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REPORT TO

THE SHELL COMPANY OF AUSTRALIA LIMITED - COAL DIVISION

ON THE

GEOTECHNICAL ASSESSMENT OF

MINING CONDITIONS

NICHOLAS RANGE - TASMANIA

DKSG

11-8-81

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P. G. FULLER
May 1981

SUMMARY

Conditions in a potential multi-seam underground coal mine on the western side of the Mount Nicholas Range have been examined. As a background to the investigation, the mining conditions encountered in the nearby Cornwall, Mount Nicholas and Silkstone Collieries have been reviewed, highlighting any difficulties which could be relevant to the new mine.

Geological logs of exploration drillholes in the area show that at least eight coal seams are developed. Only two (middle 2 and lower) appear to have potential for mining and the present evaluation of mining conditions has been confined to these, assuming that the bord and pillar method will be appropriate.

In the assessment of roadway stability for each seam, likely conditions in the roof, floor and pillars have been determined from currently available geological data and material properties obtained from a program of geotechnical testing. Where applicable, experience in old mines working the equivalent seams has been used as a basis. Roof support requirements have been recommended for the various conditions expected during mining in each seam. Pillar sizes necessary to ensure stable conditions during primary extraction and retreat mining have been specified for both seams. The economic impact of the required pillar sizes and the density of roof support has been considered relative to a set of average support requirements defined as a

basis for comparison. These data allow a direct comparison to be made of total support costs for the middle and lower seams.

Possible deterioration in conditions due to goaf formation in retreat mining and seam interaction have also been considered.

CONCLUSIONS AND RECOMMENDATIONS

1. Previous heavy roof and floor heave experienced in an area of the Cornwall Mine was due to a stress concentration caused by previous mining in a seam 11.7 m above. Weak roof and floor strata were unable to sustain the stress and failed. Such planning must be avoided in any future mining in the area.

2. Ground conditions in the four seams mined at Mount Nicholas were not excessively heavy and the roof could be controlled with 150 mm diameter wooden props and bars installed at 1.2 m centres. Support spacing was reduced to 0.6 m and 50 mm laths were used when locally heavy roof was encountered.

3. Roof conditions at the Mount Nicholas Colliery became unstable when patches of moist strata were exposed. Hence, conditions heavier than usual can be anticipated in any moist area of a new mine.

4. Where possible, main headings and cut throughs should be driven approximately north-west or north-east to minimise unstabilities caused by excessive lateral stress. This is based on the horizontal stress components being approximately east-west and north-south.

5. Varying densities of roof support comprising resin anchored or full column grouted 24 mm diameter, 1.8 m long mild steel bolts through W straps will provide adequate support. Steel mesh should also be used where the roof is laminated mudstone. Recommended support densities are summarised in Table A on page iv.

6. All roof bolts should be pre-tensioned with an applied torque of 250 to 300 Nm.

7. Bolt anchorage in sandstone must exceed 100 kN and this should be confirmed during the mine development phase.

8. Floor heave will not develop provided pillars are not overstressed and a 150 mm thick layer of coal is left on the floor of main travelling roads, the main intake and areas where free water is encountered.

9. Maximum bord widths of 5 m and 5.5 m are recommended for the middle 2 and lower seams respectively.

10. Pillar size for each seam varies with cover. Some typical sizes are as follows:

Cover (m)	Pillar Size (m)	
	Lower Seam	Middle 2 Seam
100	9	7
200	17.5	13
300	27.5	-

TABLE A

SEAM	ROOF STRATA	RECOMMENDED ROOF SUPPORT REQUIREMENTS
Middle 2	Mudstone	Roadways: W straps at 1 m spacing with continuous steel mesh; each strap bolted with 5 fully resin bonded bolts. Intersections: W straps at 1 m spacing with continuous steel mesh; each strap bolted with 7 fully resin bonded bolts.
Lower	Sandstone	Roadways: W straps at 1.8 - 2.0 m intervals, each bolted with 3 resin anchored bolts. Intersections: W straps at 1.5 m spacing, each bolted with 5 resin anchored bolts.
	Mudstone	Roadways: W straps at 1 m spacing, each bolted with 5 resin anchored bolts. 7 bolts are required if anchorage in sandstone is not possible. Steel mesh should be used in moist areas and in main headings. Intersections: W straps at 1 m spacing with steel wire mesh; each strap bolted with 7 resin anchored bolts.

11. In the split lower seam, maximum tonnage of the best quality coal will be achieved by mining lower seam 2 only and aiming to maximise total extraction in that seam.

12. Apart from the split lower seam no adverse effects due to seam interaction are anticipated.

13. There has been no evidence of methane in any of the previous workings in the Nicholas Range. Consequently, methane is unlikely to be encountered in any new workings.

14. No difficulties are anticipated during pillar recovery and the creation of a goaf in either seam. Apart from local props and lids at the retreat face, no additional support will be required.

15. Small faults and dykes can be expected to cause some localised seam displacement. In previous mining, there has been no evidence of high lateral pressures near faults. This trend should also be found in new workings.

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May, 1981

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1. SCOPE

The potential coal mining area at Mount Nicholas lies on the western boundary in the northern part of EL 5/61, north-east Tasmania (Figure 1). Mount Nicholas is a dolerite capped peak aligned approximately east-west, grading to a plain on the south side and localised ridges and peaks to the north.

Historically, the area has been mined in localised areas since the end of last century. Apart from mines of the Cornwall Coal Company to the east of the area of interest, worked out areas have tended to be small and confined to one of the many seams outcropping on the slopes of Mount Nicholas. The Mount Nicholas Coal Mining Company has mined a small portion in the south-eastern corner of the area and indications are that workings were confined to two seams.

Drilling on the slopes of Mount Nicholas by the Mines Department - Tasmania and, more recently, by The Shell Company - Coal Division, has highlighted three significant coal measure strata designated the upper, middle and lower seams. These correlate generally with the Blue, Hittit and Fenton seams referred to in documentation of previous workings. Other seams exist, but are not of sufficient thickness, quality and extent to be viable for mechanised mining. Based on data available to date, it appears that a new mine in the area would be based primarily on mining the lower seam in the sequence, with additional development to mine parts

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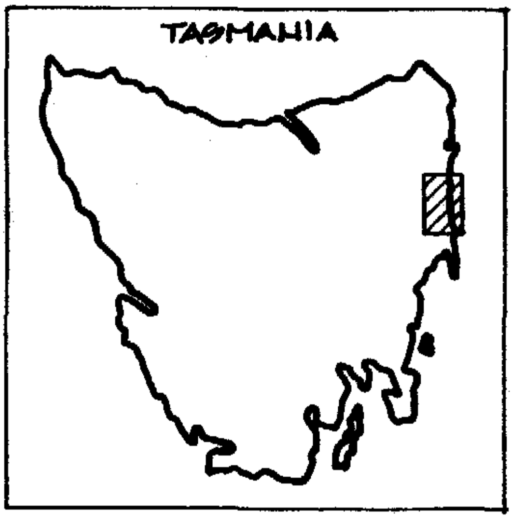

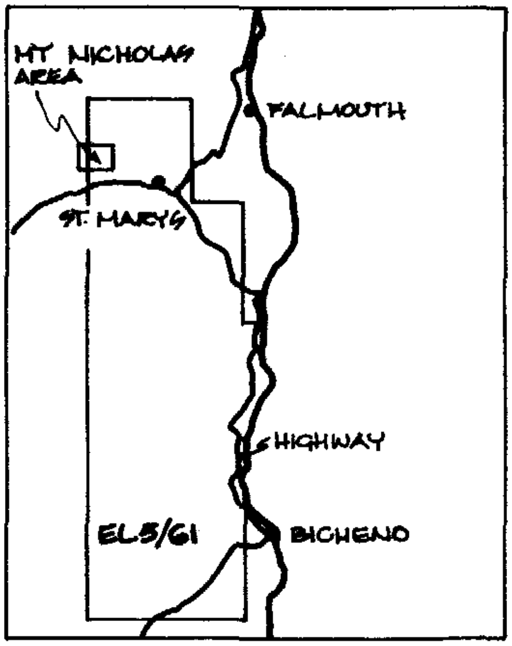

GRAY EL 5/61		FIG. 1
Scale NTS	Job Number 10-11	
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of the middle seam also a distinct possibility.

Heavy roof and floor conditions have been experienced in the Cornwall Mine and also in the Duncan Mine (further to the south-east near Fingal) operated by the Cornwall Coal Company. Since the roof and floor sediments in the Mount Nicholas area are similar to those in the Cornwall Mine, heavy roof and floor can be anticipated in any new workings. The present geotechnical study was therefore commissioned at the pre-feasibility stage to assess the likely conditions in the access drift and in subsequent primary extraction and pillar recovery cycles of a conventional continuous miner, room and pillar operation.

This report reviews the previous mining experience in the area; particularly in the Cornwall Mine and covers an assessment of mine opening stability in the potential new mine. The assessment is based on two site visits, a visit to the Mines Department, Hobart, geological data provided by the Geology Group of Shell - Coal Division and results of material property determinations on roof, coal and floor strata. Support requirements in the mine openings have also been determined, together with the impact such measures are likely to have on the economics of mining.

2. GEOLOGY AND TOPOGRAPHY

The Nicholas Range is an east-west trending ridge of Triassic sediments overlain by a Jurassic dolerite capping and dolerite scree of varying thickness on the slopes. Contours from 600 m to 800 m (Figure 2) indicate steep terrain to the top of the range. Below 660 m the country grades at approximately 1 in 6 to the Break O'Day Plain on the south. On the north side, similar gradients occur to the north-east and north-west but to the north, the country rises to another dolerite capped peak known as Hunstmans Cap.

Triassic sediments include fine grained sandstones, siltstones, mudstones and coal. Three coal seams appear to be significant, with the majority of the reserves in the middle and lower seams (Ref 1). The approximate outcrop/subcrop levels for each of these are indicated by the broken lines in Figure 3.

Drilling in the Mount Nicholas area to determine coal quality, seam thickness and geotechnical properties of potential roof and floor strata and the coal is nearing completion. Exploration drillhole locations and respective designations have been plotted in Figure 2. Apart from the dolerite capped area on Mount Nicholas, holes have been spaced at a nominal 1 km over the area. Geological logs for each hole and coal reserve determinations are covered in an associated separate report prepared by the Geology Group of The Shell Company; Coal Division (Ref 1). Sections of these geological logs in the immediate vicinity of the middle and lower coal seams

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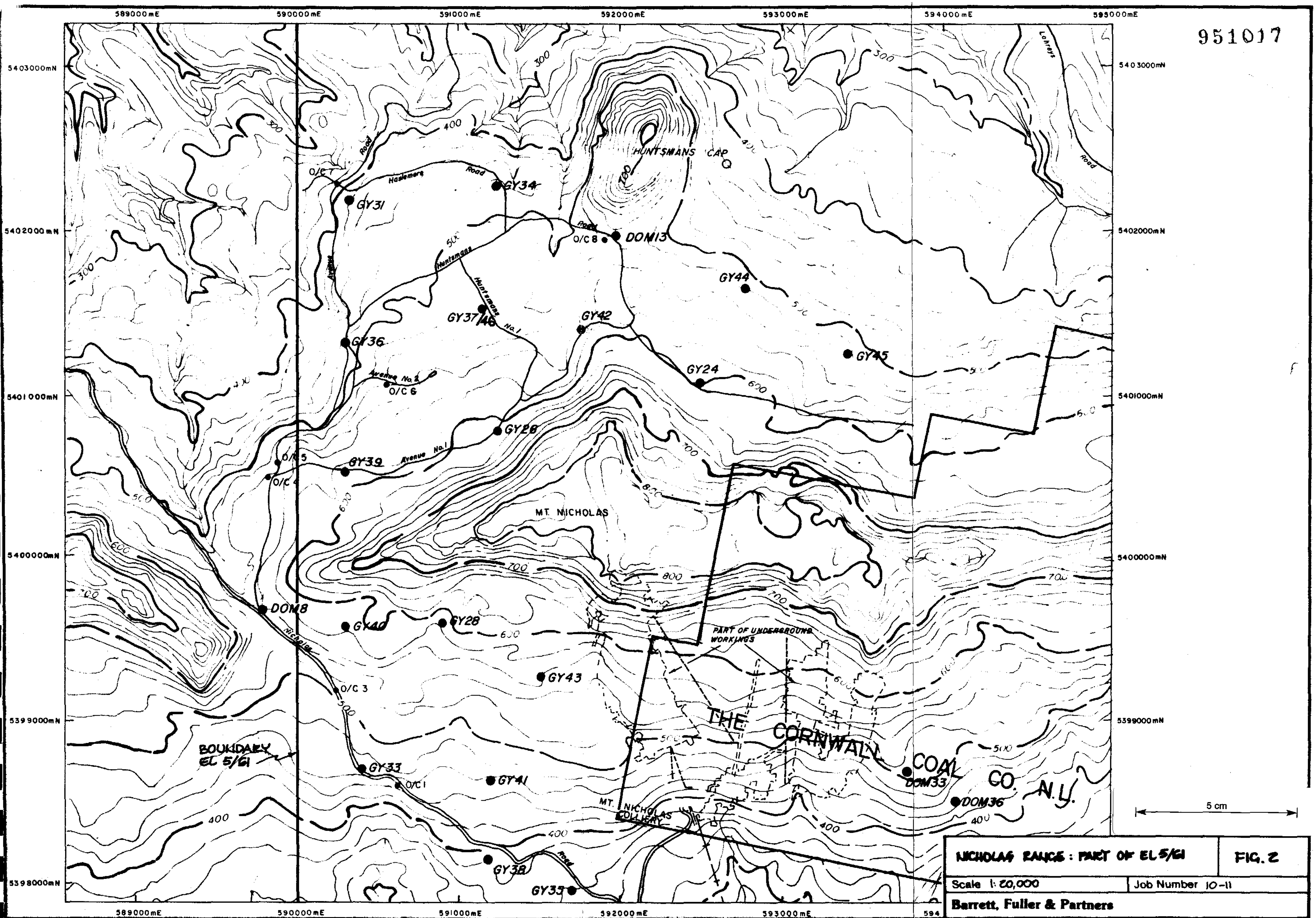

NICHOLAS RANGE : PART OF EL 5/61	FIG. 2
Scale 1:20,000	Job Number 10-11
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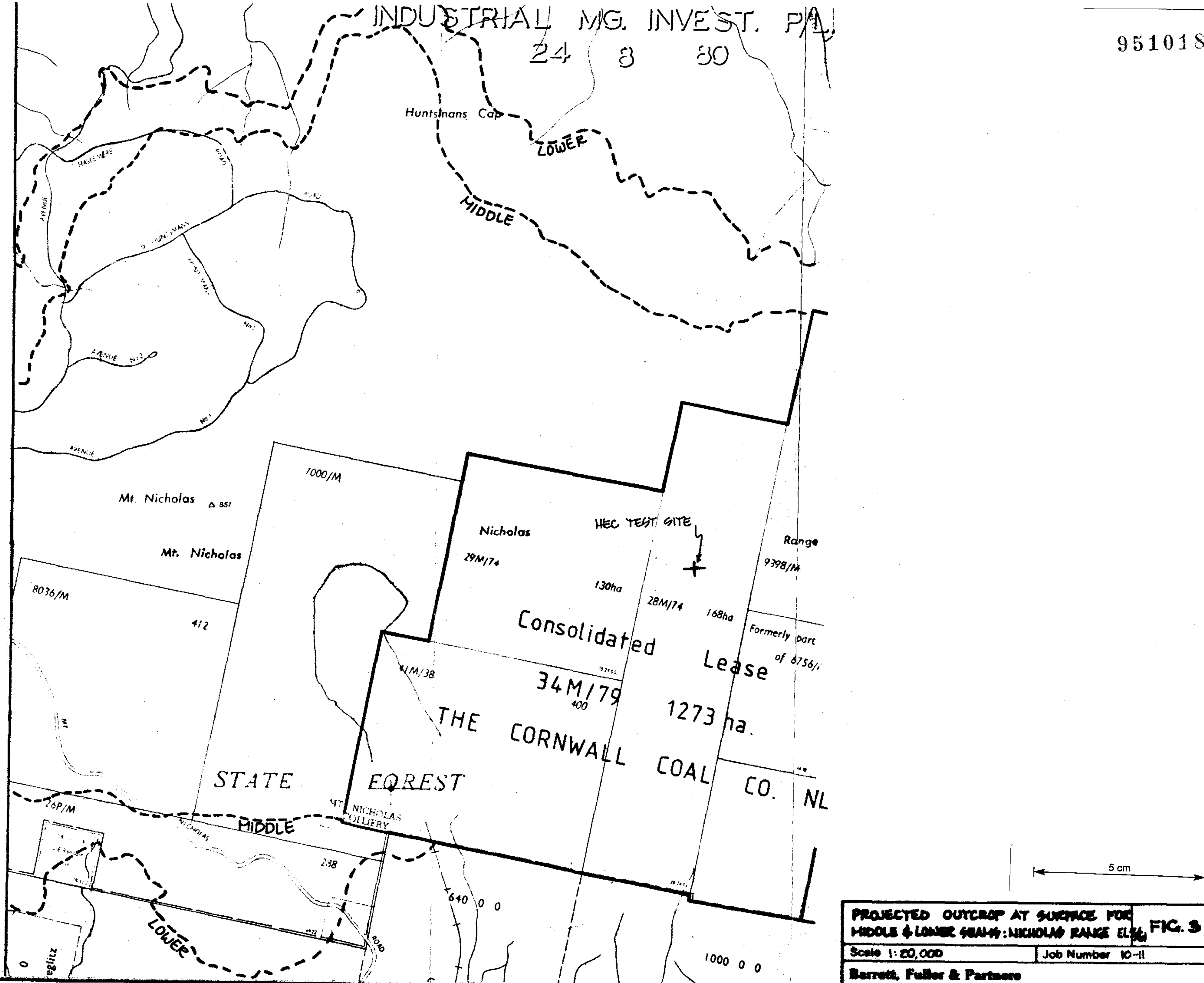

PROJECTED OUTCROP AT SURFACE FOR MIDDLE & LOWER SEAMS: NICHOLAS RANGE EL	FIG. 3
Scale 1:20,000	Job Number 10-11
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have been presented graphically in this report because of their relevance to the potential mining conditions in each seam.

