykes, however, is not difficult, as holes may be drilled into the structures from the many haulages and footwall drives existing in the shaft pillar infrastructure. Such holes may be angled up, down or horizontal, depending on where the seismic build-up is that needs to be targeted.

East Mine: lower Carbon Leader, section 332 (refer to figures 13a and 13b)
Comments were made by mine personnel that in the case of a longwall advancing between stability pillars, seismic events (and potential rockbursts) would occur on a fault ahead of the panels, but upto 70 m in the footwall beneath the pillar. This is currently the problem on the Ken Fault and it will be a future problem on the Big Boy East Fault. This situation is shown schematically in figure 14. On-reef access to the seismic hot-spot 70 m below is obviously impractical. Therefore, we propose that a cross-cut needs to be developed from the follow-behind haulage to get close to the instability and to drill injection holes from the cross-cut into the fault (as is shown in figure 14). Such is the severity of this type of rockburst problem that the mine was willing to justify the expense of extending the footwall development into a cross-cut, provided the CFS technique has been shown to work. A concern associated with this approach, however, would be the stability of the cross-cut, which would be subjected to high vertical stress, particularly where it underlies the current face position of the stopes above.

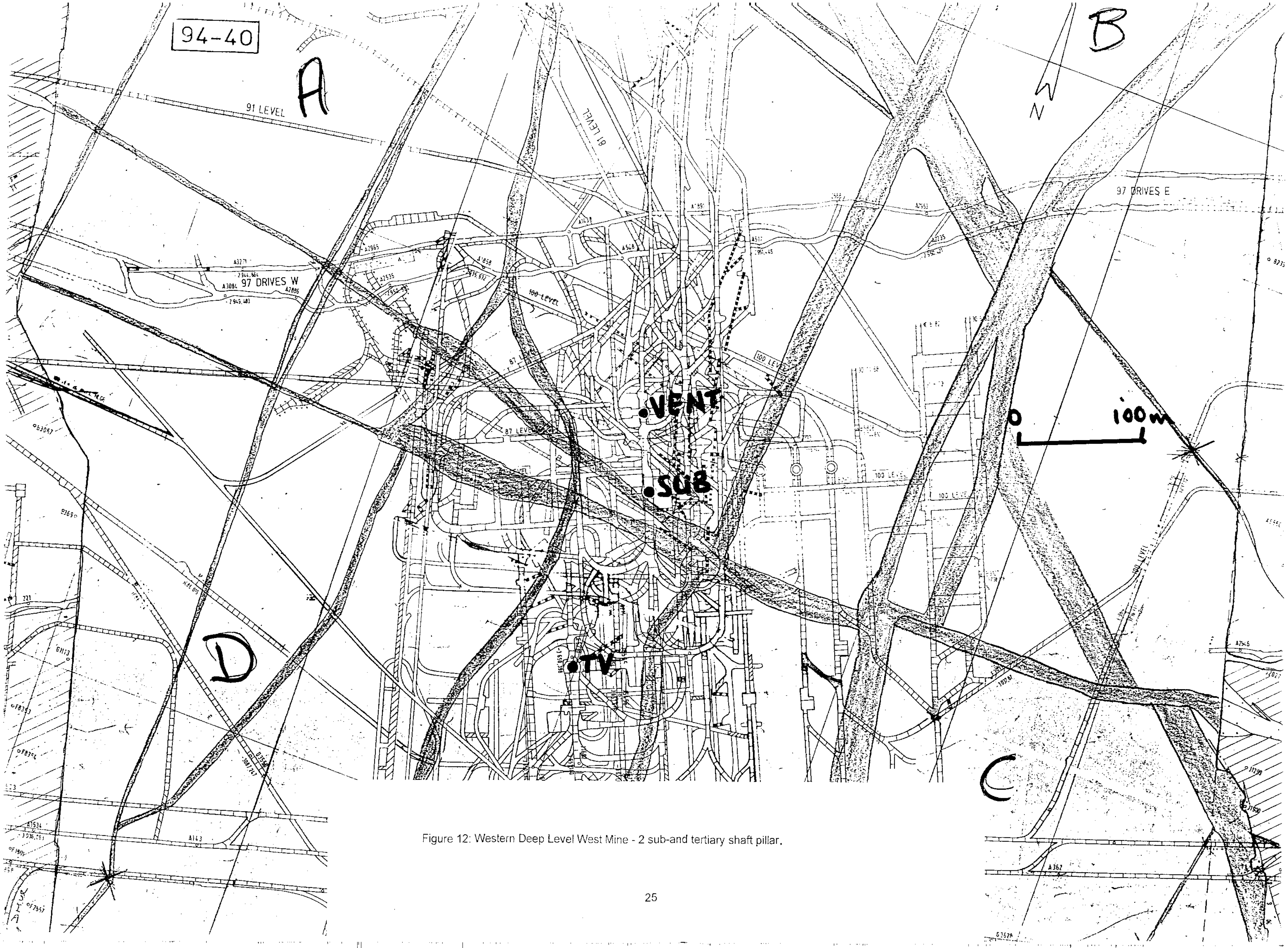


Figure 12: Western Deep Level West Mine - 2 sub-and tertiary shaft pillar.

