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STRUCTURAL GEOLOGY OF MINE NO. 1
AND ADJOINING AREAS
SUKUNKA COAL PROJECT

PREPARED FOR : COALITION MINING LIMITED

BY : CLIFFORD McELROY & ASSOCIATES PTY LIMITED

JANUARY, 1976

REPORT NO. 1/4/24

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PREFACE

This report, on specific aspects of the structural geology of the Sukunka Coal Project, was written by Geoffrey R. Jordan during his employment with Clifford McElroy & Associates Pty Limited. Some degree of compilation and editing has been subsequently carried out as opportunity offered.

It synthesises the results of observations made both on the surface and underground in Mine No. 1 over a period of years. Various elements have been documented in previous reports to Coalition Mining Ltd, but are here brought together and re-analysed in one report.

The report describes four relatively small scale structural features which occur in association with both the Skeeter Seam and the Chamberlain Seam roof and floor. The behaviour of these structures as they affect roof stability during mining, supported by a detailed joint pattern analysis, has enabled a more complete understanding of the local stress régime as it relates to rock failure than was hitherto possible.

The analytical data and the conclusions within this report form a firm foundation for further structural analysis and the design of both roof support systems and mining directions.

It is stressed that further detailed mapping of small scale structural features is essential for a more complete understanding of the structural features which will govern the success of any mining operations undertaken at Sukunka. It is believed that such lines of investigation must be multi-disciplinary, involving specialists in mining engineering, rock mechanics, structural geology etc, rather than a purely empirical approach.

G.R. Wallis

B.E., M.Aus.I.M.M.

SUMMARY

During the early phases of exploration on the Sukunka property detailed observations were made of structural discontinuities affecting the roof strata of the Chamberlain and Skeeter Seams. The introduction of outcrop stripping of the Chamberlain and Skeeter Seams as a geological exploration technique at Sukunka in 1971 afforded an excellent opportunity to study small scale tectonic features in the coal seams and adjacent strata. When practicable, these strata were related to observations made on the drill core from the various drilling programmes, with the aim of making predictions in a spatial sense. The subsequent driving of development headings, as part of a trial mining operation commencing in 1972, enabled the identification of the various structural elements to be made underground, and for these to be related to surface observations.

The purpose of these studies was to precisely define the nature of the seam roof strata and to predict any abnormal geological stresses which would influence the design of a suitable roof support system.

Within the limited domain of the investigation, four types of small scale structures affecting roof stability were identified. Two of these structures may be unique since they do not appear to have been reported in existing geological literature.

The four types of structures are:

(a) A bedding fault plane zone located between the Chamberlain Seam and its roof strata;

(b) Small scale thrust faults;

(c) Sigmoidal lamini : structures;

(d) Slip wedges

The latter two structures have been named for the purpose of reporting since no established nomenclature appears to be applicable. The former two structures are commonly encountered throughout the world and require no further description.

Sigmoidal laminite structures are small scale thrust and reverse faulted slices forming imbricate structures and are observed to lie conformably with the bedding as single stratigraphic units. While these structures are always found in thinly laminated argillaceous rock units such as the immediate Chamberlain Seam roof, they have also been reported from other stratigraphic units of a similar lithology within the Sukunka property. The thickness of the units is normally less than 5 feet and most commonly in the order of 1 foot; however, they have been observed to occur as extensive lenticular bodies extending for as much as 100 feet.

A Slip wedge is a slice of strata which has become detached from an overlying block during bedding plane faulting. This slice then forms an obstruction to bedding plane faulting such that the faulted material is transported up and over the foreign block of rock. One such block has been observed to be in the order of 8 feet thick and 50 feet wide.

Using the information from all of the structures described above, and by observing the reaction of the roof strata to mining stresses, it has been possible to determine that a relatively large and apparently near horizontal remanent tectonic stress is active in this area. It should be possible to design roof support systems and mining directions which will stabilise this stress.