Three north-south sections have been considered across the area of interest to coincide, as closely as possible, with the north-south rows of exploration drillholes. In Figure 4, data relating to the middle seam have been collated for section 590 311 m east. In holes GY 33, GY 40, and GY 39, coal intersections were very thin and considered not to be a proposition for mining. However, 1.5 m of coal was intersected in the most northerly hole; GY 36, with mudstones forming the immediate roof and floor. Similar data projected onto Section 591 065 m east (754 m further east) (Figure 5) show significant intersections of the middle seam and a continuation of the mudstone roof and floor sequence towards the north. Still further east at 592 548 m east (Figure 6) hole GY 24 intersected only two coal bands indicating a general thinning of the seam. Holes GY 42, GY 44 and GY 45 (Figure 2) nearing completion will provide further information on middle seam continuity on the northen side.

An identical sequence of figures has also been prepared for the lower coal seam. In Figure 7 at 590 311 m east, coal intersections confirm that the lower seam splits towards the south with a marked increase in coal volume. In contrast to the middle seam though, sandstone is more common in the immediate roof but mudstones still persist in the floor. A similar trend is evident further to the east (591 065 m east) (Figure 8) except for a band of mudstone becoming more prominent in

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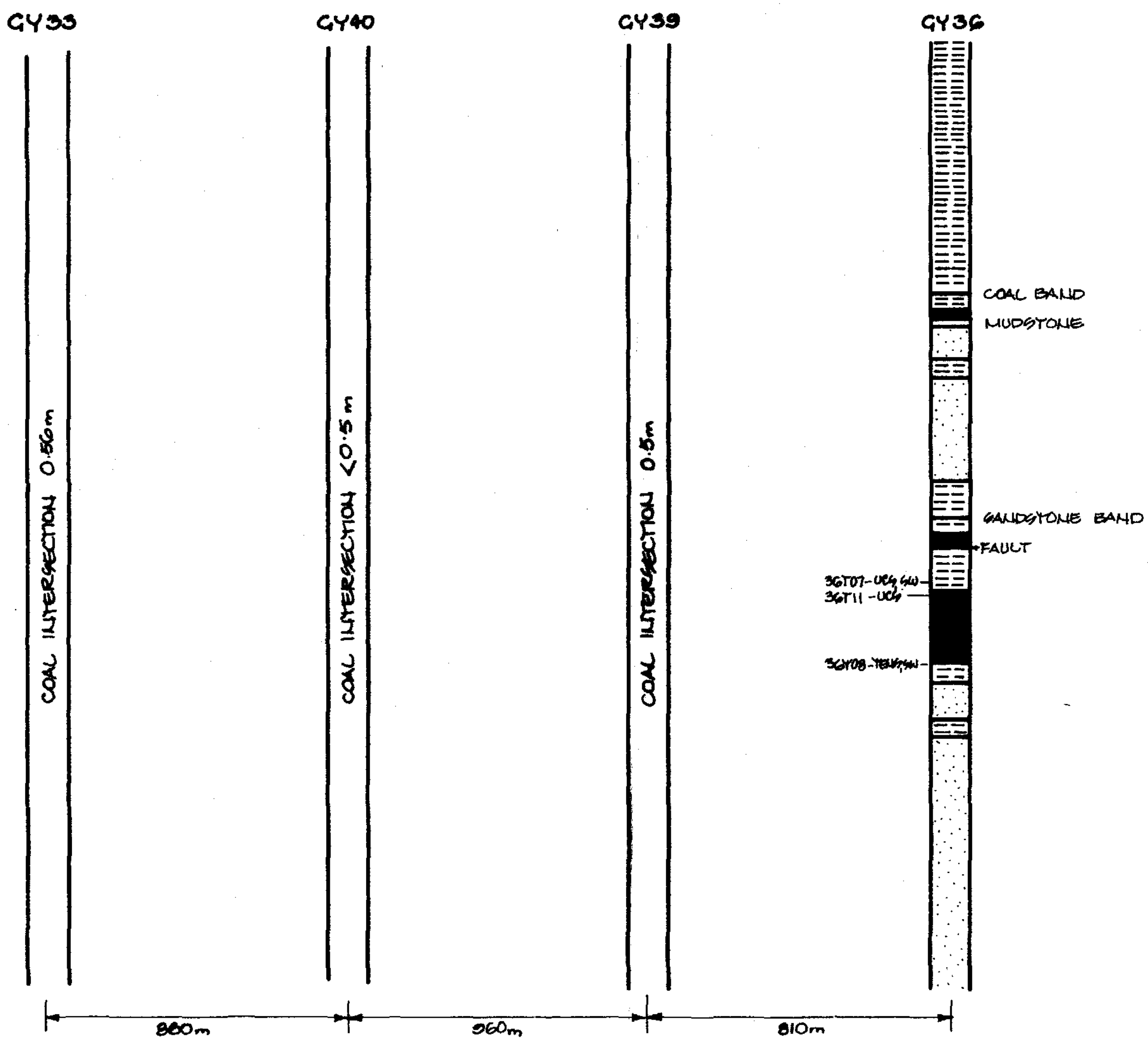

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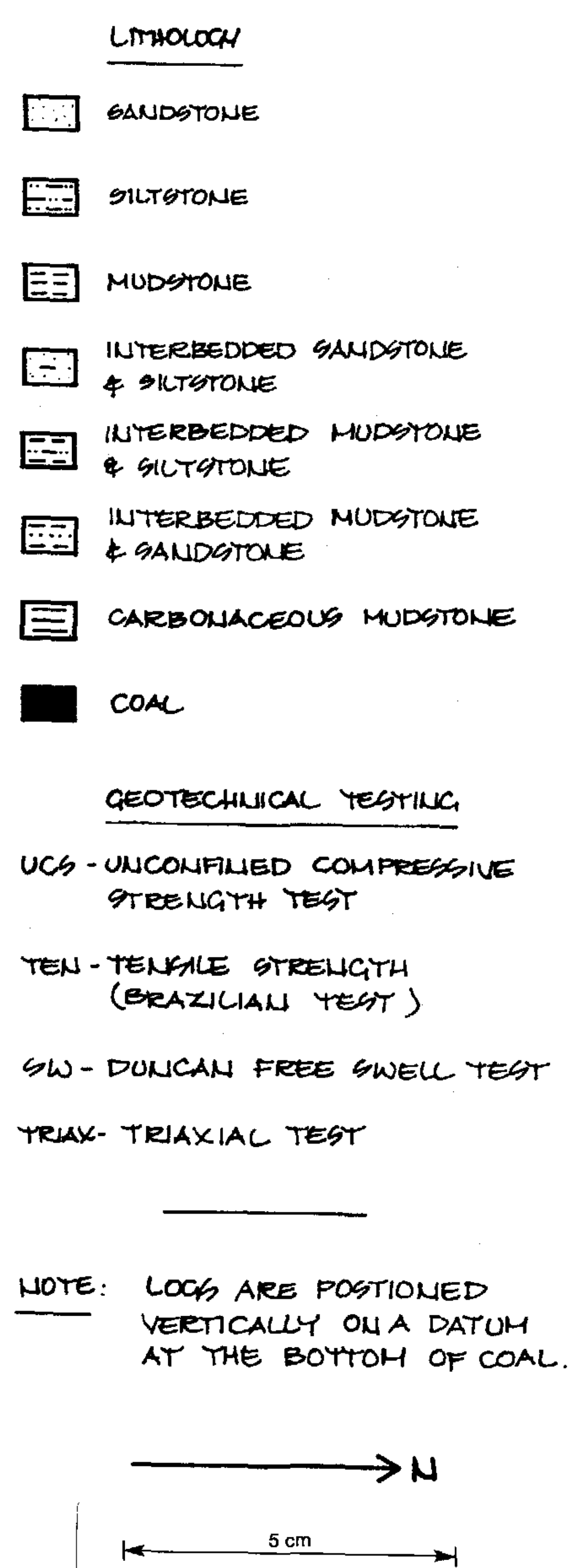

GENERALIZED LITHOLOGY ON SECTION 590 211 mE, MIDDLE SEAM; NICHOLAS RANGE	FIG.4
Scale 1:100 (VERTICAL) N.T.S. (HORIZONTAL)	Job Number 10-11
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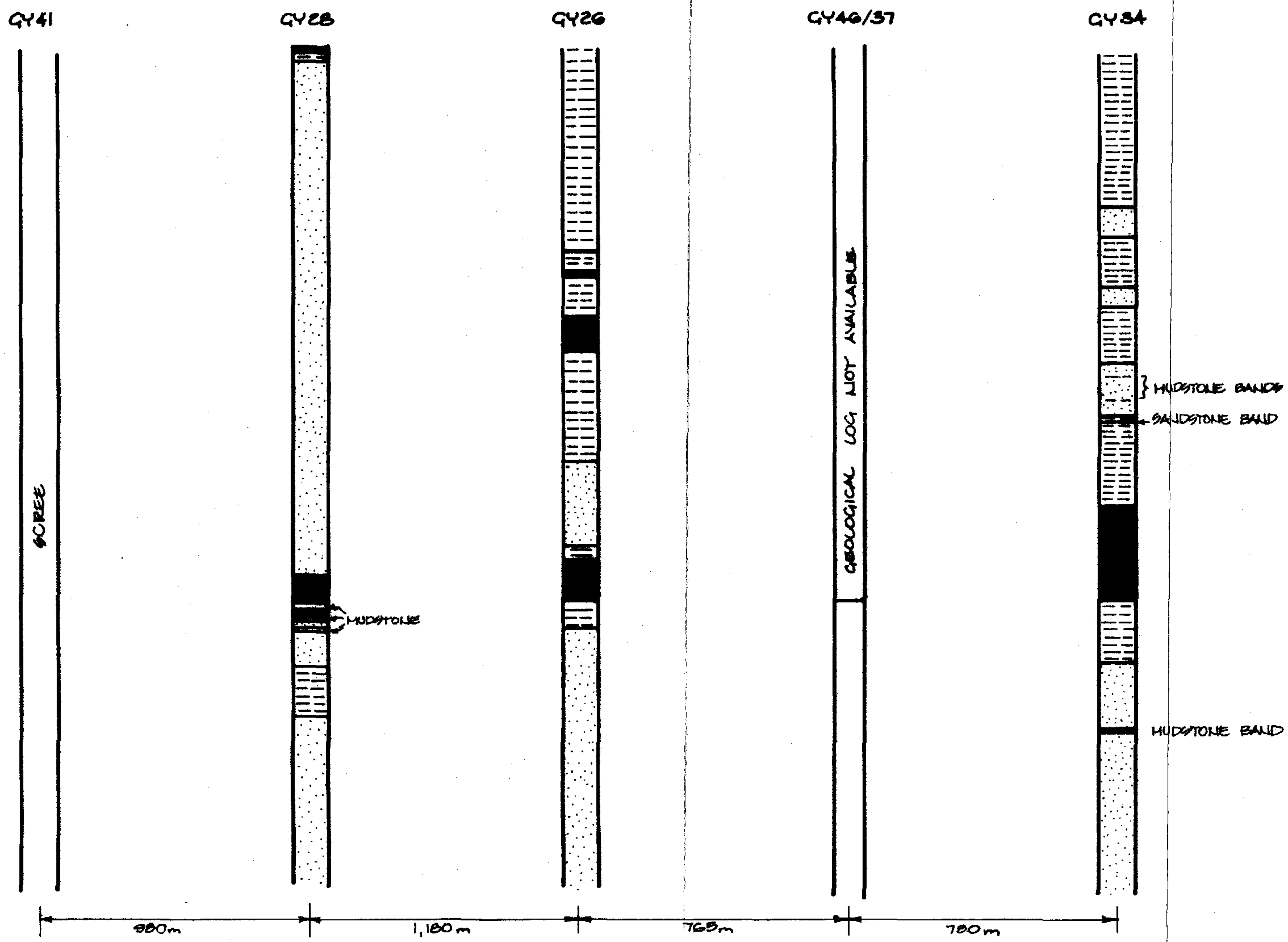

LEGEND

LITHOLOGY

- SANDSTONE
- SILTSTONE
- MUDSTONE
- INTERBEDDED SANDSTONE & SILTSTONE
- INTERBEDDED MUDSTONE & SILTSTONE
- INTERBEDDED MUDSTONE & SANDSTONE
- CARBONACEOUS MUDSTONE
- COAL

GEOTECHNICAL TESTING

UCS - UNCONFINED COMPRESSIVE STRENGTH TEST

TEN - TENSILE STRENGTH (BRAZILIAN TEST)

SW - DUNCAN FREE SWELL TEST

TRIAX - TRIAXIAL TEST

NOTE: LOGS ARE POSTIONED VERTICALLY ON A DATUM AT THE BOTTOM OF COAL.

→ N

5 cm

GENERALIZED LITHOLOGY PROJ. ON SECT. 591 065 m E, MIDDLE SEAM; NICHOLS RANGE	FIG. 5
Scale 1:100 (VERTICAL) NTS (HORIZONTAL)	Job Number 10-11
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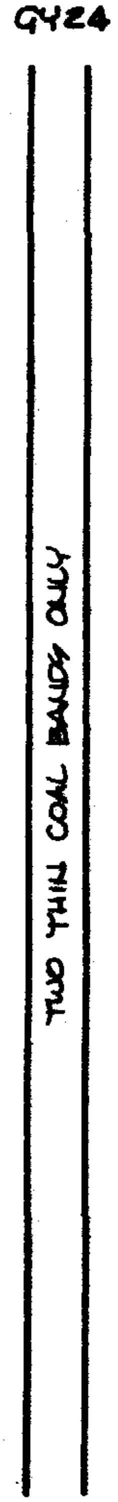

MIDDLE SEAM AT 540 1020 m N, 592548 m E, NICHOLAS RANGE	FIG. 6
Scale -	Job Number 10-11
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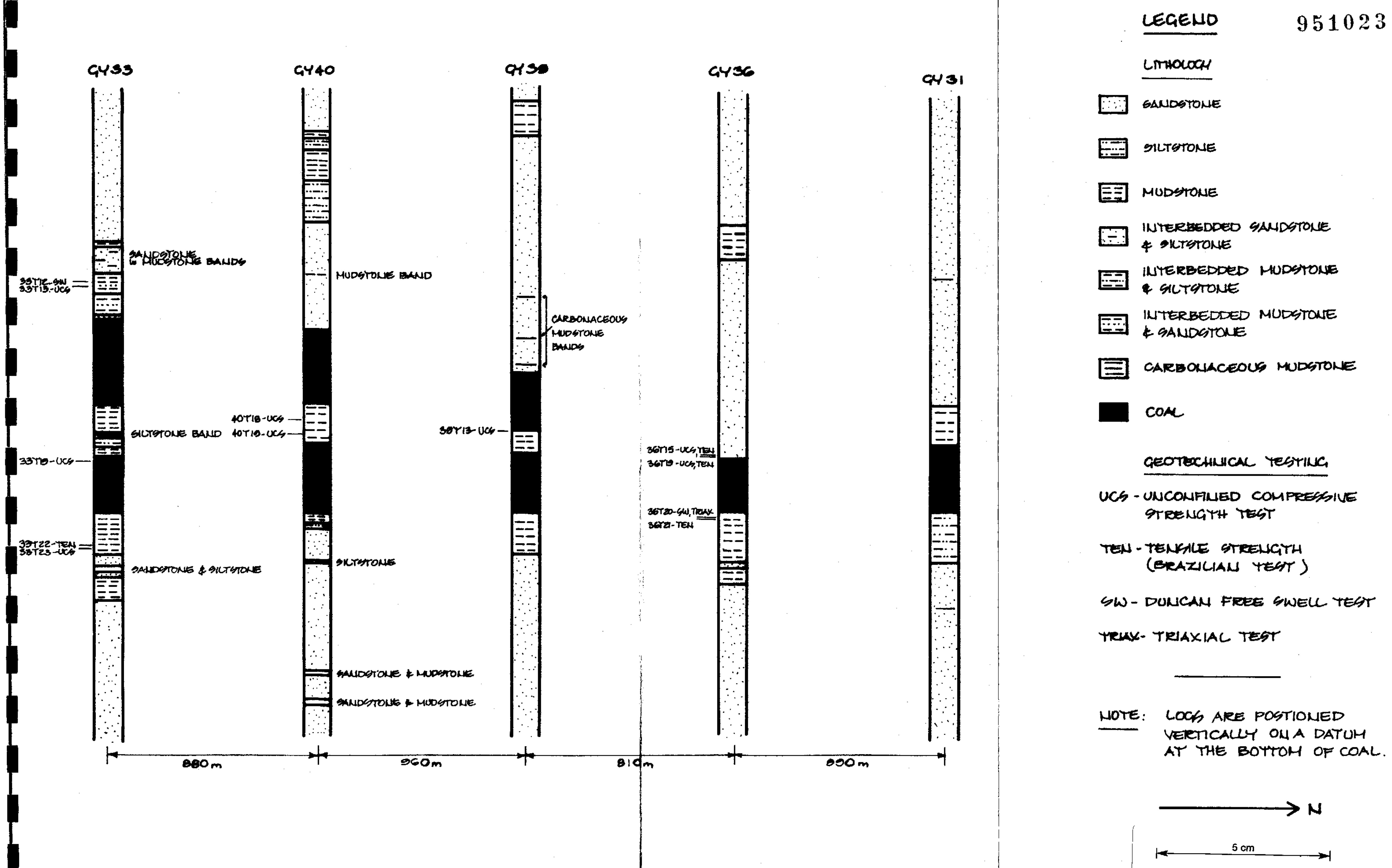