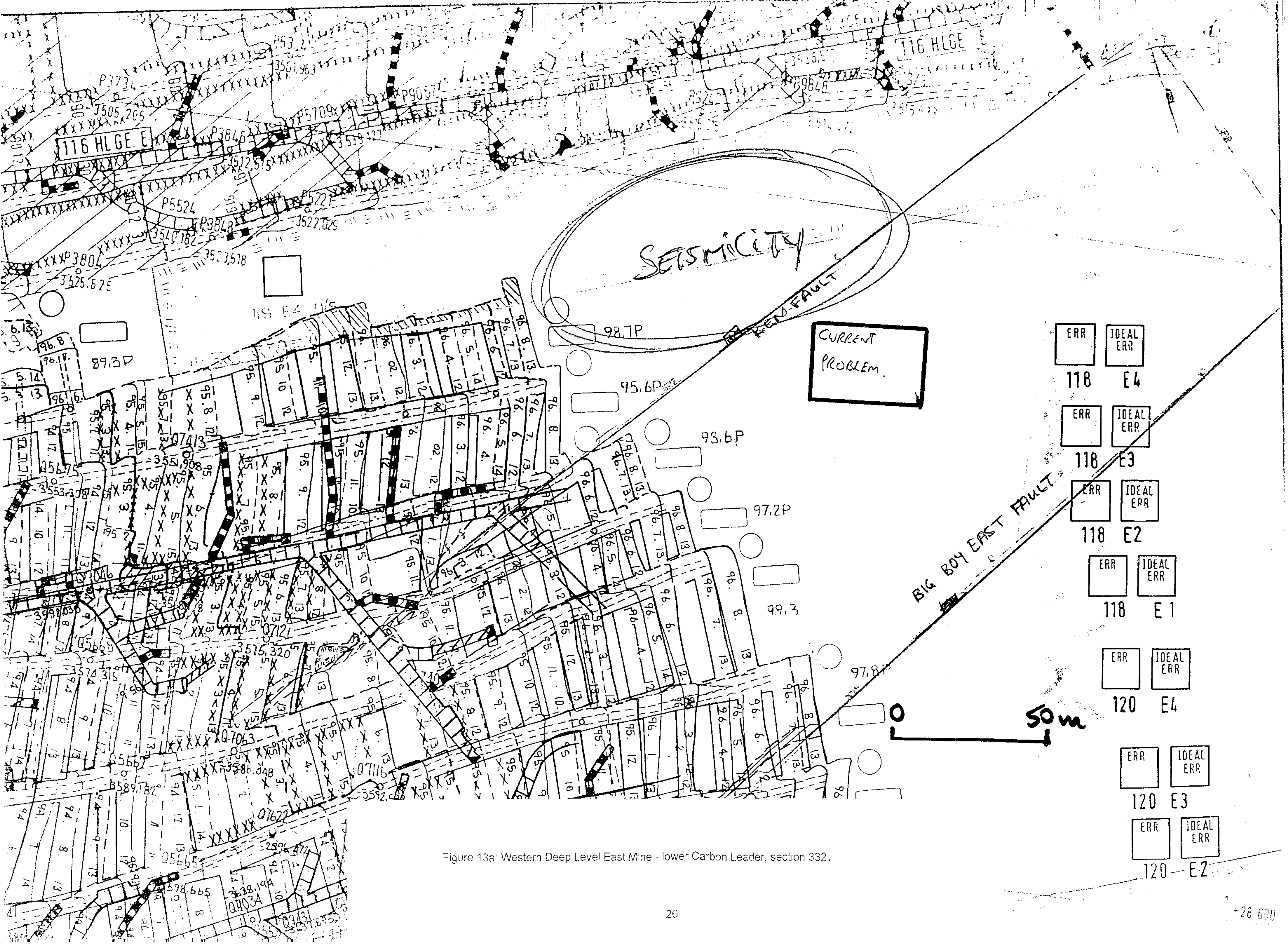


Figure 13a: Western Deep Level East Mine - lower Carbon Leader, section 332.