To assist in this aspect, a detailed investigation of joint patterns was carried out, since these planes of failure also affect roof stability.

The investigation indicated that four sets of joint pairs exist on the property. The joint pairs are unique in that individual planes of each pair are separated by a small dihedral angle. Statistical plotting of data from surface observations first indicated the presence of these sets of joints, and during subsequent observations underground, many examples of these structures were located.

Unique conditions of stress are required for the formation of fracture planes with these orientations, since they must form under conditions which are intermediate between those for the formation of the usually observed shear joints and extension fractures.

Several research workers have suggested that the unique nature of such structures allows a relatively precise depth of formation to be determined. However, it is demonstrated that the depth of formation is more dependent upon pore water pressure which can be quite variable.

The statistical study of joints shows that there is a preferred orientation for the drivage of crosscuts such that the roof instability will be reduced.

SECTION 1

SURFACE EXPOSURES

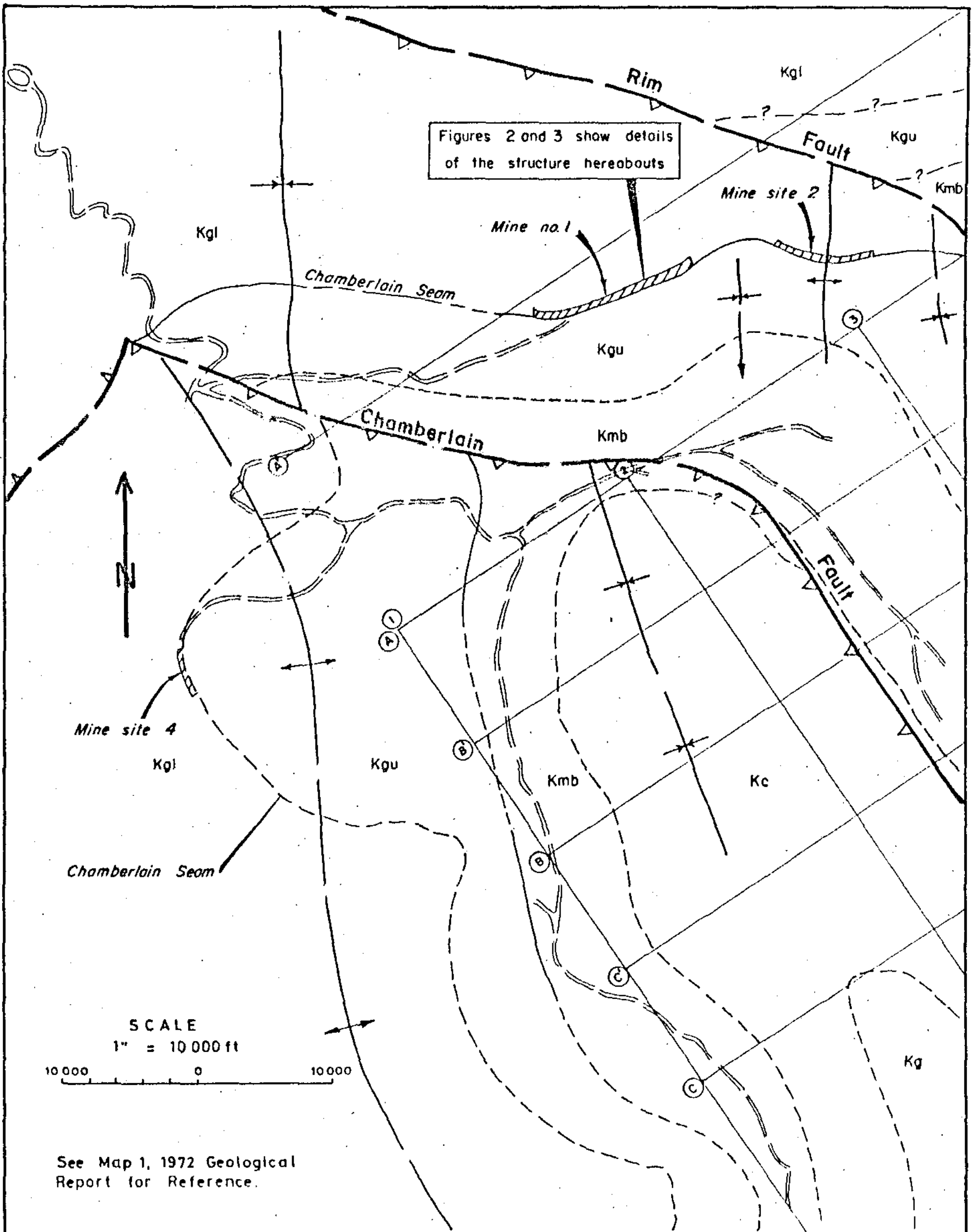
1.1 MINE NO. 1 SURFACE EXPOSURES - PLATE 2a