GENERALIZED LITHOLOGY ON SECTION 590 31 mE, LOWER SEAM; NICHOLAS RANGE	FIG. 7
Scale 1:100 (VERTICAL) NTS (HORIZONTAL)	Job Number 10-11
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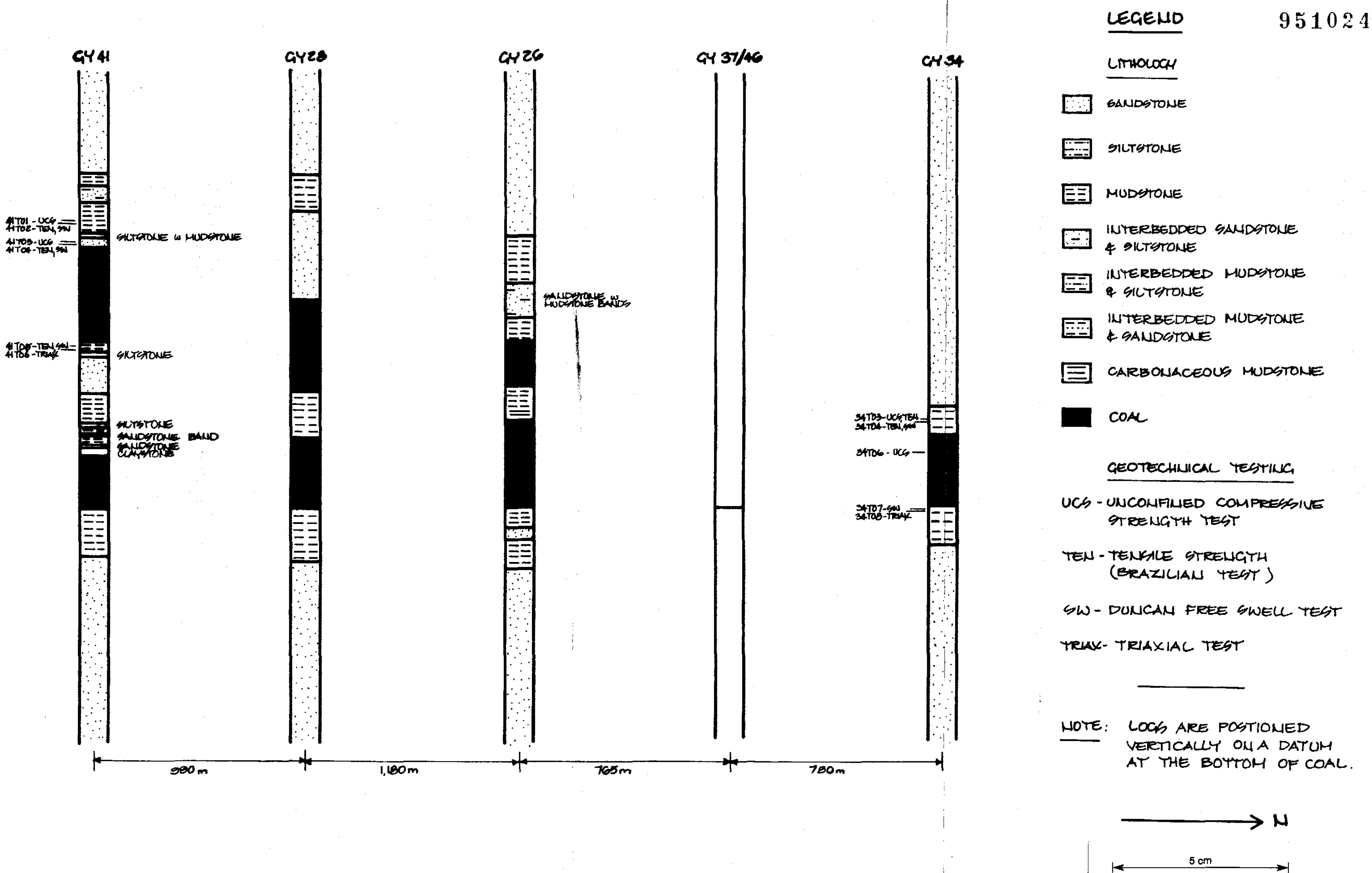

GENERALIZED LITHOLOGY PROJ. ON SECT. 591 065 mE, LOWER SEAM; NICHOLAS RANGE	FIG. 8
Scale 1:100 (VERTICAL) NTS (HORIZONTAL)	Job Number 10-11
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the roof. The lower seam is 3.1 m thick at 592 548 m east (GY 24) with sandstone and siltstone in the roof and mudstone forming the immediate floor (Figure 9).

Although there appears to be some consistency in the roof and floor sediments, the area is renown for facies changes (Ref 2). In mining the middle and lower seams, such changes should be anticipated and appropriate measures to handle any associated changes in ground conditions should be properly prepared in advance.

Both major and minor faulting exist in the Nicholas Range area. A north-south trending major fault with approximately 90 m throw is almost coincident with the western boundary of EL 5/61 and accounts for the discontinuity between Mount Nicholas and Mount Durham further west. The other major fault is the Cornwall fault which crosses the range at the saddle to the east of the Cornwall Mine. It also trends approximately north-south (Ref 2). Major faulting is associated with dolerite intrusions which have caused upward movement of large blocks (Ref 3). The near vertical dip and normal movement on major faults tends to confirm the above mechanism.

Previous mining operations at the Cornwall Mine, Mount Nicholas Mine and the Silkstone Mine (see Sections 3.1, 3.2 and 3.3 of this report) have all been influenced by minor thrust faults. The majority trend between north-east and north-west with throws of up to 25 m recorded in the old workings. Those occurring in the western workings in the Cornwall Mine were studied by HEC geologists (Ref 2) and considered to be normal faults. The wide variation in

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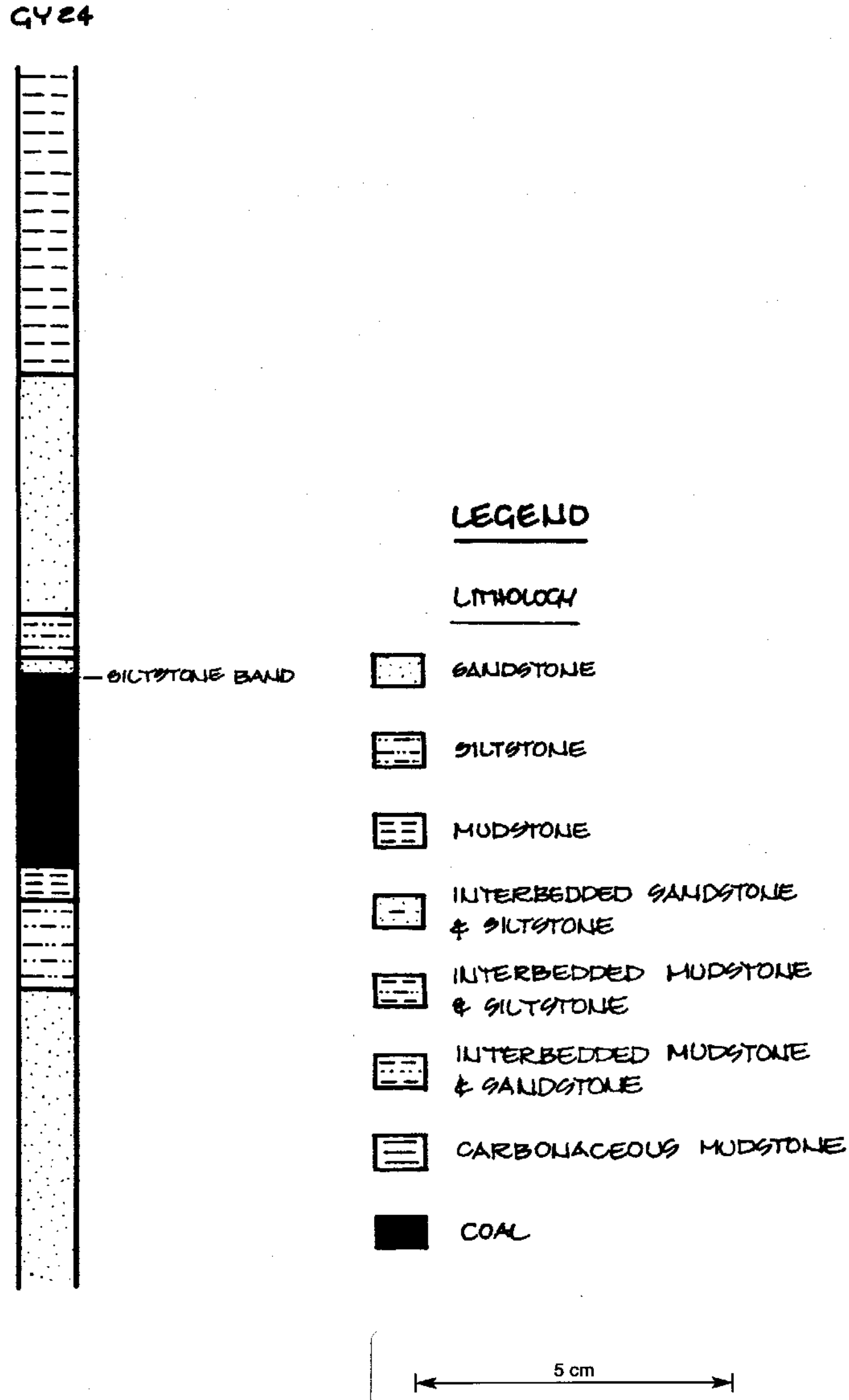

GENERALIZED LITHOLOGY AT 540 1020 m N, 592548 m E, LOWER SEAM; NICHOLAS RANGE	FIG. 9
Scale 1:1000 (VERTICAL)	Job Number 10-11
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dip suggests that minor faults have been caused by high tectonic stresses in an east-west direction together with differential upward movement possibly due to localised dolerite intrusions.

Strata in the Nicholas Range have slight variations in dip but generally dip 3^{o} to the south (Ref 2 and 4). Local variations occur due to faulting.

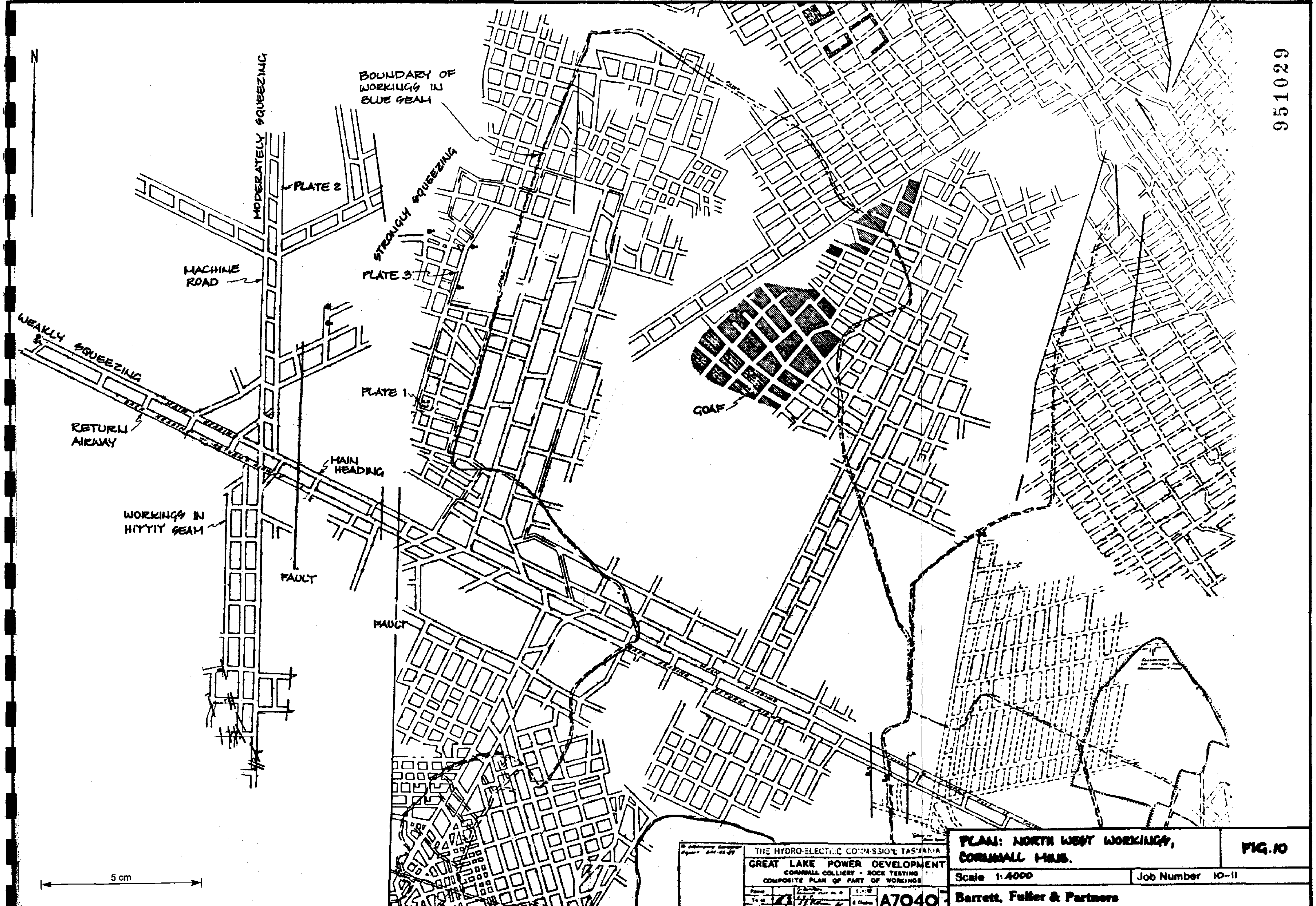
3. CONDITIONS IN PREVIOUS MINES - NICHOLAS RANGE

3.1 Cornwall Mine

The Cornwall Mine lies to the east of the Mount Nicholas area and has been closed since the early 1960's. Two seams were worked; the Blue seam and the Hittit seam and these appear to correlate with the upper and middle seams respectively at Mount Nicholas. Before closure of the mine, mining was mainly in the Hittit seam and from discussion with Mines Department staff, ground conditions were generally stable. However, in localised areas, extensive "guttering" had developed along the ribsides in the roof, together with floor heave.

Main roadways, headings and cut throughs were all approximately 6 m wide. Headings in the Hittit seam were driven on 18.3 m centres with cut throughs in the main headings every 40 to 55 m. In the working panels, cut throughs were spaced at 40 m centres. Pillars were 12 m x 36 m and the primary extraction was 43%. A double entry layout was adopted. The Hittit seam had an average thickness of 2.7 m but only the bottom 1.7 m was mined beneath a persistent sandstone band.

A report by the HEC in Tasmania (Ref 2) prepared between 1958 and 1960 is the most comprehensive documentation available on ground conditions at the Cornwall Mine. This was confined to a development in a north-west direction in the Hittit seam (Figure 10). Main headings were driven 11.6 m beneath the previously worked Blue seam



PLAN: NORTH WEST WORKINGS, CORNWALL MINE.

FIG. 10

Scale 1:4000 | Job Number 10-11

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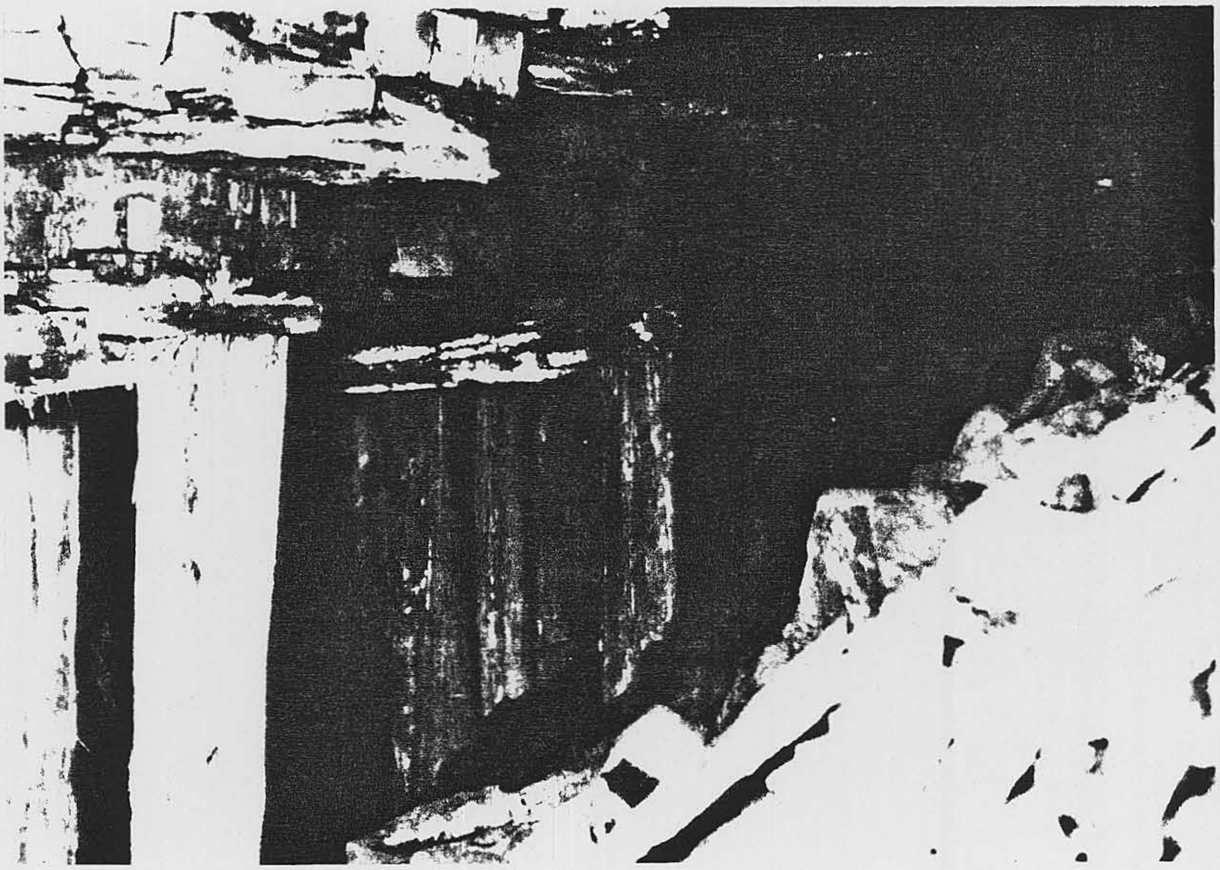
and through a series of north-south striking faults with throws of up to 10 m. Failures in main headings were confined to the roof and primarily involved "guttering" along one ribside which occasionally developed to both sides. Plate 1 (from the report), shows the extent of "guttering" between the timber prop and bar supports and the rib. It appears from the photograph that failure extended approximately 1 m into the roof where the strata graded into a more massive sandstone.

In workings to the north of the main heading, failures in both the roof and floor were common. This area was driven parallel to two normal faults (Figure 10) where the cover exceeded 250 m. In many cases, the weak, soft mudstones in the floor heaved 0.3 to 0.5 m at the roadway centres (Plate 2). In a localised area to the north ("Right Hand Workings" in Figure 10) pressures were sufficient to heave the floor and cause roof sag to such an extent that roadways would completely close. Sufficient lateral movement occurred at the floor to cause loss of support by rotation of props at their base (Plate 3). Continual "brushing" of the floor was therefore required to keep the headings open.