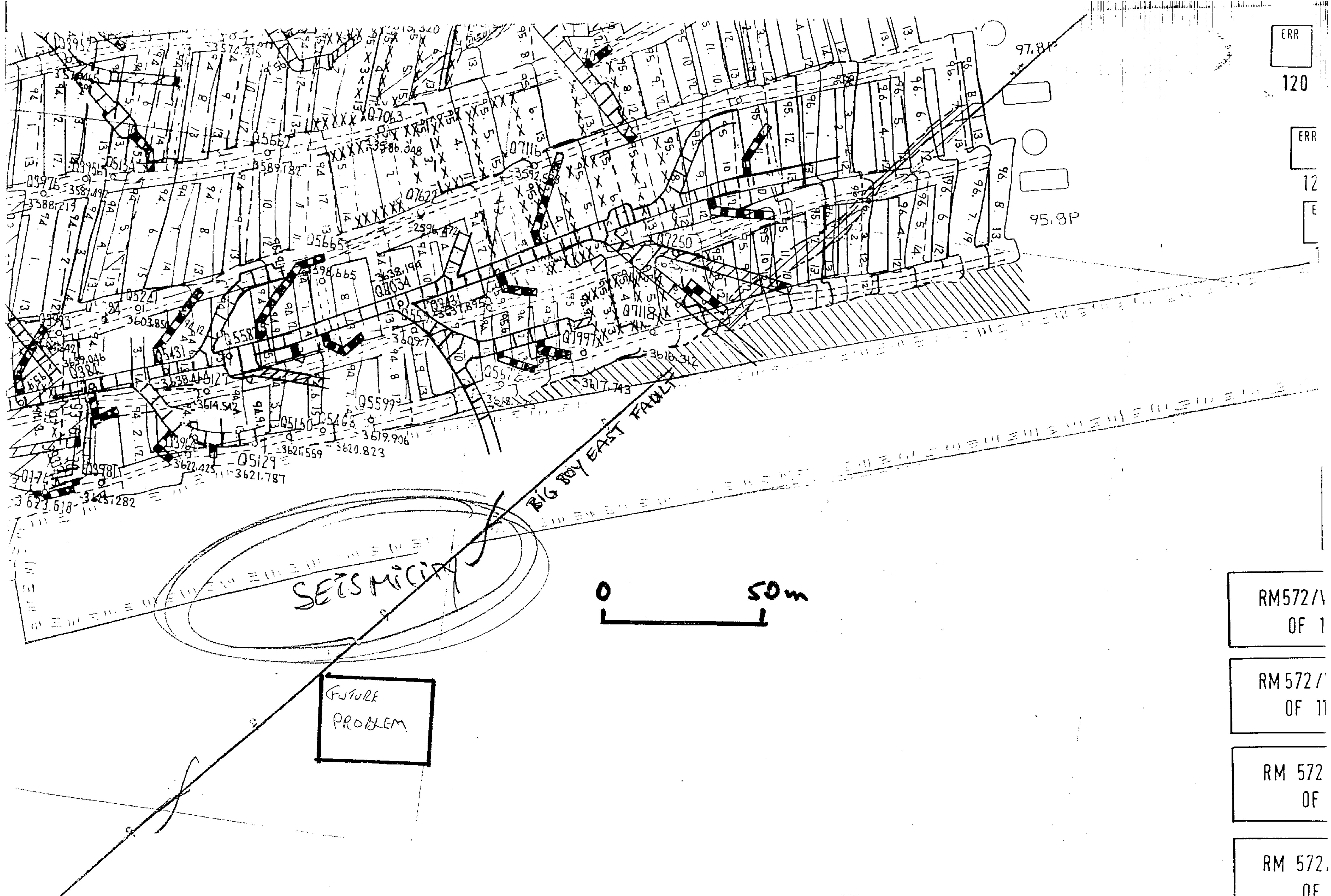


Figure 13b: Western Deep Level East Mine - lower Carbon Leader, section 332.

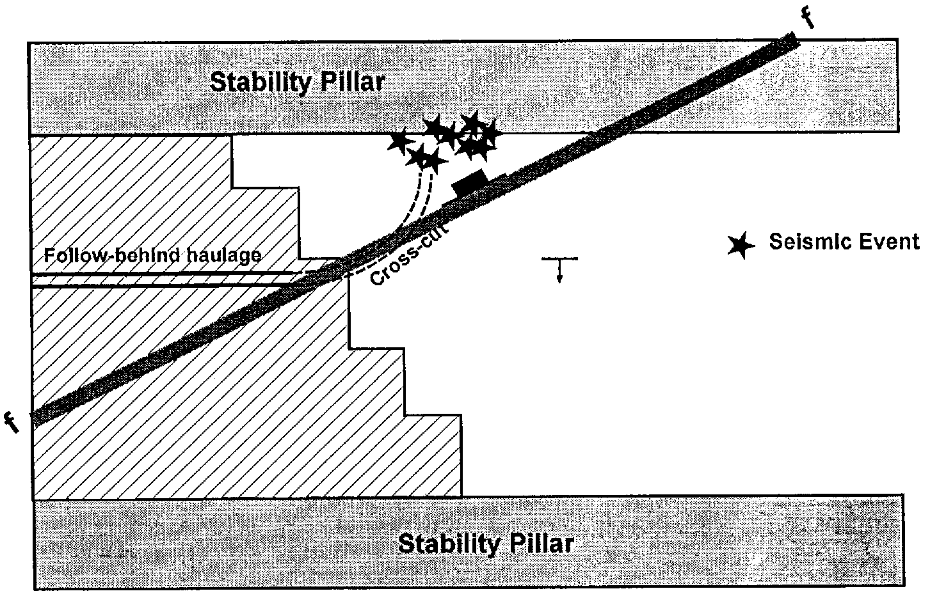


Figure 14: Schematic of a longwall approaching a fault. The observed seismicity locates 70 m below the pillar on the fault. Access to the seismic hot-spot is proposed via a cross-cut extension of the follow-behind haulage.

4.3 Sequential Grid Mining Environment

4.3.1 Elandsrand

The following mine personnel were consulted at Elandsrand:

Mr J. De Lange - Rock Mechanics Officer

The advantage of a sequential grid mining layout is that one has a priori information about geological features from pre-developed cross-cuts and haulages that intersect the features. Access to these features would be possible from the advance development and it can be established well in advance of mining if seismic problems are expected. The fact that the advance development is fully equipped with air, water and tracks and is supported helps accessibility and drilling.

My discussions with the rock mechanics officer indicated that sequential grid mining is a very safe way of mining: geological features are generally not mined through; instead, they are bracketed with unmined ore to create a pillar. These pillars are in addition to regularly spaced 30 m wide dip pillars. Nevertheless, experience has shown that seismicity often occurs 30 m below reef on geological structures when mining takes place close-by. This observation formed the basis for the accessibility examples given below. Seismic "hot-spots" would already be identified during the initial down-dip ledging operations using the seismic energy index. CFS holes would then be drilled during the subsequent period of one to two years before stoping commences in order to actively de-stress the identified "hot-spot" during the stoping operations.