The benching for Mine No. 1 exposed both the Chamberlain Seam and the Skeeter Seam, affording an opportunity to study some of the small scale structures that occur within these seams and in the relatively thin interval of interseam sediments. Figure 1 shows the location of Mine No. 1.

1.1.1 STRUCTURAL SETTING

Sukunka Mine No. 1 is located at the outcrop of the Chamberlain Seam at the northern end of Plate 2a. The portals are located to the west of the crest of the southerly trending, south plunging anticline which lies immediately west of the Pond Fault. The anticline locally plunges at 11° on a bearing of 130° at the outcrop. The regional trend of the anticline is 147°.

The axial plane of the fold dips almost vertically and the fold is essentially symmetrical; dips on either limb vary locally, but average 7° regionally. In the immediate vicinity of the small monocline, shown on Figure 2, the Chamberlain Seam is significantly thinner (5.3 feet) than elsewhere along the exposure where the thickness varies from 5.5 feet to 6.6 feet. A number of structures which affect the coal seams are described below.



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DRW BY K.W.
DATE: OCTOBER, 1973

LOCATION OF MINE SITES
Figure 1

1.1.2 DESCRIPTION OF STRUCTURES

(a) Shear Zone in Roof - Chamberlain Seam

The upper part of the Chamberlain Seam is sheared in this area, with up to 0.8 feet of sheared coal and laminite lying immediately below unsheared roof strata. Sheared and iron-stained laminite occurs as a distinct unit above the sheared coal. The thickness of sheared coal is usually greater than the thickness of sheared laminite, although minor amounts of sheared laminite or mudstone occur within the sheared coal.

The nature, thickness and extent of this sheared unit in A, B and C Headings of Mine No. 1 are included with the data collected during the underground mapping, Section 2.2 below.

The shearing in the coal at the top of the Chamberlain Seam is attributable to movement along the bedding during tectonic deformation. The bedding planes in the laminite above the shear zone are extensively slickensided and highly polished, reflecting the relative movement between the roof strata and the coal seam. A local thickening of the sheared coal near the hinge of the anticline is detailed in Sketches 2A and 2B, Figure 2.

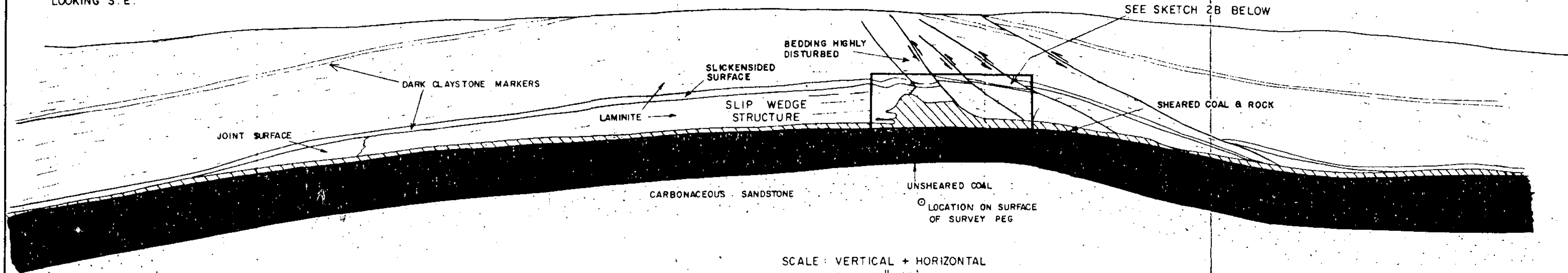
(b) 'Slip Wedge' of Roof Strata - Chamberlain Seam