Heavy roof and floor conditions were attributed to a combination of cover (greater than 250 m) and the small north trending fault trough. The presence of old workings were also acknowledged as a complicating factor.

PLATE 1



GUTTERING FAILURE IN THE CARBONACEOUS SANDSTONE ROOF IN THE RIGHT HAND WORKINGS - CORNWALL MINE

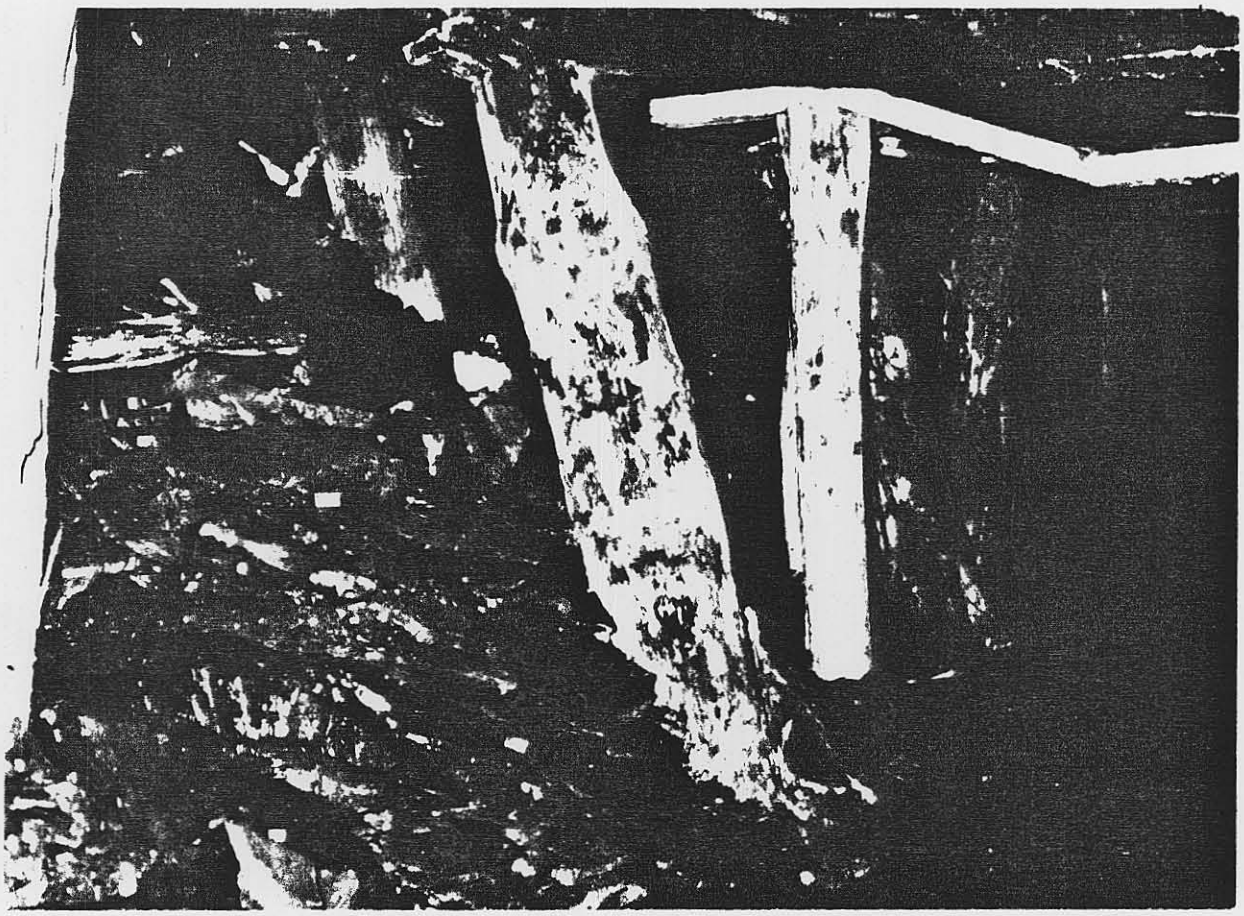
(From Ref 2)

PLATE 2

HEAVE OF MUDSTONE FLOOR IN THE MACHINE ROAD WORKINGS - CORNWALL MINE.

(From Ref 2)

PLATE 3



FLOOR HEAVE IN MUDSTONE SHOWING ROTATIONAL FAILURE OF SUPPORTS: RIGHT HAND WORKINGS - CORNWALL MINE

(From Ref 2)

From an assessment of the evidence presented in the report, it appears that the heavy ground was partly due to a locally high horizontal stress locked in across the north-south striking normal faults. It is unlikely that the increased stress due to the gradually increasing cover would have contributed greatly to the problems because in the main heading developed further to the north-west under even greater cover (Figure 10), the conditions were described as only "weakly" squeezing. The proximity of the old workings in the Blue seam are likely to be more significant than indicated in the HEC report. These were only 11.6 m above the Hittit seam workings and the areas where excessive roof and floor movement occurred were immediately beneath the pressure arch ahead of the terminated face of the Blue seam workings. This would greatly increase the vertical stress and also add to the already high horizontal stresses. Thus, the localised area in the Hittit seam would have been grossly overstressed and the weak strata (particularly the mudstones in the floor) responded by deforming into the opening.

This experience has some relevance to future mining in the Mount Nicholas area because the Triassic sediments and regional faulting patterns are generally consistent over the area. Because the north-south striking faults are normal faults, it is likely that east-west stresses (across the faults) are greater than those in the north-south direction. Ground conditions in future mining adjacent to these faults are therefore expected to be heavier than in fault free blocks.

Increasing cover will give rise to a steady increase in pre-mining stresses, but mining under a cover of 250 m and greater is not expected to create any abrupt deterioration in ground conditions unless other local stress raising factors such as faults are encountered. The effects of seam interaction experienced at the Cornwall Mine are not anticipated during mining of the lower and middle seams but this aspect will be covered more extensively in Section 6 of this report.

3.2 Mount Nicholas Mine

The Mount Nicholas Colliery operated until 1958 on the south side of Nicholas Range. Five seams were mined (Ref 5) at the approximate vertical locations in Figure 11. The extent of workings is outlined by the broken lines in Figure 12.

3.2.1 8 ft Seam (Fenton Seam)

Entry to the 8 ft seam was via a portal labelled M.D.1 in Figure 12. Workings only covered a small area because the seam contained bands of carbonaceous mudstone. During the 1930's, when the seam was mined, coal washing was not practised. The best coal was found in a 9 inch band at the bottom of the seam.

The adit driven due north from M.D.1. is still standing and readily accessible from the old tramway. Near vertical coal faces have

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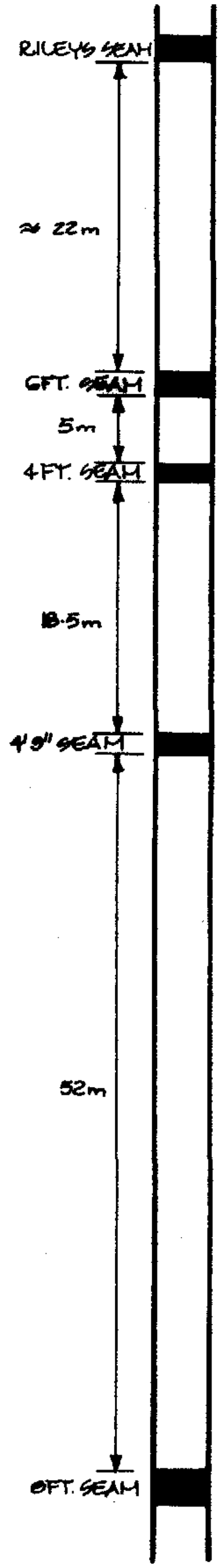

5 cm

COAL SEAMS MINED; MOUNT NICHOLAS COLLIERY	FIG. 11
Scale 1:500 (VERTICAL)	Job Number 10-11
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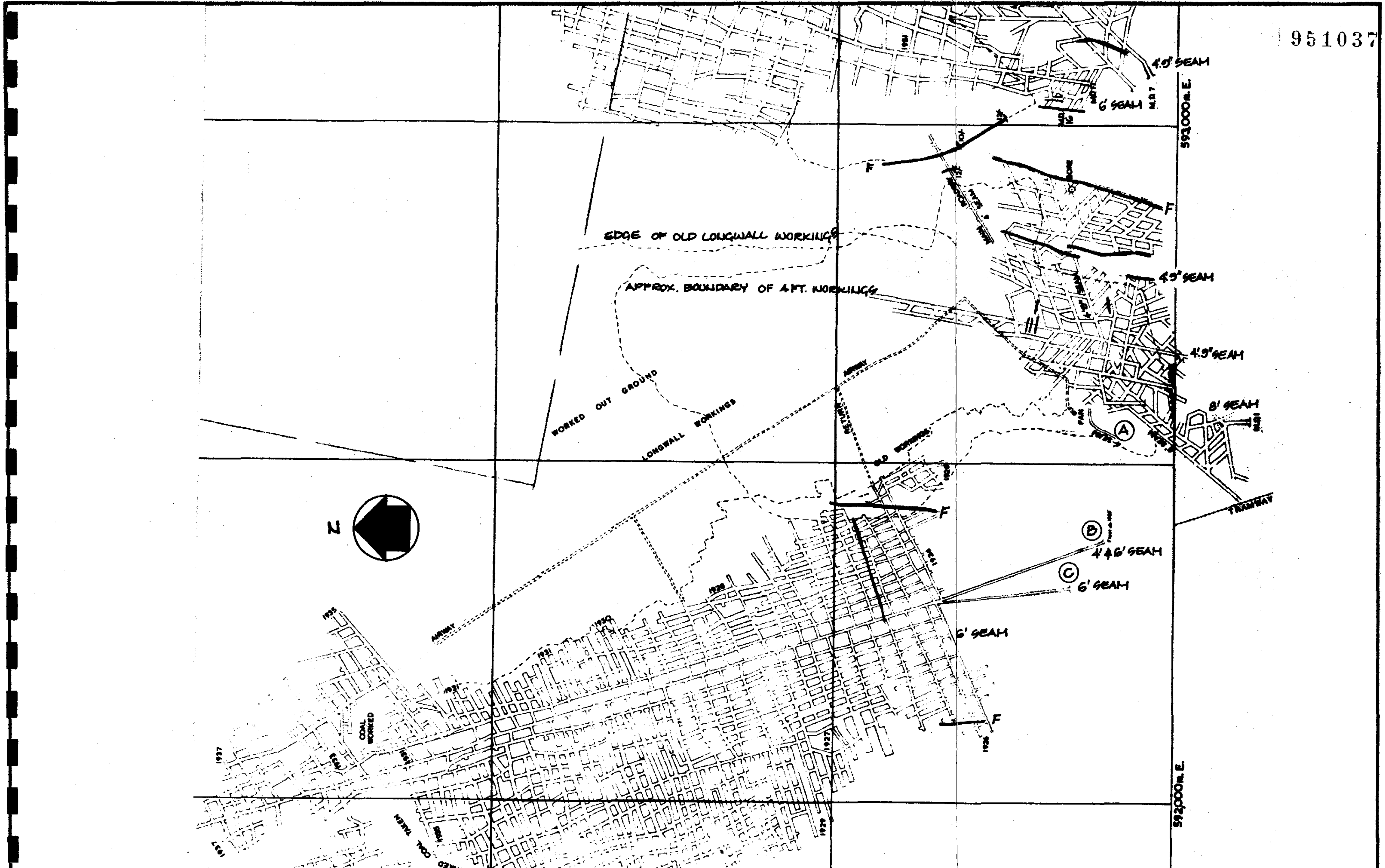

PLAN OF NORTH & NORTH WEST WORKINGS: MOUNT NICHOLAS COLLIERY

FIG. 12

Scale 1:5000 | Job Number 10-11

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shown virtually no sloughing and the siltstone roof, which is quite wet in places has broken back to a stable arch shape. The thickness of failed material varies from 300 mm to 1 m. Timber props and bars (approximately 150 mm diameter) originally placed on nominally 1.2 m centres for roof support have rotted and crumbled on the floor. Numerous slickensided structures are clearly visible in the roof but the majority appear to have only limited (0.5 m) continuity. At the first intersection, roof spans of up to 12 m are still stable.

Conditions in these old workings in the 8 ft seam are expected to be similar and very relevant to future mining in the lower seam. Both roof and floor showed no signs of heavy conditions or excessive deterioration with exposure to moisture.

3.2.2 4 ft 9 in Seam (Hittit Seam)

The 4 ft 9 in seam was extensively worked in the latter years of the Mount Nicholas operation, after closure of workings to the north-west. Two areas were mined, and each was cut off on the eastern side by faults trending north 17°. One area was accessed via portal M.D.4 and the other further east, through portal M.D.7. (Figure 12). The adit driven from portal M.D.4 is still standing for approximately 50 m, with an arched shaped roof in scree. The existing stable roof is up to 1 m above the timber bars. Coal faces on the walls have been covered with debris but the limited exposures near the top of coal appear to be stable.

Coal from the 4 ft 9 in seam was regarded as good steaming coal with much less dirt than the 8 ft seam (Ref 5). However, the overall quality was not considered to be as good as coal from the 4 ft and 6 ft seams.

Roof and floor strata were mudstone and in most areas, were quite stable. No floor heave was experienced and the roof could be adequately supported by timber props and bars. Even near the faults, conditions showed no signs of excessive pressure (Ref 5).

3.2.3 4 ft Seam

Initial mining at Mount Nicholas in the 1890's was limited to the 4 ft seam. Three areas were developed. Areas to the north and north-east were mined from a main roadway at north 60^{o} with access through a portal A in Figure 12. A third area was mined to the north-west with access through portal B (Figure 12). Portal B was slightly lower than the seam and the adit entering the workings therefore had a slight up grade. Both portals A and B have failed completely, closing off the entries, but their locations can still be clearly identified. Workings to the north-west are not shown on the plan in Figure 12 but were smaller in area than the north-west workings in the 6 ft seam. All mining was by hand methods and this seam was chosen for the initial mining because the coal was of good steaming quality and free from stone and dirt bands.

Mining was mainly bord and pillar but longwall was attempted in the workings to the north. A face approximately 100 ft long (Ref 5) was set up but the ground could not be controlled with the timber supports and massive roof failures eventually resulted in closure of the area and no further use of this mining method.

3.2.4 6 ft Seam

Of all the seams mined at Mount Nicholas, the best quality coal came from the 6 ft seam. It had high volatiles and consequently was the best coal for household use. A large area was mined by bord and pillar to the north-west (Figure 12) which was originally accessed from portal B by rising up from the closed workings in the 4 ft seam. Transport of coal became a problem in this entry and a second entry was driven from the workings on a slight up grade, which broke through to surface at portal C (Figure 12) (Ref 5). This area was worked in the 6 ft seam until 1937 when haulage distances became excessive and the area was closed. Only minor faulting was encountered and mining was relatively problem free (Ref 5).

Following closure of the north-west workings, another area further east was opened in this seam. Workings were entered through

M.D.17 with the return airway exhausting through the portal M.D.16 in Figure 12. M.D.16 is still open but the workings have not been inspected.

The 6ft seam had a sandstone roof and was mined by bord and pillar. Coal faces were advanced by undercutting the seam and blasting the tops by charging 5 holes drilled across the face (Ref 5). Roof and floor conditions were quite stable and timber props and bars provided roof support, where necessary.

Hard lumps (known locally as "nigger's heads") were frequently encountered during mining in the 6 ft seam.

3.2.5 Riley's Seam

Little is known of mining in this uppermost seam in the sequence (Figure 11). The single portal entry lies to the north-west of the tramway, further up the slope from portal C (Figure 12). Workings were thought to cover only a small area (Ref 5).

3.2.6 General Mining Conditions

Apart from localised areas, mining in all seams at Mount Nicholas was considered to be relatively stable, showing no signs of the very heavy conditions experienced at the Cornwall Mine (Ref 5). All seams had slight rolls (maximum amplitude approximately 0.6 m) and apart from the extra cost of brushing the floor in some areas, these "waves" in the seams had no adverse effect on mining.

Standard roof support was 150 mm diameter timber props and bars on 1.2 m centres. This proved to be adequate where the roof was dry. "Moist" roof was encountered occasionally causing a much heavier roof prone to failure. In these conditions, intermediate props and bars were erected where required. Lagging, consisting of 50 mm thick wooden laths, was also used between bars and the roof to contain the failure (i.e. to prevent the development of progressive failure). In very heavy ground, laths would be driven ahead of the last prop and bar (similar to spiling) to provide forward support. Even where the roof was heavy, there was no evidence of props punching into the floor (Ref 5).

Underground fires have occurred at the Mount Nicholas Mine and also at the Cornwall Mine, but there has been no evidence of methane at either mine. The fire at Mount Nicholas developed when coal adjacent to a "hot air" pump caught alight, bringing down a large area of roof (Ref 5).

Mining conditions at Mount Nicholas represent a marked contrast from the heavy conditions reported at Cornwall. However, it is likely that similar conditions may have developed if the 6 ft seam had been mined first. Attempts to then mine the 4 ft seam under the boundary of workings in the 6 ft seam would very likely have generated large pressures and consequent heavy roof and floor conditions. Clearly, in any future mining of two seams where interaction effects can develop, it is advisable to mine the bottom seam ahead of the top seam.

In general, the experience in mining all seams at Mount Nicholas is very relevant to mining in the lease area currently under consideration. The stability of the roof, floor and coal faces in the 8 ft seam (corresponding to the lower seam) indicates that if the immediate roof layers are adequately supported, stable conditions should be assured. Perhaps more importantly, the lack of any floor heave in the workings is indicative of a stable working floor in new workings provided precautions are taken not to induce high pressures on the workings by poor planning and scheduling.

3.3 Silkstone Mine

Silkstone is an old mine on the south side of Mount Durham approximately 1.8 km further west of the EL 5/61 western boundary (Figure 13). Sediments have been displaced approximately 90 m upwards by the Silkstone Fault. Mining was confined to two seams; thought to be the uppermost Delta seam where coal was 1.8 m thick and in Theta seam, the lowermost seam in a four seam sequence (Ref 6).