In addition to the de-stressing of geological features when mining takes place close-by, the mine expressed interest in the possibility of using gas injection as a means of dispensing with bracket pillars to increase ore recovery during primary extraction. This is assuming that gas injection was a proven technique.

CAD Dyke - example 1 (refer to figure 15)

If seismicity is expected on the CAD Dyke 30 m below reef, then one can gain access to this "hot-spot" by drilling 40 m long up-holes from the underlying cross-cut.

Van Zyl Fault (refer to figure 16)

Seismicity occurring on the Van Zyl Fault 30 m below reef could be accessed by 10 m to 20 m long up-holes drilled from various cross-cuts as shown in figure 16.

CAD Dyke - example 2 (refer to figure 17)

The limitation of the field example given in figure 15 is that seismicity on the CAD Dyke can only be accessed from a single position in the cross-cut. Figure 17, by contrast, provides an example of how excavations can be developed parallel to geological structures, thus allowing multi-point access into seismic "hot-spots" occurring on the structure. In this example the CAD Dyke can be drilled into at any location from the cross-cut or raise. Holes (less than 40 m in length) would be angled either up, down or horizontal, depending on where the seismic build-up was concentrating. This multi-point accessibility could enable the mine to strip against the dyke without leaving a bracket pillar. If the gas injection technique is proven, this would lead to increased ore recovery, while mining at a reduced level of risk.