The term 'slip wedge' is introduced here to specifically apply to a wedge-shaped section of roof strata which has suffered lateral movement with respect to the underlying coal seam, and which has been over-ridden by stratigraphically equivalent roof strata along fault planes coincident with bedding.

SKETCH SECTION – CHAMBERLAIN SEAM EXPOSURE
MINE No. 1
SHOWING 'SLIP WEDGE'

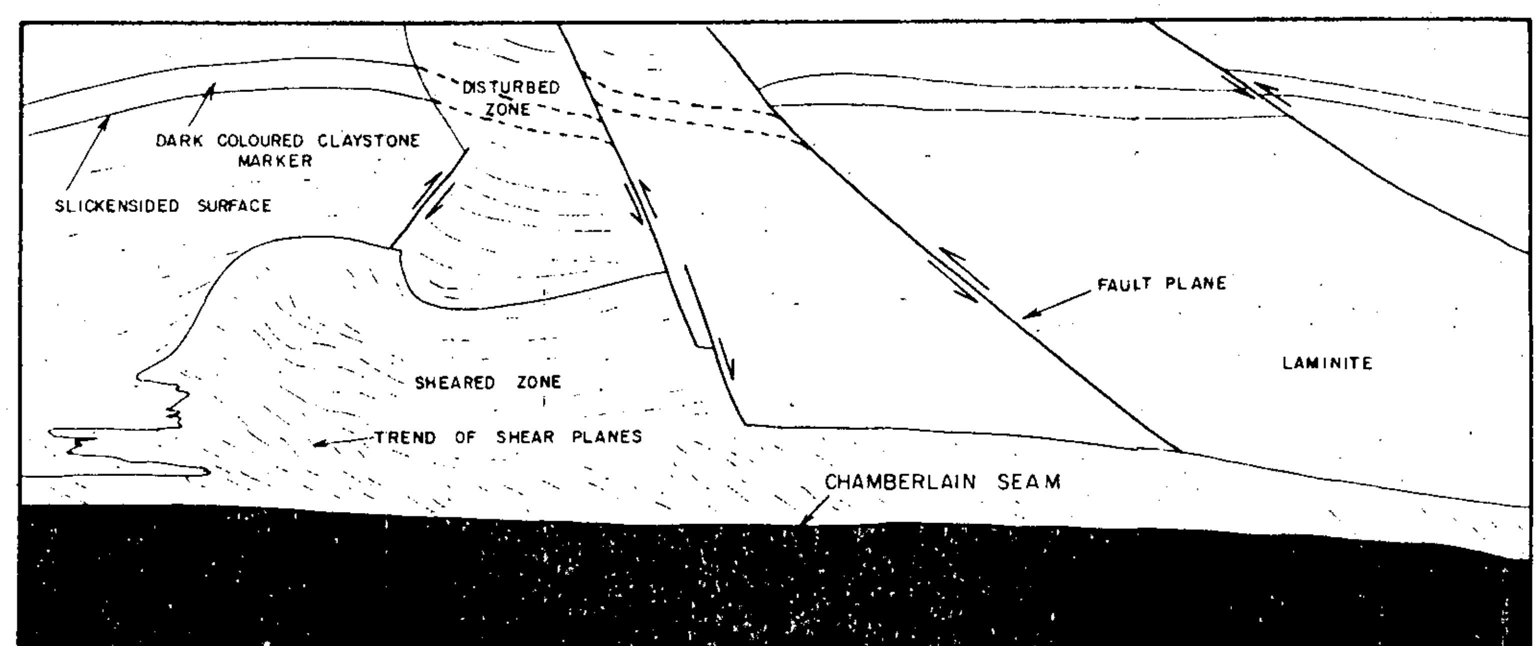
FIGURE 2

SKETCH No. 2A
LOOKING S.E.