Workings in the Delta seam consisted primarily of one heading driven approximately north-east. Cover increased evenly for the first 37 m of the heading and thereafter remained relatively constant at 27 m. All coal, after driving the heading 64 m, showed some oxidation with air or oxygen emanating from ground water circulation through dirt bands at the top of coal. A major fault striking north 358^{o} and dipping 64^{o} west was encountered 98 m from the portal which provided a continuous channel

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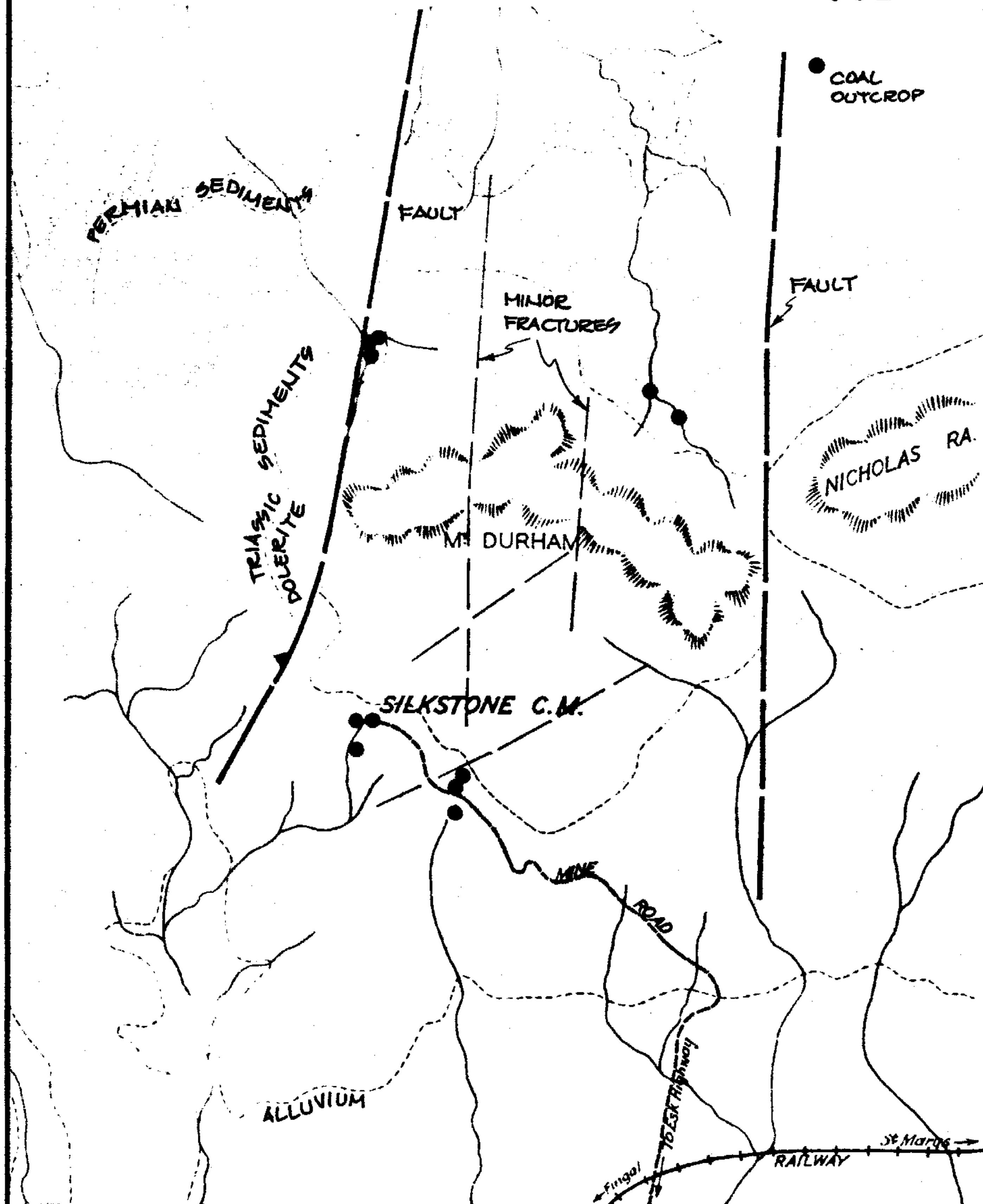

LOCATION OF SILKSTONE COAL MINE	FIG. 13
Scale 1: 23,760	Job Number 10-11
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for inflow of water from the surface. A second fault 79 m from the portal remained dry and did not create a problem. Due to the poor quality coal and the problems with water inflow, development of a regular bord and pillar layout, in the Delta seam did not occur. Conditions in the sandstone roof of the main heading were said to be stable (Ref 5) with no evidence of movement in the shale floor. An adit driven north 337^{o} also showed oxidised tops and similar, stable roof and floor conditions.

An adit was driven 42.7 m in the Theta seam located some 14 m below the Delta seam. Coal on the lower part of the seam was oxidised and the tops were stoney (Ref 6).

The lack of unoxidised, clean coal combined with water inflow from a fault hindered further development and the mine closed during the 1950's (Ref 5). Problems caused by the water at Silkstone could indicate that similar effects may be anticipated in a new mine at Mount Nicholas. However, the relatively low and constant cover at Silkstone is atypical of the area and therefore, a similar situation at Mount Nicholas is unlikely to occur. Relatively dry conditions in the Mount Nicholas workings confirm this assessment.

4. MINING CONDITIONS - LOWER SEAM

4.1 Pre-mining Stress

Only relatively few stress measurements have been undertaken in Tasmania in the past, and in all cases, the now inferior "flat-jack" methods were used. At Poatina, in mudstone at 160 m depth, a vertical stress of 8.5 MPa was measured. This is very high compared with the expected vertical stress due to the depth of cover which increases at 25 kPa per m cover. On this basis, a value of 4 MPa would have been expected, and it is therefore possible that local geometry influenced the stress at Poatina. Vertical stresses measured in Australia reported by Worotnicki and Denham (Ref 7) generally increase at approximately 25 kPa per m and this will be taken as a guide for the vertical stress in Nicholas Range area.

Apart from the local region around Huntsmans Cap, the cover at Mount Nicholas increases gradually on both the north and south sides; with the gradient on the south side being somewhat greater than the north. The vertical stress is expected to increase accordingly with few, if any, stress concentrations induced by the terrain.

Horizontal stresses in mainland Australia tend to be 1.5 to 2.0 times the vertical stress due to additional tectonic components. (Note that the component of horizontal stress due to confinement is only 0.5 times the vertical stress). There is some evidence (Ref 7) for this trend continuing in Tasmania with the east-west component being slightly less than the north-south component. Steeply dipping major normal faulting and low angle minor thrust faults observed at the Cornwall Colliery tend to indicate the reverse. i.e., stresses east-west, are greater than north-south.

In peripheral areas of the Nicholas Range Deposit on the north and south sides where the cover is low, horizontal stresses will be substantially less than 1.5 - 2.0 times the vertical stress. Consequently, high lateral pressures on roof and floor strata are unlikely in these areas but are expected to become more significant where cover is maximum. This expectation is confirmed by mining experience in the Mount Nicholas and Cornwall Mines.

Since the Nicholas Range is aligned approximately east-west, it is reasonable to assume that the two horizontal stresses will be close to north-south and east-west. Roadways and cut throughs should therefore be driven on the skew to minimise lateral pressure effects on the roof and floor. In old workings, at Mount Nicholas and Cornwall, headings were developed in almost every direction. In the most recent workings, main roadways were inevitably driven either north-west or north-east where, from practical experience, conditions were found to be more stable.

In summary, pre-mining stress is unlikely to cause heavy roof and floor in areas up to 1.5 to 2 km in from the sub-crop. In the remaining area under maximum cover, both vertical and horizontal stresses will be maximum and it will be important to plan headings and cut throughs in north-east/north-west directions. It will also be essential to avoid geometrical layouts which locally cause stresses to increase.

4.2 Roadway Stability

Conditions in roadways depend on the stability of the roof, floor and pillar faces and each are inter-related. For example, both roof and floor stability can be adversely effected by "punching" caused by stiff, high strength pillars. In this section of the report, conditions in each zone will be treated separately while recognising the implications of any interaction.

4.2.1 Roof Stability

Stability of roof strata will change across the lease area due to:

- variations in roof strata
- stress variations
- influence of minor structures

The most stable roof will be found in moderately stressed regions where sandstone roof extends greater than 3 m above the top of coal. Stability will not be due to the inherent strength of the sandstone (Table A1.2 indicates that sandstone and mudstone have similar strength and stiffness) but to the lack of bedding and other planes of weakness. Thus, providing thick slabs of sandstone remain intact during and after mining, the roof will remain stable.

The performance of layered roof strata can be readily assessed from fixed end beam calculations, particularly in this case since material testing has shown that the coal pillars are substantially stronger ($UCS_{coal} = 35$ MPa; $E_{coal} = 3.11$ GPa) and just as stiff as the immediate roof ($UCS_{sandstone} = 24.9$ MPa; $E_{sandstone} = 3.32$ GPa). Because the sandstone has a low tensile strength (2.4 MPa) compared to its compressive strength, the tensile strength will be the physical property most critical to roof stability. In a typical profile of the sandstone roof (Figure 14) a beam of thickness t will bend due to its own weight and lateral pressure. Maximum deflection will occur at mid-span while maximum tension will develop on the upper face (see Figure 14). A plot of maximum tensile stress developed as the beam thickness t varies (Figure 15) shows that 6 m long beams thinner than 0.43 m are prone to cracking unless adequately supported.

Results of material testing in Appendix 1; Table A1.2 show that the respective strengths of sandstone and mudstone are similar. Therefore, if mudstone showed no structural imperfections, roof conditions would be similar to the sandstone. But mudstone is banded and bedding tends to be much more prominent than in sandstone. Consequently, worst roof conditions

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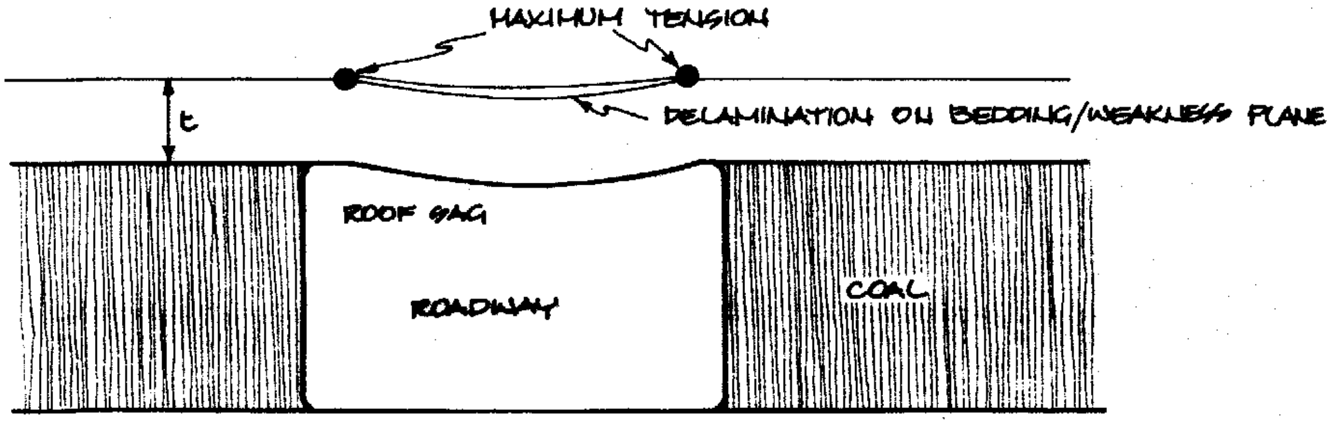
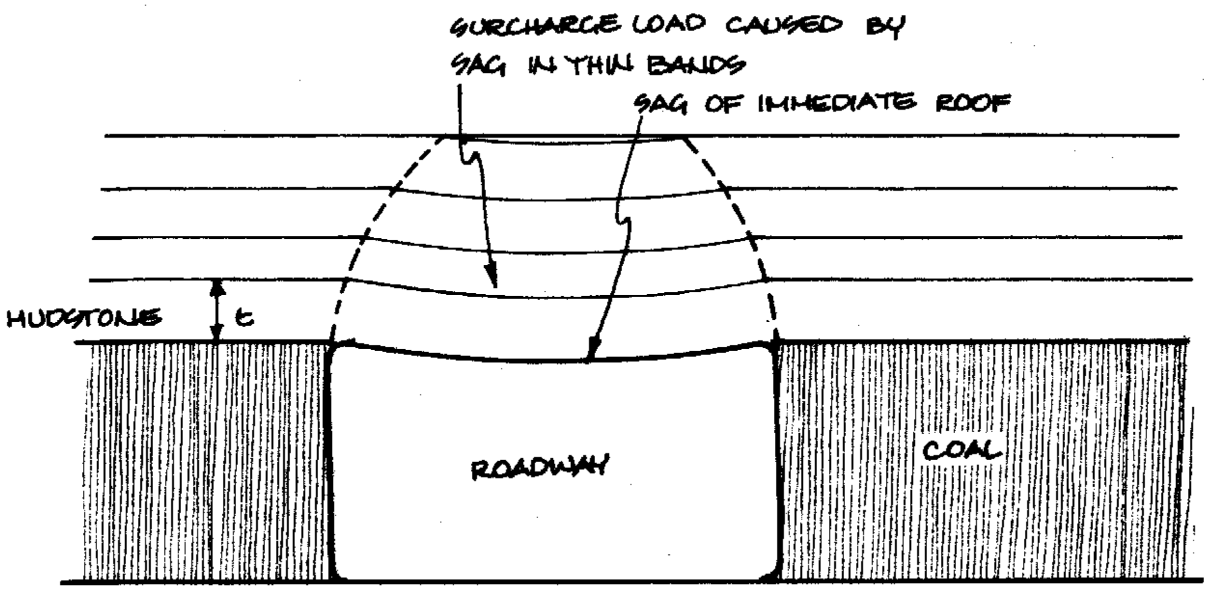
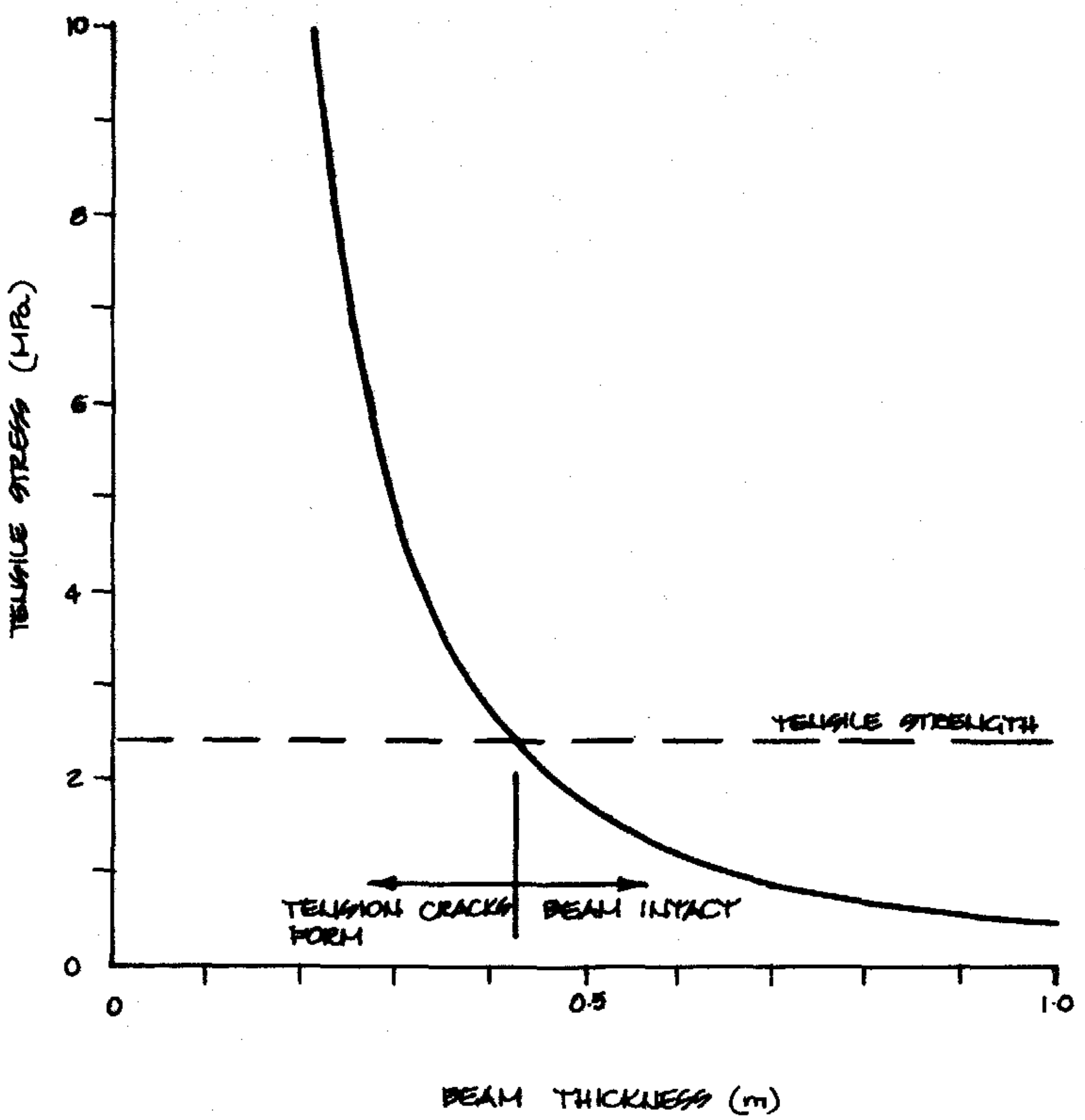


SANDSTONE ROOF



LAMINATED MUDSTONE/SILTSTONE/SANDSTONE ROOF

SKETCHES OF TYPICAL ROOF PROFILES	FIG. 14
Scale NTS	Job Number 10-11
Barrett, Fuller & Partners	