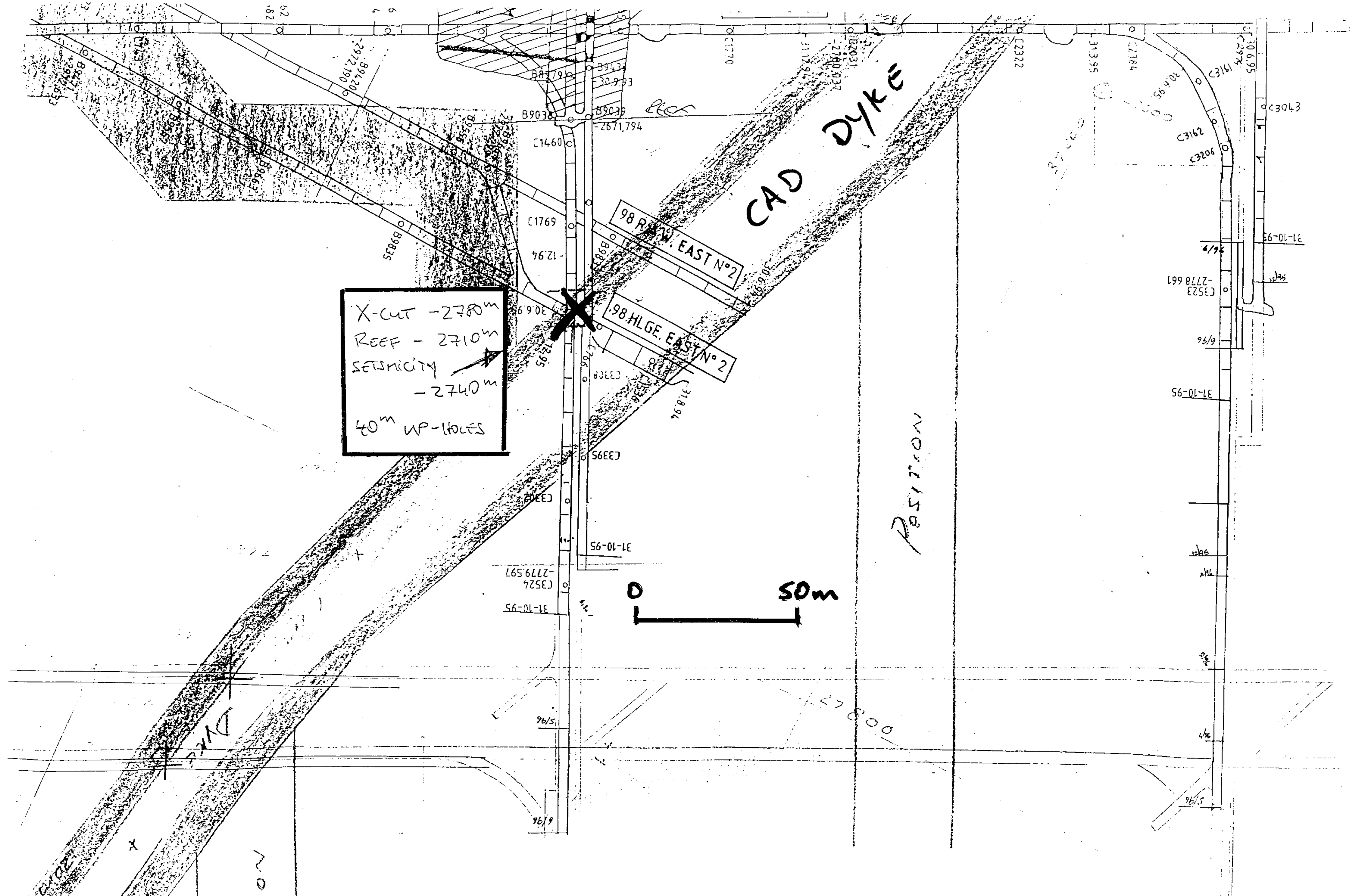


Figure 15: Elandsrand - CAD Dyke (example 1).