SCALE: VERTICAL + HORIZONTAL
Approx. 1" = 10'

SKETCH No. 2B
SHOWING DETAIL OF SKETCH 2A
& TRENDS OF SHEAR PLANES IN SHEARED ZONE



SCALE: VERTICAL + HORIZONTAL
Approx. 1" = 2'

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FOR LOCATION: SEE PLAN 1

DRAWN BY: M.G.   DATE: 6-11-72   REF. No. SKR 175

A 'slip wedge' of this type exists above the Chamberlain Seam in the axial region of the anticline at Mine No. 1 bench. Sketch 2A, Figure 2, shows the extent of the slip wedge and the nature of the structures developed within it and in the overlying strata.

(c) Thrust Fault in Roof - Skeeter Seam

Figure 3 illustrates the nature of a minor thrust fault which displaces the roof of the Skeeter Seam, Figure 3 (i) shows that the fault has a throw of 2 feet and a heave of 5 feet. The fault extends from the roof strata into the seam, but does not affect the floor. Tectonic thickening of the Skeeter Seam has occurred on the upper plate of the fault.

(d) Thrust Fault in the Floor - Skeeter Seam

A minor thrust fault displaces the floor of the Skeeter Seam at the hinge of the anticline, above the 'slip wedge' structure in the Chamberlain Seam roof. The fault, which is considered to be related to similar faults within the 'slip wedge', is parallel to the fold axis and dips at 22^{o} to the south-west displacing the floor of the seam 0.5 feet. (See Figure 3 (ii).

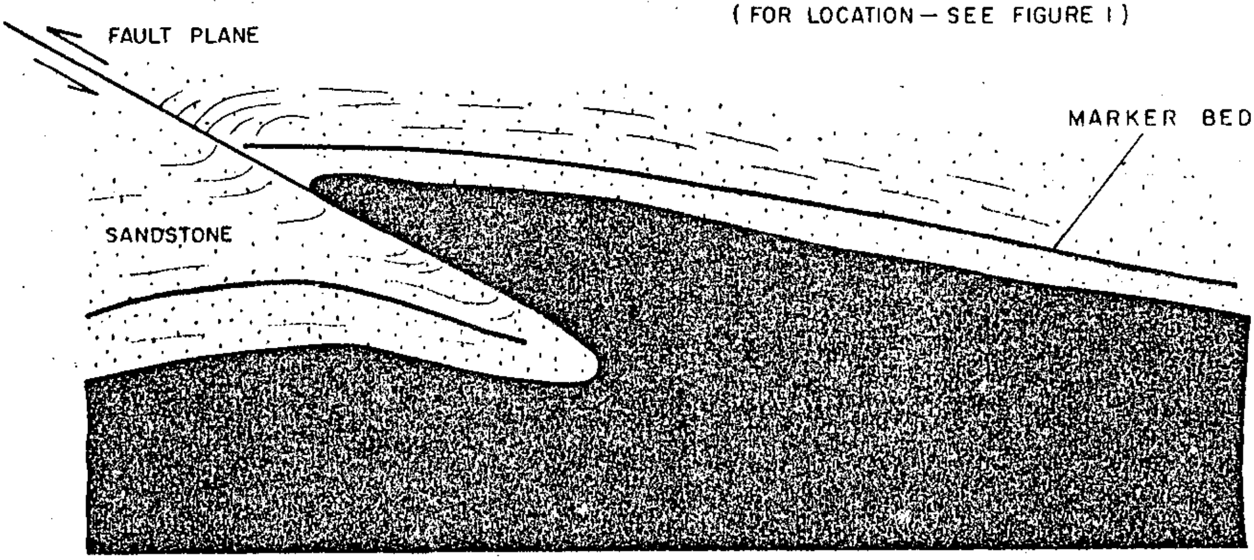
1.2 MINE NO. 2 SURFACE EXPOSURE - PLATE 2b