MAXIMUM TENSILE STRESS IN FIXED END BEAM - SANDSTONE		FIG. 15
Scale	Job Number 10-11	
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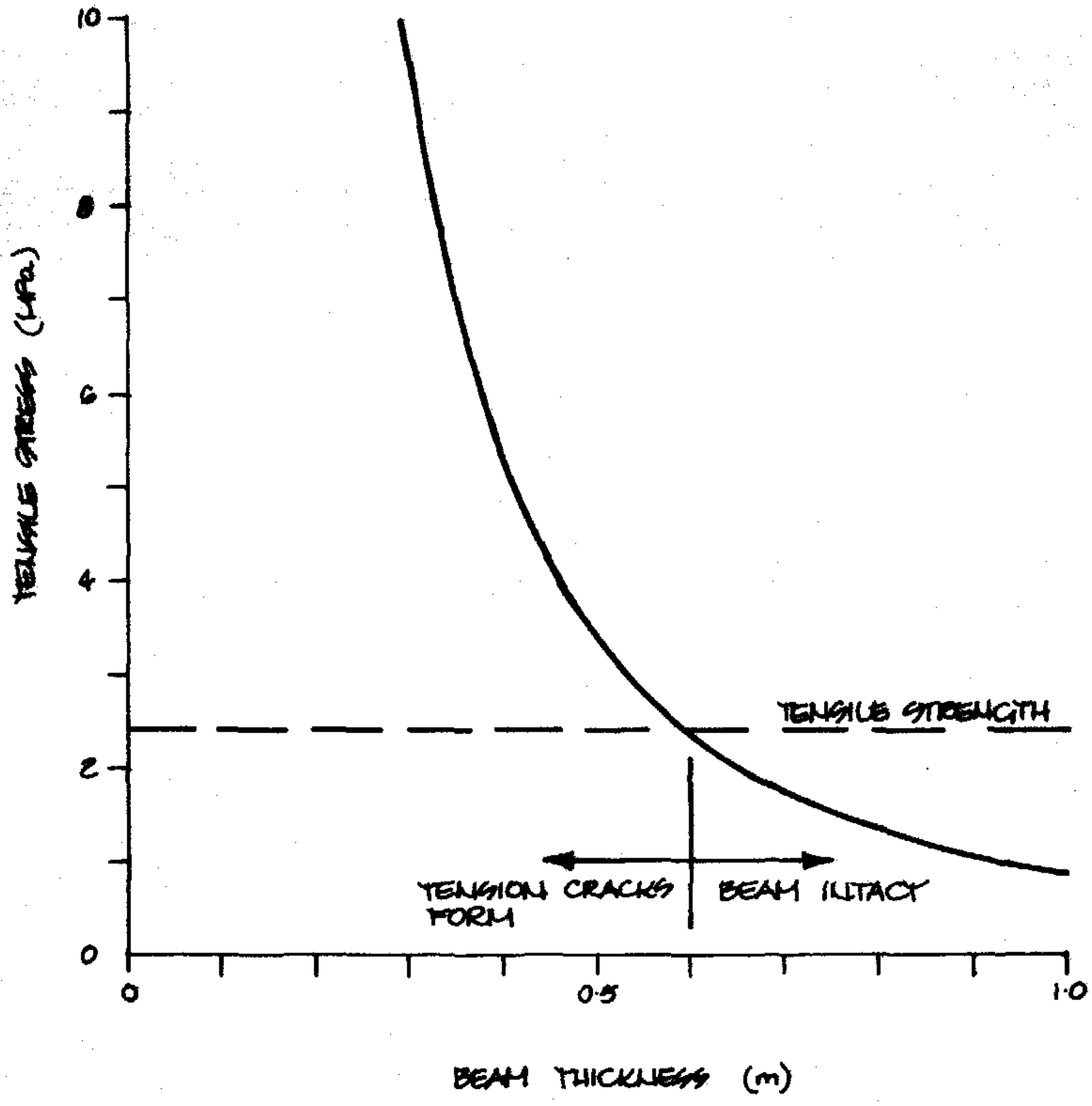
will develop in areas where the foor comprises thin layers of mudstone, sandstone and siltstone, with mudstone forming the immediate roof. Thinner layers above the mudstone will follow any downward sag, develop tensile cracks and effectively add a surcharge load to the immediate mudstone. Assuming that the loading on the beam is doubled due to the surcharge, 6 m long mudstone beams thinner than 0.6 m (Figure 16) will develop tensile cracks and subsequently fail unless adequately supported.

In both of the above cases (i.e. sandstone and mudstone roof), the effect of lateral pressure on roof stability will reduce the tendency for tensile cracks to develop but roof sag will increase.

Experience at the Mount Nicholas Colliery has highlighted heavier roof conditions in areas where roof strata were moist. Free swell tests on mudstone have shown them to be susceptible to swelling when wet, but the average swelling coefficient of 2.64% is not abnormally high for weak mudstones. Thus, special problems due to swelling are not anticipated. Of far more significance is the likely strength reduction when mudstones become wet.



MAXIMUM TENSILE STRESS IN FIXED END BEAM - LAYERED MUDSTONE	FIG. 16
Scale	Job Number 10-11
Barrett, Fuller & Partners	

No specific data are available on this reduction but simple immersion tests on mudstone suggest that the strength may reduce to only 50% of the dry strength. Wetted samples tend to crumble into small fragments with a texture similar to fine gravel. If this occurred in the immediate roof strata, only two forms of support would be capable of preventing progressive failure. These are:

- fine wire mesh held in place by multiple bolted W straps, or
- timber or steel sets with timber lagging.

In some areas, mudstones may already be wet due to ground water, but initially dry material will absorb moisture from the air, particularly inby from the intake where the relative humidity will be maximum. This problem can be tackled by two approaches;

(i) accept the fact that moisture ingress will occur over a long time period and provide adequate support, anticipating the heavier conditions in the long term, or

(ii) attempt to seal the mudstone surfaces as they are exposed and provide supports at the usual density.

The second alternative may appear more attractive if proven guniting or shotcreting techniques could be used. However, due to the degree of movement normally experienced in stratafied materials, thin layers of either shotcrete or gunite would debond from the mudstone, crack and tend to fail. The only material which would be suitable is a sprayed on silicone based coating which has been developed in the United Kingdom. This has not been used in N.C.B. Collieries because it cannot meet the safety standards of the N.C.B. Consequently, there has been very little experience with the method world-wide and it can only be recommended as a technique worth developing in Australia. The more practical solution is to accept that the mudstones will gradually deteriorate and to provide mesh, straps and rock bolt support from the outset.

Supports for both mudstone and sandstone roof must be designed to reinforce the roof layers and oppose the formation of thin layers in the immediate roof. (<0.4 m for sandstone and <0.6 m for mudstone) For sandstone roof, 1.8 m long, 24 mm diameter resin anchored roof bolts will be required with 3 bolts per steel W strap and straps every 1.8 - 2.0 m along roadways. The face should not advance more than 4 m (2 straps) ahead of the last strap before installing support. Apart from areas of locally broken ground, bolt anchorage will not be a problem.

In laminated roof and particularly where mudstone is directly exposed, W straps should be spaced at 1 m intervals with 5 bolts per strap. The more permanent openings such as main headings etc and any sections where the roof is moist should be meshed to contain progressive failures. Roof bolt anchorage in mudstones will be unreliable where moisture is present and bolt lengths should be altered to anchor in sandstone. If this is not possible, 7 bolts should be installed in each strap instead of the usual 5.

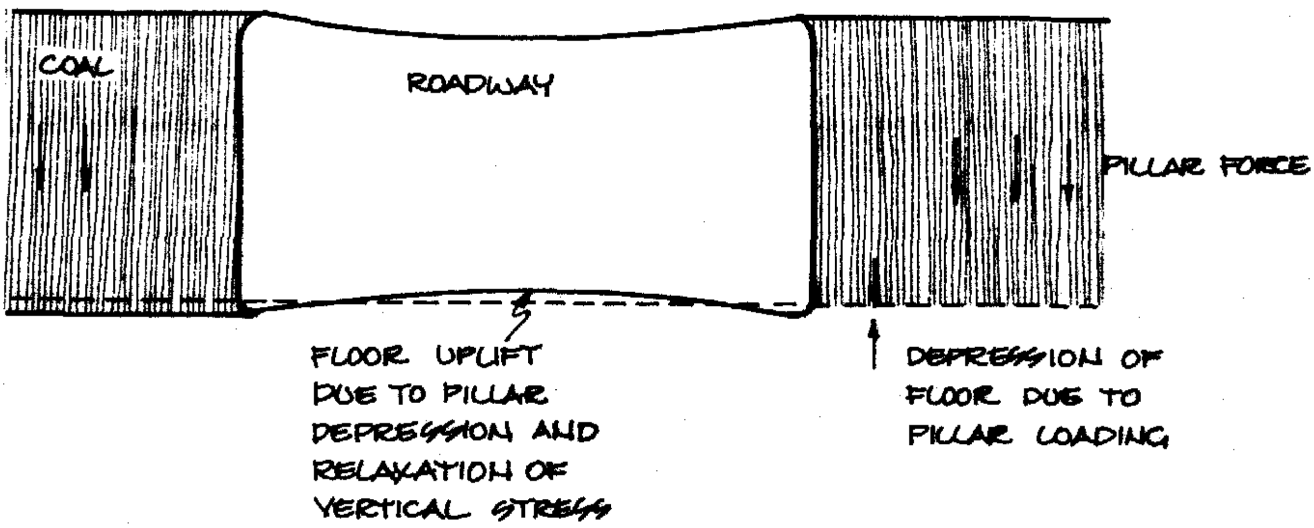
All bolts should be pre-tensioned to a nominal 40 kN (4 tons) by applying an installation torque of 250 to 300 Nm.

4.2.2 Floor Stability

Extracts from geological logs (Figures 7, 8 and 9 in Section 2) indicate almost without exception that the immediate floor is mudstone. From the operational viewpoint, it is preferable that the floor be relatively level and remain so for long periods. This is particularly important in travelling and haulage/transport roadways. As coal is cut, floor strata normally expand into the opening, with the maximum uplift occurring near the roadway centre. This is caused by pillar pressing into the floor and the relaxation of stress, both vertical and horizontal, in the immediate floor layers. (Figure 17). Additional floor heave can be caused by:

- lateral stress
- swelling of moisture sensitive layers
- bearing capacity failure in the floor due to low strengths in the floor and/or high pillar loadings.

The "punching" action of pillars into floor strata depends on pillar loading which is



SKETCH OF TYPICAL FLOOR UPLIFT AS COAL IS MINED	FIG. 17
Scale NTS	Job Number 10-11
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related to pillar and roadway dimensions and vertical stress. At particular values of these parameters, maximum expected floor displacements due to pillar loading are given in Table 1.

Lateral stress is not expected to be high in the area and there is no evidence in previous workings that lateral stress caused floor heave. The extreme floor heave in the Right Hand Workings at the Cornwall Mine was the result of a bearing capacity failure in mudstone floor mainly due to high, mining induced pillar loading. Cohesion and friction angle of mudstone determine the susceptibility of a mudstone floor to fail due to excessive bearing pressure applied by pillars. For square pillars on the mudstone at Mount Nicholas, with no surcharge load on the floor, bearing failure will occur when the pillar stress exceeds P where:

$$P = 30.6\ C + 0.06\ B$$

C is the cohesion of mudstone (MPa)

B is the pillar width (m)

Based on the cohesion determined from triaxial testing of mudstones, values of P for the pillar sizes in Table 1 are given in Table 2, together with the factor of safety against bearing failure in the floor.

Thus, unless pillar stresses are increased significantly due to seam interaction or during pillar extraction, bearing failure and consequent heaving of the floor as experienced at the Cornwall Mine will not occur during mining.

TABLE 1

FLOOR DISPLACEMENTS DUE TO PILLAR LOADING - 6 m WIDE ROADWAY

Cover (m)	Pillar Size (m)	Vert. Stress {25 kPa/m} (MPa)	Pillar Stress (MPa)	Floor Displacement (mm)
150	15	3.8	7.4	15.1
250	22	6.3	10.1	30.5
350	33	8.8	12.2	55.3

TABLE 2

BEARING CAPACITY OF MUDSTONE FLOOR

Pillar Size B (m)	Bearing Capacity* (MPa)	Factor of Safety
15	86.6	11.7
22	87.0	8.6
33	87.7	7.2

* Bearing Capacity is based on a cohesion of 2.8 MPa determined from triaxial tests on floor mudstones

The one possible exception to the above may develop if the cohesion and friction angle decrease substantially when mudstone is subjected to water, or moisture from humid air. It is therefore recommended that a thin layer (150 mm) of coal be left on the floor in areas where free water is encountered, on the main intake and on all main travelling roads. As an alternative, the application of sealants has been considered but the necessity to have roadways accessible to traffic makes thin layers of sealant unsuitable.

4.2.3 Pillar Stability

The stability of coal pillars depends on their strength capacity compared to the stress developed due to mining. Pillars in the centre of panels tend to be more highly stressed than those near barrier pillars around workings and, as the panel width increases in lateral extent, pillar stresses will increase.

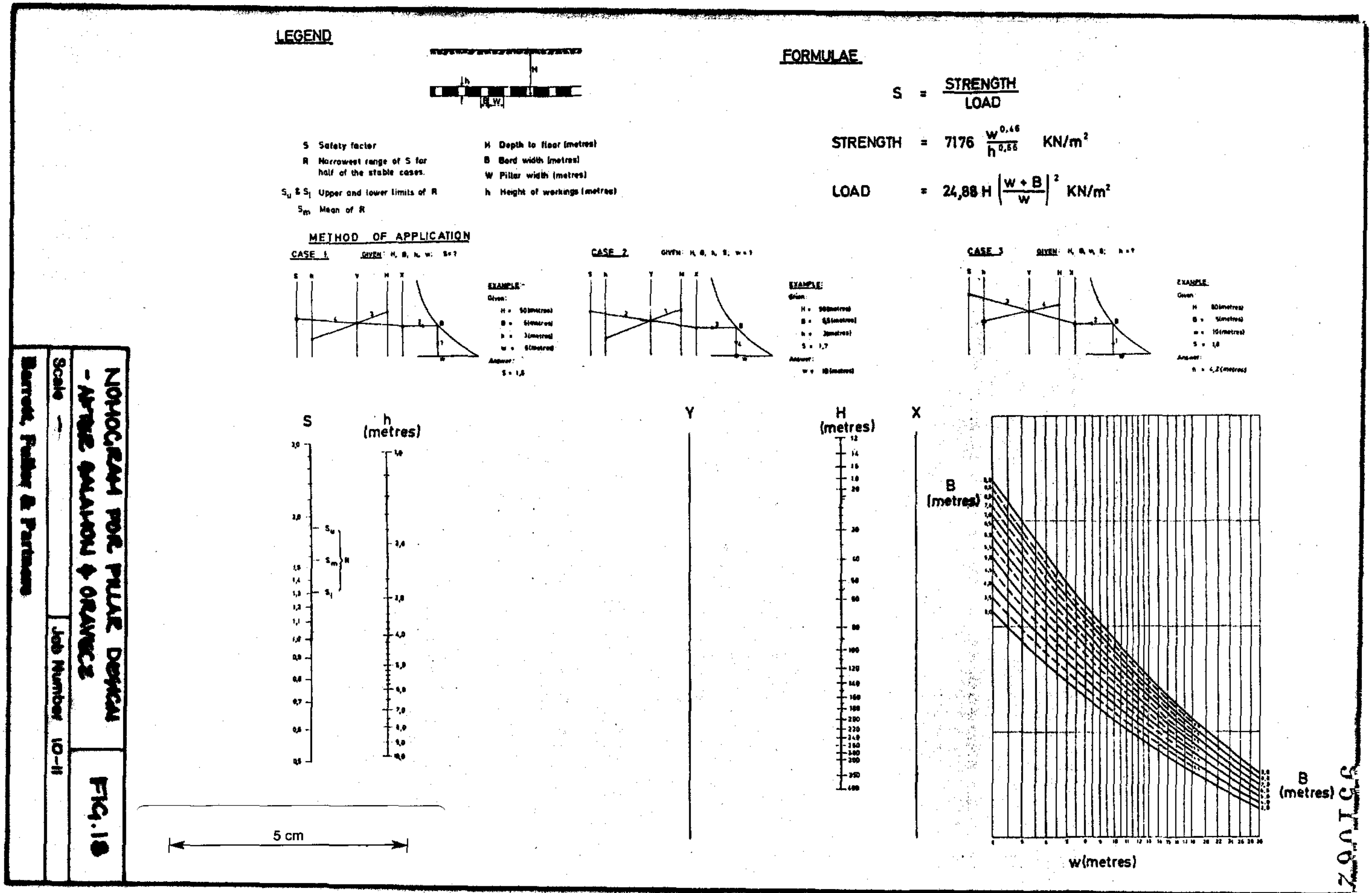
In designing pillars, there is the conflicting requirement that the size of pillars should be as small as possible to maximise primary extraction yet sufficiently large to remain stable. Salamon and Oravecz (Ref 8) have developed a design procedure for coal pillars based on a safety factor against failure. Pillar strength and load formulae have been developed by correlation from operating mines where drilling and blasting are used. Under normal conditions, a safety factor of 1.6 to 1.8 can be used but in the Nicholas Range area where roof and floor strata are relatively weak, less pillar confinement is likely and a safety factor of 1.9 is recommended. The complexity of the design process has been simplified to a nomogram (Ref 8) in Figure 18. The required pillar sizes and the variation in primary extraction ratio at various values of cover are given in Figure 19 for two roadway widths; 5 m and 5.5 m.

Minor sloughing can be expected from all pillars due to the weak roof and floor contacts. This should not have any adverse effect on roadway access and overall stability and not cause any danger to miners and equipment. Provided the roof is supported with pattern rock bolts, W straps and mesh, where necessary, there is no necessity to install props and sprags for pillar support. If major spalling did develop in a localised area such as a fault zone, this could be contained by bolting mesh directly to the affected area of the pillar.

4.3 Stability at Intersections

Mining experience has shown that any problems with roadway and cut through stability tend to be amplified at intersections due to the larger spans and reduced confinement. Both sandstone and laminated mudstone roof will show increased sag at intersections and as a result, the tensile stresses in the immediate roof layer can be expected to double. Thus, beams somewhat thicker than those considered in section 4.1 could become unstable and therefore increased roof support must be provided.