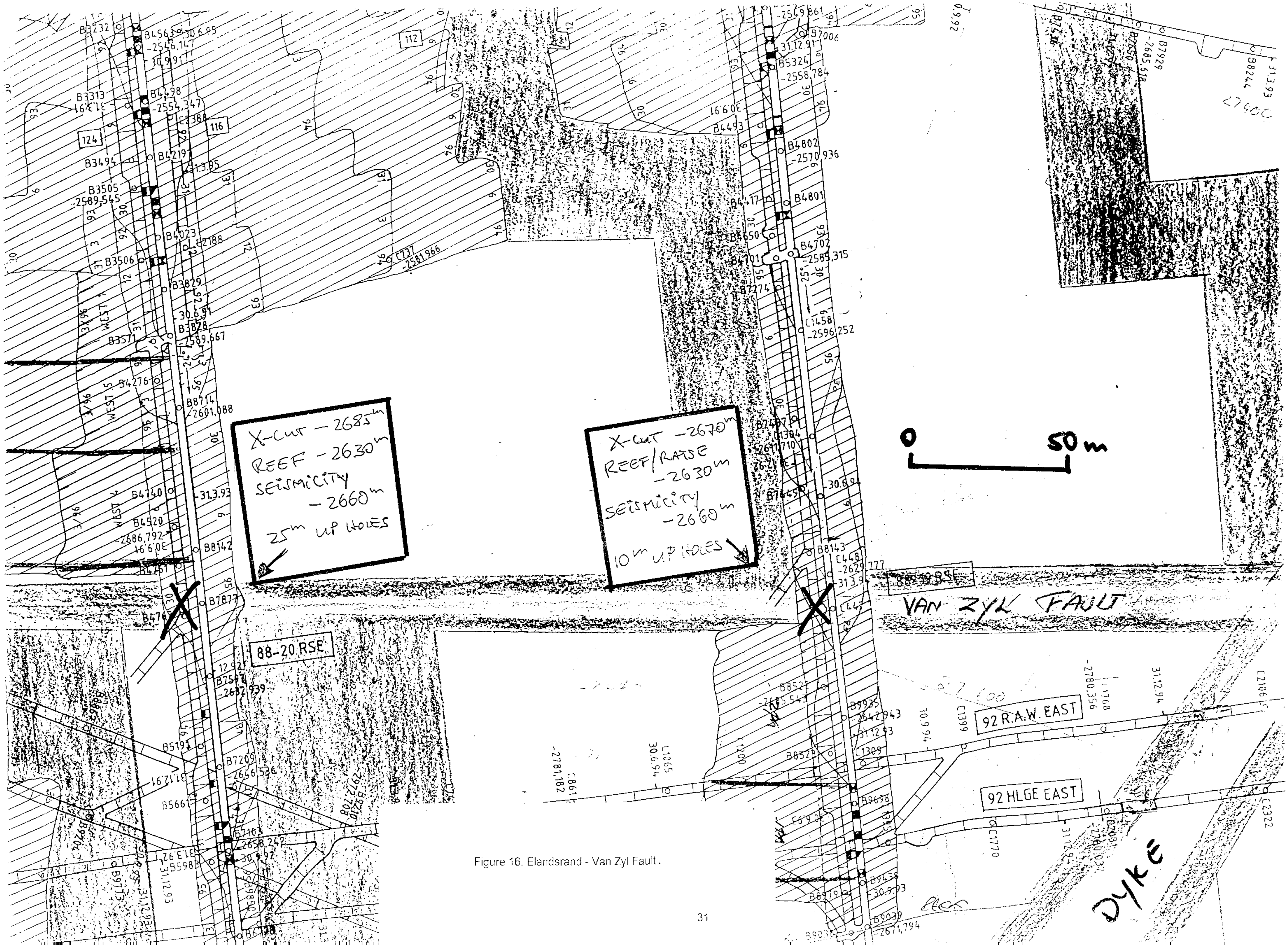