An analysis of some small scale tectonic structures affecting the laminite roof of the Chamberlain Seam in the surface exposure of the Mine No. 2 bench was conducted. These structures are of a type not exposed at Mine No. 1 but have been encountered in the underground workings of that mine.

SKETCH SECTION – SKEETER SEAM EXPOSURE
MINE No. I

(i) SHOWING ROOF STRUCTURES – 'THRUST FAULTS'
ABOVE SKEETER SEAM

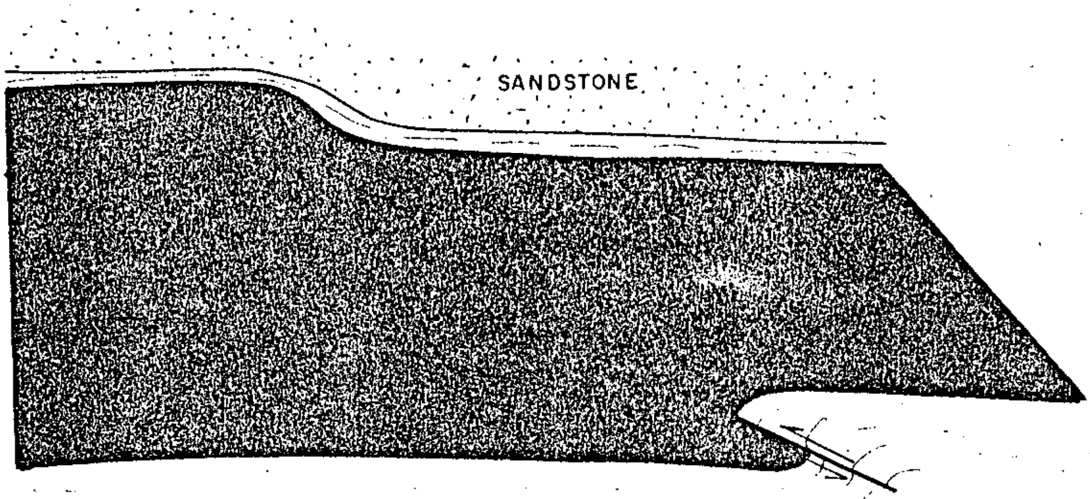
(FOR LOCATION – SEE FIGURE I)



SEAM THICKNESS DIAGRAMATIC ONLY

SCALE 1" = 2'

(ii) THRUST FAULT – FLOOR OF SKEETER SEAM



SEAM THICKNESS DIAGRAMATIC

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Figure 3

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1.2.1 STRUCTURAL SETTING

Sukunka Mine No. 2 Surface Exposure is located at the outcrop of the Chamberlain Seam at the northern end of Plate 2b. As at Mine No. 1 this mine site is located on a meridional trending, south plunging anticline lying between the Rim and Pond Faults. Locally the anticline plunges at 4° on a bearing of 147° at the outcrop and has a similar regional trend. The axial plane of the fold dips almost vertically and the fold is essentially symmetrical; dips on either limb average 7°.

One particular structure, which affects the Chamberlain Seam roof, has been encountered here and is described below.

1.2.2 'SIGMOIDAL LAMINITE' OF ROOF STRATA - CHAMBERLAIN SEAM

The term 'sigmoidal laminite' is introduced to describe a tectonic structure consisting of a single stratigraphic horizon internally deformed into a series of imbricate structures. The deformed bed is contained within strata of a similar lithology showing little or no deformation. The sigmoidal laminite has a maximum thickness of approximately 5 feet, though is usually less than 1 foot thick.