Intersections with sandstone roof should be supported with 1.8 m long, 24 mm diameter resin anchored rock bolts and steel W straps installed every 1.5 m. Five bolts are required in each strap. The above support density is substantially greater than the



LEGEND
S Safety factor
R Narrowest range of S for half of the stable cases.
S_u & S_l Upper and lower limits of R
S_m Mean of R
H Depth to floor (metres)
B Bord width (metres)
W Pillar width (metres)
h Height of workings (metres)
FORMULAE
$S = \frac{STRENGTH}{LOAD}$
$STRENGTH = 7176 \frac{w^{0,46}}{h^{0,66}}$ KN/m²
$LOAD = 24,88\,H \left(\frac{w+B}{w}\right)^2$ KN/m²
METHOD OF APPLICATION
CASE 1 GIVEN: H, B, h, w; S = ?
CASE 2 GIVEN: H, B, h, S; w = ?
CASE 3 GIVEN: H, B, w, S; h = ?
EXAMPLE
S
h (metres)
Y
H (metres)
X
B (metres)
w (metres)
5 cm
NOMOGRAM FOR PILLAR DESIGN - AFTER SALAMON & ORAVECZ
Scale —
Job Number 10-11
Barrett, Fuller & Partners
FIG. 18

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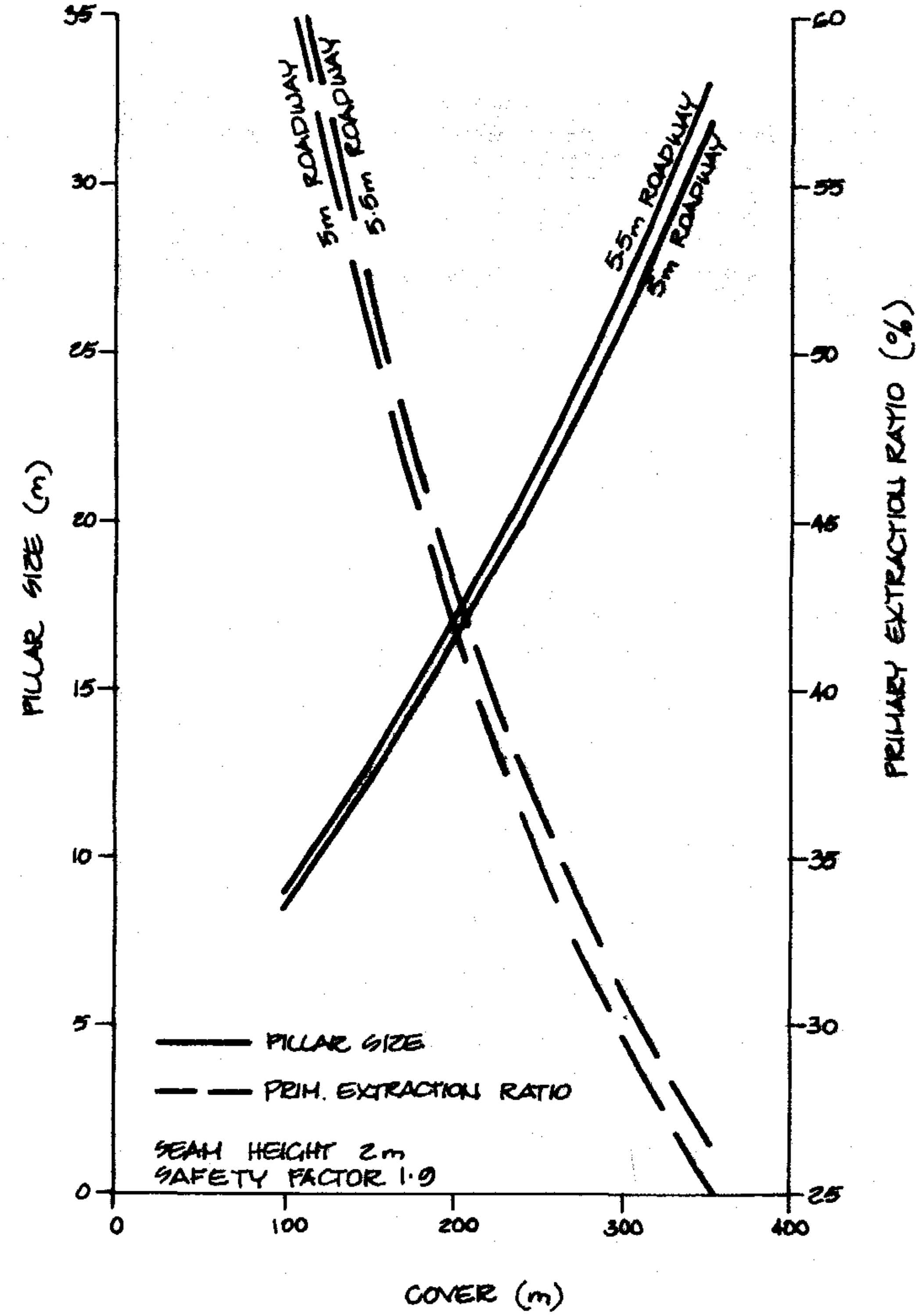

PILLAR REQUIREMENTS & EXTRACTION RATIO - LOWER SEAM	FIG.19
Scale —	Job Number 10-11
Barrett, Fuller & Partners	

equivalent roof support in roadways to ensure adequate support for the thicker sandstone layers. Roof bolting is intended to reinforce and confine the roof, thereby preventing tensile crack development.

Laminated mudstone roof will also require denser support at intersections. Seven bolts should be installed in each W strap instead of the five bolt layout recommended for roadways and cut throughs. Mesh should be placed between the straps and the roof at all intersections irrespective of whether the roof is dry or moist. This will provide some bridging action between W straps and control failures which may develop as the mudstone becomes weaker. This insistence on mesh at all intersections may appear conservative but it must be noted that intersections will be the first zones to show the adverse effects of the weakening of mudstones.

The floor at intersections will show less uplift and tendency to buckle than in roadways and cut throughs. Ingress of moisture into mudstones in the floor will remain critical at intersections. It is therefore recommended that the guidelines for roadway floor (i.e. 150 mm of coal should be left where free water is present, in the main intake and on all travelling roads) also apply across intersections.

4.4 Mining the Split Lower Seam

A series of mining scenarios is possible depending on coal quality in the split seam (top split is designated lower seam 1 and the bottom split, lower seam 2; Ref 1).

Indications from coal quality testing completed to date are that the better quality coal is in lower seam 2. Therefore in terms of mining, lower seam 2 would be considered in preference to lower seam 1 since the total reserves of each are approximately equal. Based on these data, the number of mining options is reduced to the following:

- mine lower seam 2 only and aim for maximum total extraction.
- mine both seams separately but in a co-ordinated manner, with maximum total extraction of lower seam 2 and only primary extraction in lower 1.
- mine both seams simultaneously.

The first option is clear cut and the roadway conditions discussed in Section 4.2 and 4.3 can be anticipated. The immediate roof will generally be in mudstone and this can be supported by bolts anchored within seam 1.

In terms of overall stability, the second option is unattractive. Pillars formed in both seams would need to be aligned vertically and workings in seam 1 would always need to be mined in advance of the seam 2 to avoid concentrations of pressure due to the seam interaction. The relatively thin band of mudstone between the seams would become the floor of seam 1 and the roof of seam 2. Even with costly support techniques, this zone will tend to be unstable. Such failures will result in the loss of access to areas in lower seam 1, making any pillar extraction in seam 1 virtually impossible. In addition, only minimal recovery of pillars from lower seam 2 could be contemplated because the overall stability of workings in lower seam 1 depend on stable pillars remaining in lower seam 2. If a goaf was formed, it would, of necessity, involve both splits of the lower seam and because of the total effective seam height involved(i.e. between 5 and 7.5 m) roof conditions on the retreat in lower seam 2 would be very difficult to support and control.

The third option to mine both seams simultaneously would involve primary extraction in lower seam 2 and selectively cutting the mudstone parting to expose the lower face of lower seam 1. Depending on the "reach" of the continuous miner, part or all of the lower seam could be extracted at the primary mining stage. Roof support in these circumstances would be difficult, expensive and require special equipment because of the high working height. Assuming primary extraction was possible, retreat mining would suffer from the same difficulties as the second mining option due to the extreme face pressures created by goaf formation of a very thick seam.

Option 1 is clearly the most viable method and if mining is well planned to aim for maximum recovery of lower seam 2, it is likely that the total tonnage mined will be similar to either option 2 or 3 and the overall coal quality will be better.

5. MINING CONDITIONS - MIDDLE SEAM NO. 2

5.1 Roadway Stability

Geological logs in the vicinity of the middle seam in Figures 4, 5 and 6 indicate that the roof will generally be layered, with mudstone or carbonaceous mudstone directly exposed. In some cases the layered structure persists for a distance greater than the seam height so conventional rock bolt supports could only be anchored within the layered zone.

Mudstones also appear to be reasonably consistent in the immediate floor but this will be further clarified when logs of holes being drilled in the north-east area become available.

5.1.1 Roof Stability

A limited test program on mudstones above and below the middle seam has revealed that they are significantly weaker in both compression and tension than mudstones near the lower seam.

From the test results in Table A1.3 of Appendix 1, it can be inferred that mudstone has virtually no tensile strength and therefore negligible resistance to tensile cracking.

Ground stresses around the middle seam should be somewhat lower in magnitude than for the lower seam and should not have any adverse effects on roof stability.

Due to the very low strength of roof materials, the roof can be expected to be very heavy irrespective of the amount of moisture present. The immediate roof layers will crack as soon as they are exposed and the confinement provided by the coal is removed. Excessive roof sag will develop and the sequence of cracking and downward movement will progress rapidly to upper layers unless roof deflection is quickly arrested by the placement of adequate support. Clearly, even minimal exposures of unsupported roof will progressively fail due to the very low material strength. Bord width (L) is critical to the roof stability in such weak roof since:

- maximum roof deflection is proportional to L^4, and
- maximum tensile stress is proportional to L^2.

In the middle seam, the specified bord width should be the minimum to ensure compatibility with the particular continuous miner-shuttle car equipment to be used. For the purpose of this study, 5 m will be assumed on the basis that special narrow heading equipment will not be purchased.

Roof support for roadways in the middle seam can take the form of:

- pattern roof bolting at high density with mesh and W straps (similar to that recommended for the lower seam), or
- timber props and bars, with minimal bolting through bars and timber lagging where necessary.

Both methods are expensive in terms of component costs plus the loss in production time due to the long cycle times required for support installation. Dense rock bolting backed with mesh will contain blocky material and tend to choke off progressive failures, provided sufficient anchorage strength can be developed and bolts long enough to span the broken ground can be used. Timber props and bars, on the other hand, is a proven support method in the area (the Hittit seam was extensively mined at Cornwall and Mount Nicholas with timber props and bars) but will substantially reduce accessibility, particularly in narrow headings.

In terms of overall efficiency, the rock bolt support method is recommended. Given the constraints of low working height, rock bolts should be as long as possible and must be anchored in sandstone. High thrust and torque capacity roof bolters should be used so that bolts can be fully resin bonded rather than point anchored as recommended for the lower seam. In localised areas of roof where the thickness of laminated material is greater than the maximum possible bolt length, flexible strand bolts of the form detailed in Appendix 2 should be used. If required, the length of strand bolts can be up to twice the height of the workings. The free end of the strand should be "splayed" to act as a guide in the drill hole and provide good resin mixing. Strand bolts will add to the total support cost but they are a practical alternative to coupled mild steel rock bolts when working height limits the maximum bolt length.

The bolting pattern recommended in all roadways and cut throughs is 5 bolts per

W strap with straps every 1 m of advance, and a continuous cover of steel mesh. Straps and mesh should extend to the rib on both sides and be bolted as close as practicable to the ribs. If possible, these side bolts should be angled over the ribs.

5.1.2. Floor Stability

Conditions in the mudstone floor are expected to be similar in both middle and lower seam workings. From the one test conducted on mudstone floor, very low tensile strength (0.14 MPa) was measured but the sample was particularly weak and atypical of the floor mudstone. Therefore, provided adequately sized pillars are formed and stress concentrations induced by mine planning are minimised, dry mudstone floor will not heave due to bearing capacity failure. As with the lower seam, a thin layer of coal (150 mm) should be left in moist areas, main travelling roads and in the main intake to protect the mudstone against the ingress of moisture.

5.1.3. Pillar Stability

Based on the design concepts of Salamon and Oravecz (Ref 8) used previously for the lower seam (Section 4.2.3.) with a factor of safety against pillar failure of 1·9, pillar sizes required and the associated primary extraction ratios at various cover values are plotted in Figure 20. A fixed seam height of 1.5 m and roadway width of 5 m have been assumed for the design.

Some spalling of thin surface layers from pillars will be inevitable due to movement in the roof causing increased compression

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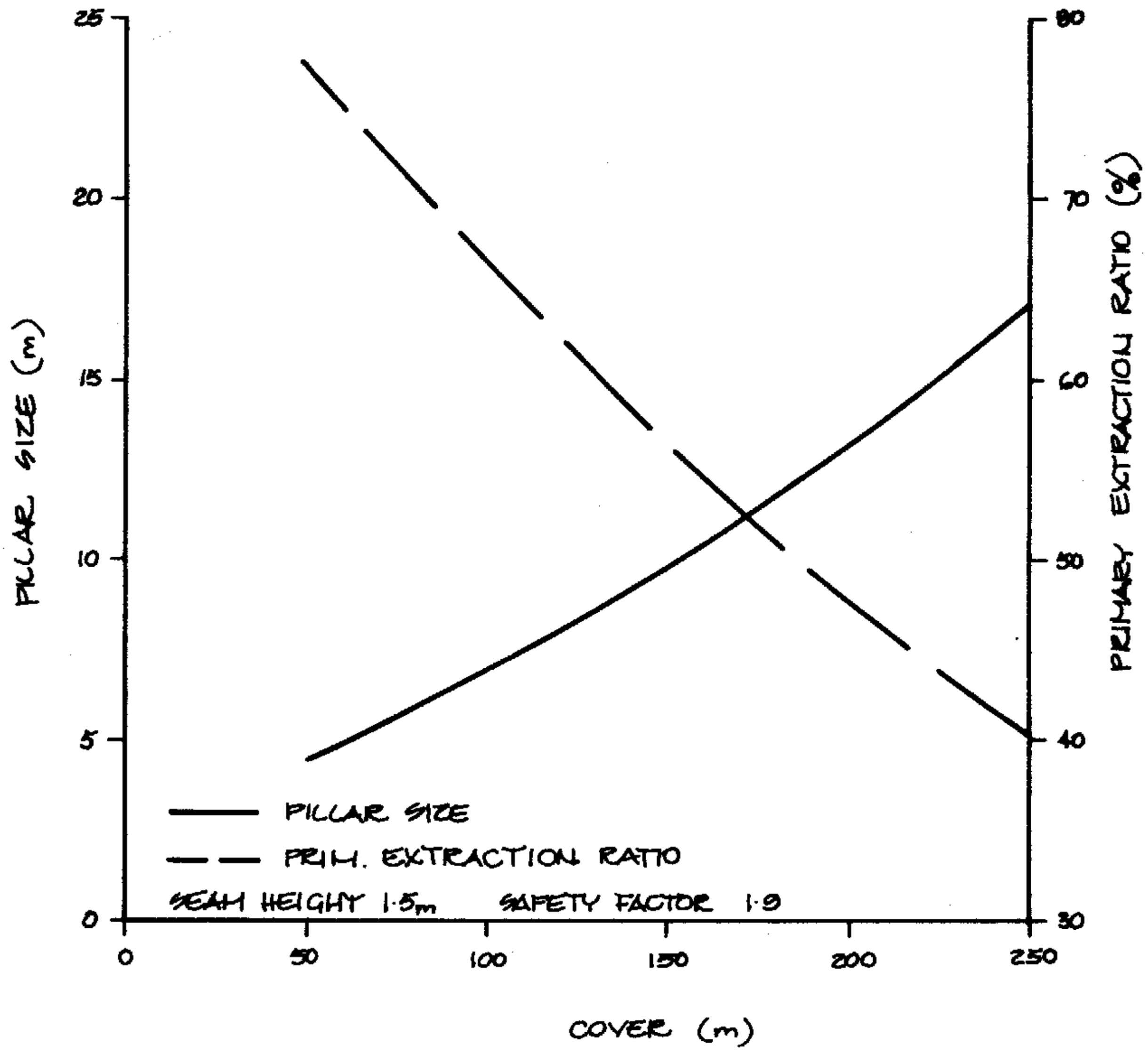

PILLAR REQUIREMENTS & EXTRACTION RATIO - MIDDLE SEAM	FIG. 20
Scale –	Job Number 10-11
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and buckling in the pillar layer. This minor sloughing will also be assisted by vibration associated with the normal operation of a continuous miner and shuttle car. Props and sprags will not be required and should any pillar face show signs of a more deep seated failure, mesh can be bolted directly to the weak zone to prevent the development of progressive failure. Localised failures on pillar surfaces will not have any adverse effects on overall pillar strength and provided the pillar sizes similar to those indicated in Figure 20 are used, pillar stability can be assured.

5.2 Stability at Intersections

Roof conditions will tend to be more unstable at intersections than roadways due to a reduction in confinement. Cracked roof strata on roadways can tend to self-stabilise if blocks are prevented from falling and overall confinement of the broken mass is supplied by the roof supports and coal pillars. At intersections, any confinement provided by pillars becomes negligible and therefore a greater support density is required.

It is recommended that the normal practice of strapping and meshing be continued at intersections, with straps at 1 m intervals. The number of bolts per strap should be increased from 5 to 7 and each should be full-column resin grouted to reinforce the broken ground. As with roadways, strand bolts should be used if a sandstone anchorage horizon cannot be reached with conventional rigid bolts.

The floor strata at intersections should be similar to roadways and a 150 mm thick coal band should be left on the floor where necessary to minimise the deterioration of mudstone layers.

6. SEAM INTERACTION

To date, mining conditions in any one seam have been considered independent of mining activities in any other. However, in some of the potential mining situations within the deposit, mining conditions in one seam could be dependent on activities in other seams. Such dependence is a function of the geometry, the mining methods used and the mining sequence.

In regular bord and pillar workings the influence of extracting one seam on the extraction of an adjacent seam is negligible once the distance between the seams is greater than 75% of the centre to centre spacing of the pillars. When seams are closer, the redistribution of vertical stress due to forming the pillars in one seam affects the pillars in the other seam and the pillars should be superimposed. Neighbouring seams with partings of 30% to 50% of the bord width can be mined but only if the separating strata contain a reasonable proportion of competent sandstone. At intervals between the above two limits (generally at intervals up to 1.5 times the bord width) failure of the parting could occur. Mining can be undertaken by using proper roof support, a higher factor of safety for the pillars in each seam to allow for failure of the parting and proper sequencing.