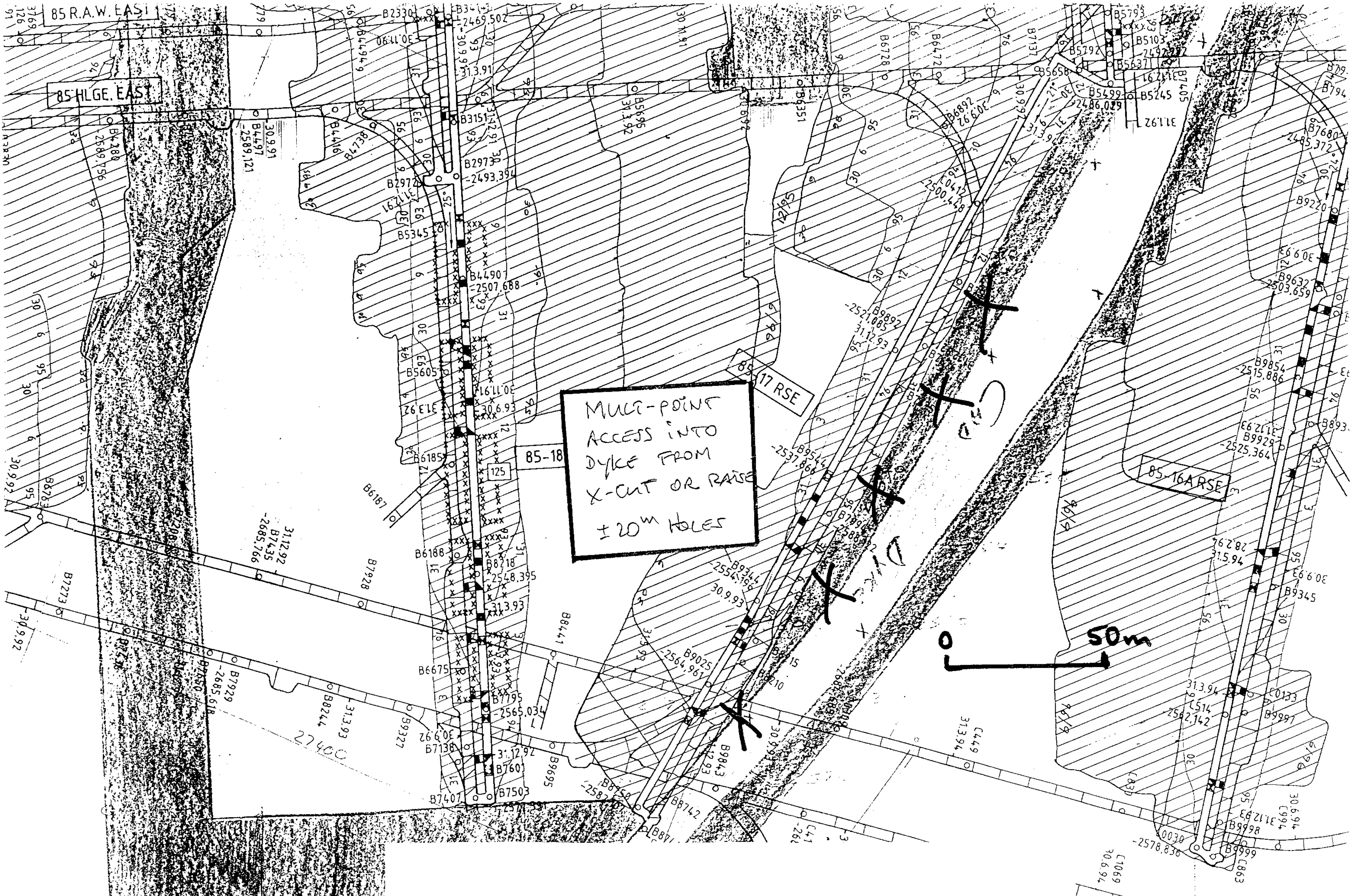