When the seams are not thick and the separating band is not more than 1 m thick, the two can be worked as one face and the dirt between used as packing material for roadside and waste support. Alternatively, the lower seam may be worked 2 to 3 m in advance of the upper, then the dirt brought down and packed in the waste and the top coal finally mined out. At each stage, supports are set as required to secure the band or seam forming the temporary roof. Good partings and strong bands are needed if undesirable mixing of coal and dirt is to be avoided. Thin dirt bands may be removed by cutting machines and the two seams worked together.

When the intervening dirt between the seams is too great for the above method, the bottom seam is worked first then the higher one a convenient distance behind. Often the lower seam is in panels, each worked out to the panel boundary. The top seam is then worked on the retreat.

In some cases the upper seam is worked at 45° and even at right angles to the lower seam, especially in intensive mechanised methods.

If barrier pillars are used in any seam, the stress redistribution over each panel affects a large area - much greater than if a regular pattern of pillars is used. The affected zone is greater above rather than below a panel. Even if the barrier pillars in adjacent seams are superimposed, a large strain differential exists near the boundary of the barrier pillars. In such a situation if the bottom seam is mined first, the rib-sides in the upper seam should be mined first, especially if the roof rock is poor. Case history studies have been reported where such interaction is marked even with seams 44 m apart.

Thus in all cases in which multiple seams are to be mined with other than regular room and pillar layouts, detailed studies of interaction need to be undertaken.

7. PILLAR EXTRACTION AND GOAF FORMATION

Retreat mining can substantially alter the stability of the roof, floor and pillars created during primary extraction depending on the ability of the roof to form a goaf. Few, if any, problems are anticipated in developing a goaf in both the middle and lower seams at Mount Nicholas due to the predominance of layered mudstones. Sandstones will also tend to break up readily due to their comparatively low compressive and tensile strength. To promote goaf formation and thereby minimise associated increases in vertical pressure, retreat faces should be planned, where possible, to parallel the continuous structure in the roof strata.

Any instability which may arise will occur in the roof of headings and cut throughs as the increased vertical pressure is applied behind the retreat face. However, provided the guidelines for support detailed in Sections 4 and 5 of this report are followed and the support is installed correctly, roof falls will not be common.

The increase in pillar load due to goaf formation has been analysed (Ref 9) for roof with a UCS of 45 MPa and modulus 7 GPa and coal with UCS 28 MPa and modulus 3GPa. The relatively stronger, and stiffer roof caused maximum pillar loadings to increase by a factor 1.8, some 18 m behind the goaf. At Mount Nicholas where roof strata are generally weaker than the coal and of similar stiffness, a load increase factor of 1.3 to 1.5 can be expected. Thus, pillars designed with the safety factor of 1.9 against failure should remain stable during pillar extraction. The lack of localised areas of much stronger roof will ensure that roof characteristics remain consistent and predictable and consequently, pillars should be loaded evenly.

Floor heave caused by increased pillar loading is a common problem in many retreat mining operations. The mudstone floor at Mount Nicholas has sufficient bearing capacity to withstand a large increase in pillar load (see section 4.2.2.) provided it remains dry and the full shear strength is retained.

Conditions overall are not expected to deteriorate during pillar extraction due mainly to the inherent caving potential of all roof strata expected to be encountered. Apart from wooden props and lids installed at the retreating face, no additional supports should be required.

8. INFLUENCE OF GEOTECHNICAL ASSESSMENT ON MINING ECONOMICS

Mining conditions in both the middle and lower seams assessed from available geological data and material properties affect the following two main factors of economic significance:

- primary extraction ratio, and
- roof support requirements.

The total extraction will depend more on the method chosen for retreat mining and because a goaf is expected to form without any problems, the geotechnical properties of the materials will have only a minor effect on the total extraction. The only exception is in the area where the lower seam splits into lower 1 and lower 2, with better quality coal in the latter. Because of ground conditions in the mudstone parting and high pressures created by goaf formation, mining of both seams either separately or simultaneously cannot be recommended. Maximum extraction of lower seam 2 will result in total extraction of only some 40% of the total coal over the area where the lower seam splits.

Primary extraction is determined by pillar size, the width of roadways and the fraction of the seam height which is mined. Pillar size is mainly controlled by the cover but the roadway width and safety factor used for pillar design have some influence. For example, the choice of a safety factor of 1.9 (due to weak roof and floor contacts) instead of the normal 1.6 causes a 15% increase in pillar size and a 7 - 9% decrease in primary extraction. A similar decrease occurs if the bord width is reduced from 6 to 5 m due to ground conditions. Therefore, on the basis of 1.6 and 6 m being "average" values for pillar safety factor and bord width respectively, mining with the ground conditions at Mount Nicholas causes the reduced primary extractions detailed in Table 3. Note that an allowance is made for a layer of coal to be left on 30% of the total floor area. The implication of these reductions on the economics depends on local costs and company accounting methods and is beyond the scope of this study.

Roof support required at Mount Nicholas will be more costly than in most other underground coal mines in Australia. If "average" support of 3, 1.8 m long bolts per strap with straps at 2 m intervals of advance is taken as a basis for comparison, Table 4 shows the anticipated increased support required due to the conditions at Mount Nicholas.

Thus, taking the defined "average" conditions as a reference, anticipated mining in the middle seam will require four times the amount of support and cause a 19% reduction in primary extraction ratio. In the lower seam, approximately 2.3 times the "average" support will be required and the conditions cause a 12% decrease in primary extraction ratio.

TABLE 3

INFLUENCE OF CONDITIONS ON
PRIMARY RECOVERY AT MOUNT NICHOLAS

SEAM	Percentage Reduction in Primary Extraction Ratio Due to:			TOTAL
	Safety Factor	Bord Width	Coal Floor	
MIDDLE 2	8%	8%	3%	19%
LOWER	8%	2%	2.3%	12.3%
NOTE:	(i) The above reductions are based on 6 m bord width and 1.6 safety factor being "average" (ii) The reduction in primary recovery where the lower seam splits has not been included in the above data.			

TABLE 4

INFLUENCE OF CONDITIONS ON ROOF
SUPPORT REQUIRED AT MOUNT NICHOLAS

SEAM	Support Costs at Mount Nicholas "Average" Support Costs (see below)	
	Consumables	Installation Time
MIDDLE 2	4.0	4.3
LOWER	2.2	2.4
NOTE:	The above increases are based on support comprising 3 bolts per strap with straps at 2 m intervals being "average".	

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APPENDIX 1

GEOTECHNICAL TEST PROGRAM & DATA

APPENDIX 1

GEOTECHNICAL TEST PROGRAM & DATA

A large proportion of the core from the triassic sediments in the Nicholas Range can be classified as having low strength with some potential for swelling. Core sampling for geotechnical testing has been concentrated in the lithologies within 4 m of coal seams because the strength and physical properties of the materials in this 4 m band above and below coal have a major influence on working conditions.

Four different tests were selected to provide the material parameters most relevant to the assessment of stability of the proposed workings. These are as follows:

- Unconfined Compressive Strength (UCS) Test: A compression test on end faced core with height 2.5 times the core diameter. The failure strength (UCS), Elastic Modulus (E) and Poisson's Ratio (ν) are obtained from the test. E is an indicator of the stiffness of the material during axial compression.

- Tensile Strength Test (Brazilian Test): An indirect tension test in which a disc of core is compressed across the diameter causing a near uniform state of tension along the compressed diameter.

- Triaxial Test: A compression test on end faced core confined at various pressures to determine the failure curve, cohesion and friction angle.

- Duncan Free Swell Test:
  A test on oven dried end faced core which is immersed in water for 12 hours at a constant temperature to determine the strain (expansion) due to swelling (swelling coefficient).

The UCS, tensile strength and swelling coefficient are relevant to the stability of the immediate roof layers. In floor materials, the susceptibility to heaving due to a bearing failure can be related to the cohesion and friction angle obtained from a triaxial test. The potential of floor sediments to swell (swelling coefficient) on exposure to water or humid mine air is also an important factor.

Data from the testing program related to the lower seam are summarised in Table A1.1 for each drill-hole. Average properties for roof and floor strata, based on the test results in Table A1.1, are given in Table A1.2. Similarly, Table A1.3 is a summary of all geotechnical data obtained from testing in the vicinity of the middle seam.

TABLE A1.1

GEOTECHNICAL TEST DATA: LOWER SEAM, GRAY EL 5/61, NICHOLAS RANGE

Sample No.	Rock Type	Degree of Weathering	Density (kg/m^3)	UCS (MPa)	Elastic Modulus E (GPa)	Poisson's Ratio (ν)	Brasilian Tensile Strength (MPa)	Duncan Free-Swelling Coefficient (%)	Cohesion (MPa)	Friction Angle ϕ (deg)
33T12	Mudstone	Fresh						2.18		
33T13	"	"	2387	21.6	4.64	0.43				
33T19	Coal	"	1280	29.0	2.59	0.32				
33T22	Mudstone	"					5.3			
33T23	"	"	2511	14.2	3.07	0.25				
40T18	Carb. Mudstone	"	2370	33.2	3.95	0.29				
40T19	"	"	2210	41.0	5.88	0.16				
39T13	"	"	2400	29.8	5.88	0.47				
36T15	Sandstone	"	2358	15.6	2.13	0.34	1.3			
36T19	"	"	2474	17.3	2.79	0.35	3.2			
36T20	Mudstone	"	2380					4.75	4.0	25
36T21	"	"					2.1 , 1.6			
41T01	"	"	2415	27.3	3.65	0.34				
41T02	"	"					2.7	0.61		
41T03	Sandstone	"	2415	41.7	8.95	0.31				
41T04	"	"					2.6	1.77		
41T05	Mudstone	"					1.4	4.22		
41T06	"	"							2.7?	30
34T03	"	"	2448	20.5	1.68	0.42	2.6			
34T04	"	"					2.0	3.10		
34T06	Coal	"	1388	41.0	3.63	0.32				
34T07	Mudstone	"						4.20		
34T08	"	"							1.8	27

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TABLE A1.2

AVERAGE STRATA PROPERTIES: LOWER SEAM, GRAY EL 5/61, NICHOLAS RANGE

Strata	Rock & Condition	Density (kg/m^3)	UCS (MPa)	Elastic Modulus E (GPa)	Poisson's Ratio (ν)	Brazilian Tensile Strength (MPa)	Duncan Free-Swelling Coefficient (%)	Cohesion (MPa)	Friction Angle ϕ (deg)
ROOF	Fresh Sandstone	2416	24.9	4.62	0.33	2.4	1.77	-	-
	Fresh Mudstone	2417	23.1	3.32	0.40	2.4	2.64	-	-
SEAM	Fresh Coal	1334	35.0	3.11	0.32	-	-	-	-
FLOOR	Fresh Mudstone	2446	14.2	3.07	0.25	2.6	4.39	2.8	27
	Fresh Carbonaceous Mudstone	2327	34.7	5.24	0.31	-	-	-	-

TABLE A1.3

GEOTECHNICAL TEST DATA: MIDDLE SEAM, GRAY EL 5/61, NICHOLAS RANGE

Sample No.	Rock Type	Degree of Weathering	Density (kg/m^3)	UCS (MPa)	Elastic Modulus E (GPa)	Poisson's Ratio ν	Brazilian Tensile Strength (MPa)	Duncan Free-Swelling Coefficient (%)
36T07	Mudstone	fresh	2317	3.4	0.09	0.55		3.46
36T08	"	"					0.14	
36T11	Coal	"	1363	38.0	6.36	0.31		

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APPENDIX 2

SPECIFICATION OF STRAND BOLTS

THE DEVELOPMENT OF THE STRAND BOLT

A dowel as applied to the support of underground excavations, is an untensioned reinforcing member that is placed in a drill hole and bonded to the walls of the hole by means of a suitable grout. Bonding occurs along the full length of the dowel, therefore there is a high resistance to movement on any joints that are crossed because stretching of the dowel is concentrated in a relatively short section of the dowel.

The length of dowel in general use in standard size openings in Australian and overseas mines is 2.3 metres, but the length may be varied depending upon requirements dictated by a number of important factors including ground conditions and the span of the excavation.

Although it has long been accepted that fully mortar grouted short dowels can be used to provide very reliable, high quality and effective support of underground excavations, the introduction of such a system at The Zinc Corporation, Limited and New Broken Hill Consolidated Limited (ZC/NBHC) mines has not been feasible until fairly recently due to the non-availability of a suitable grout placement system.

As the result of an investigation conducted by the ZC/NBHC Rock Mechanics Department, a suitable light-weight air operated pump capable of pumping a viscous sand/cement grout into 32 millimetre diameter holes bored in the backs (or roofs) and walls of excavations was selected.

Careful consideration had to be given to the selection of a suitable reinforcing member. Basically the choice was between solid deformed bar and high tensile seven wire strand.

Seven wire strand was selected for the following reasons -

1. Strand exhibits excellent bond characteristics with the grout.
2. As a consequence of the surface shape of strand, strand exhibits high load transfer between grout and steel even after significant movement has occurred. This is important because there are situations where relatively large strains occur in the rockmass adjacent to the excavation.
3. When subjected to dynamic loading (blast vibrations), strand exhibits better characteristic behaviour than solid bar. Solid bar, when subjected to dynamic loading, tends to produce cracking and deterioration of the surrounding grout.
4. Strand is easy to handle.
5. Strand can be purchased at a competitive price.

Because it is often necessary to install mesh adjacent to the walls and backs of excavations, some means of utilising the strand dowels to retain the mesh was called for. Where conventional rockbolting is used, the support of mesh is not a problem as an additional nut and washer can be placed on the protruding thread of bolt to retain the mesh.

To overcome the mesh support problem, A. Noble and Son Limited were approached with a request to investigate the technical and economic feasibility of producing a reinforcing member consisting of a length of 12.5 millimetre (nominal diameter) seven wire strand with a threaded fitting on one end. The investigation by A. Noble and Son Limited resulted in the successful fabrication of the "strand bolt" which is manufactured by using a swaging technique to secure the threaded fitting onto the strand.

Mortar grouted short dowels with and without the swaged threaded section have now been successfully introduced at ZC/NBHC and have a number of significant applications ranging from drawpoint and maintenance bay reinforcement to the reinforcement of permanent trucking drives. In using "strand bolts" in these situations the technical advantages of strand are realised without compromising on the practical versatility normally associated with threaded bar.

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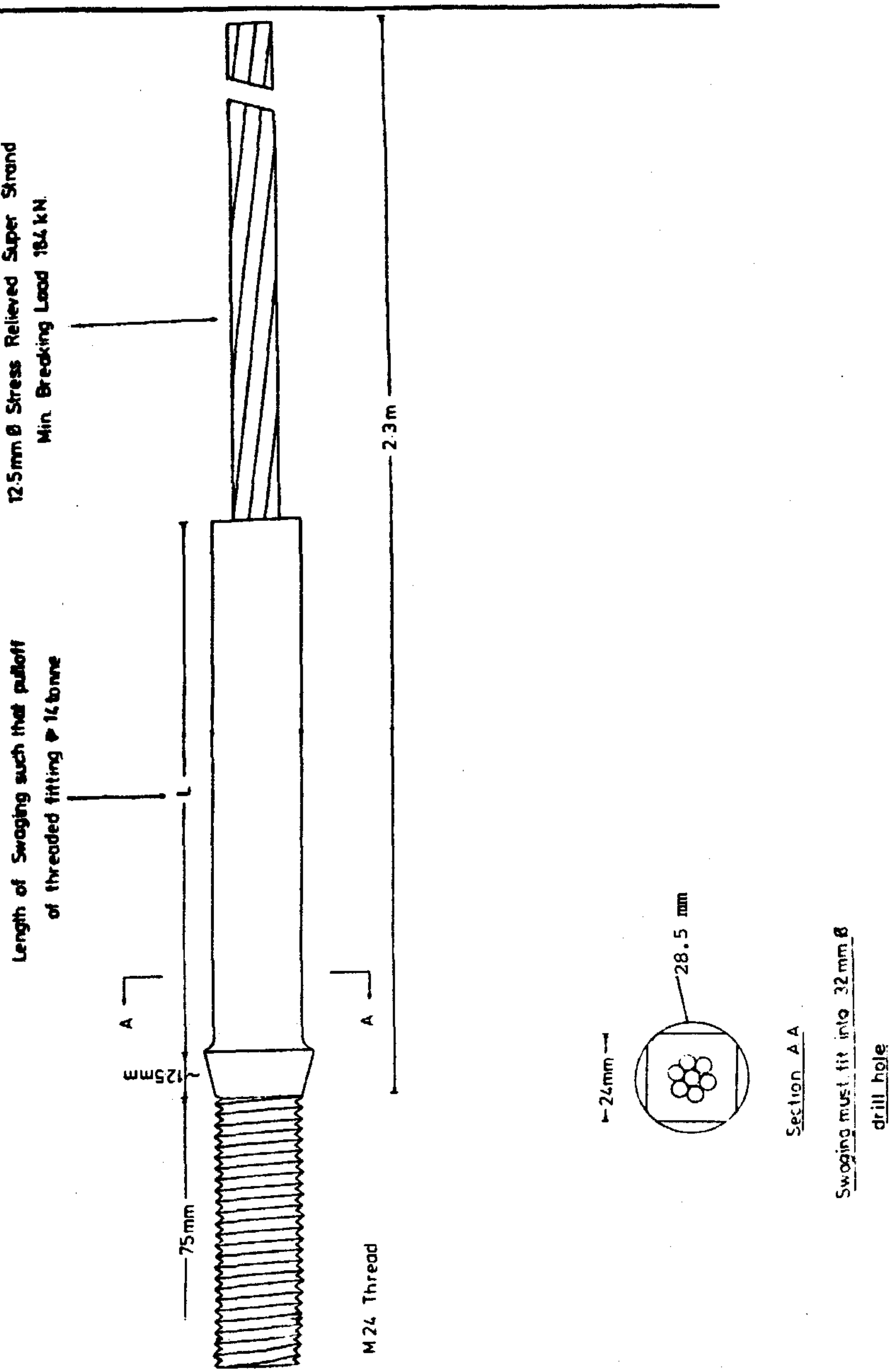

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