Figure 16: Elandsrand - Van Zyl Fault.



MULTI-POINT ACCESS INTO DYKE FROM X-CUT OR RAISE ±20m HOLES

Figure 17: Elandsrand - CAD Dyke (example 2).

5 CONCLUSIONS

If CFS using propellant gas injection is shown to be a promising method of pro-actively releasing stored strain energy by promoting slip on discontinuities, then all mines visited during this investigation indicated their willingness to make sites available for field trials of the technique. This enthusiasm reflects the seriousness with which the South African gold mining industry looks at the problem of reducing the rockburst hazard.

It should be noted that the approach of the CFS project has always been to promote the controlled release of strain energy on faults in an incremental fashion. In this way, a large rockburst would be prevented by de-stressing the fault through the release of many small magnitude seismic events. The gas generating capabilities of propellants can be designed carefully to pressurize only a certain 'safe' radius of a fault. This ensures that only small magnitude, non-damaging seismic events are initiated. Damage to the excavation serving as access to the fault would, therefore, not occur since only small-scale slip is initiated.

This investigation has shown clearly that gaining access to seismically hazardous geological structures by drilling into them is possible in all gold mining layouts. The most likely potential applications for the gas injection method appear to exist in the scattered mining environment. Accessibility of fault planes was almost always possible within the prescribed drilling criteria. Fault access in a longwall mining environment is more restricted and may require planning of access ways to get close to the targeted structures. The advance development of haulages and cross-cuts, together with ledging up to two years prior to the commencement of stoping provide various possible access points to geological structures requiring de-stressing in a sequential grid mining layout.

In general, though, each potential CFS application depends on the specific layout of the site. Access to a targeted fault plane then needs to be assessed in terms of the relative merits and drawbacks of the site.

I hope that this study has been able to address the practical concerns expressed by SIMRAC in terms of the accessibility of discontinuities targeted for gas injection. I believe that this investigation has shown that CFS using propellant gases has many practical field applications aimed at reducing the rockburst hazard in South African gold mines.

6 RECOMMENDATIONS

Based on the findings presented in this report and also from recent investigations of propellant gas injection on simulated fractures in the laboratory, CFS by propellant injection is promising, fundamental work that deserves further research. The work that still needs to be done to gain a better understanding of the technique, to assess its effectiveness and to implement it on mines includes:

- performing numerical modelling studies to simulate the mechanics of the technique in the laboratory and in the field.
- designing the field site requirements for propellant gas injection into faults.
- performing field trials.

In this light, we recommend that the committee re-look SIMRAC proposal GAP030: Part 2 - Propellant Injection by allowing Miningtek to submit a revised proposal that embodies reworked budgetary figures and more stringent milestones as determined by investigations performed on propellant injection since GAP030 was suspended.

An important spin-off of this work would be to provide input into the current uncertainty about the relative effects of shock and gas energy, which are proposed as being the mechanisms operating in the face preconditioning technique. Pursuing CFS by gas injection in the laboratory and scaling up to field trials would quantify the extent to which slip is possible with gas only.

7 ACKNOWLEDGEMENTS

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Finally, I thank my colleague, Mr Apie Janse van Rensburg, for providing valuable input into the accessibility details of each site example presented in this report.

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