Internally, this structure consists of single stratum or blocks of strata rotated and stacked adjacent to each other by means of a series of thrust and bedding plane faults.

A more detailed description of these structures and a discussion of their origin is given in Section 2.4.

1.3 MINE NO. 4 MINE SURFACE EXPOSURE - PLATE 1

This mine exposure is located at the north-western exposure of the Chamberlain Seam in Plate 1. (See Figure 1).

Only one of the previously described tectonic structures has been encountered at this mine site, that being the sheared coal and rock layer lying above the coal of the Chamberlain Seam and below the laminite of the seam roof. At this locality considerable variation in thickness of this structure can be seen where it varies between 0.3' and 3.12' thick.

SECTION 2

MEGASCOPIC STRUCTURES
DESCRIPTION AND ANALYSIS

2.1 INTRODUCTION

Four types of megascopic structures have been identified in surface exposures and briefly described in Section 1 above. In this section these four types of structures are more fully described, using additional data from underground observations. These structures affect the Chamberlain Seam and the immediate 20 feet of roof strata.

An analysis of those structures is presented, in terms of a common feature of the structural geology of the Rocky Mountains Foothills; that is, the low angle thrust faults and bedding plane faults which have been observed on both macro- and microscopic scales.

To re-list the structures which are discussed in this section:

- A bedding plane fault zone at the top of the seam below the laminite roof.

- Small scale thrust faults located in the laminite roof and sandstone floor.

- Zones of imbricate structures termed 'sigmoidal laminite'; (Section 1.2.2 above).

- Roof structures which have been termed 'slip wedges' (Section 1.1.2 (b) above).

2.2 BEDDING PLANE FAULTS

The principal structure within the immediate 20 feet of roof strata is a bedding plane fault zone varying between 0.1 feet and 3.12 feet in thickness, which is represented by a shear zone between the top of the Chamberlain Seam and the laminite roof rocks. Figure 4, Diagram A, shows the relationship of the sheared zone to the coal seam and roof rock. This fault zone extends throughout the current underground workings of Mine No. 1 and the surface exposures of Mines No.1, 2 and 4.

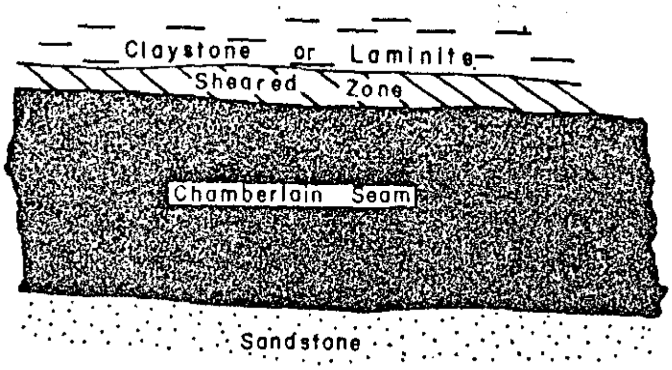
Sheared coal, and in some places sheared rock fragments, constitute the fault gouge. In much of this zone there are sheared fragments of the 'bone' layer which, in its undisturbed state, is located at the top of the seam. The informal term 'bone' is more strictly defined as 'stone, coaly'.

At several levels within the laminite roof, bedding plane faulting has also taken place. At these levels the faulting normally consists of a slickensided plane without the presence of fault gouge.

Judging by the degree of deformation, the principal displacement would appear to have taken place at the top of the Chamberlain Seam with relatively minor adjustments occurring in the overlying strata.

In earlier studies the presence of different movement directions on the bedding was established, as indicated by slickenside directions etched on top of each other on a film of sheared coal at the base of the laminite. It is possible that two different stages of movement may have been

SKETCH SECTIONS SHOWING SHEARED ZONE IN ROOF OF CHAMBERLAIN SEAM.



Scale: 1" = 2'

DIAGRAM A

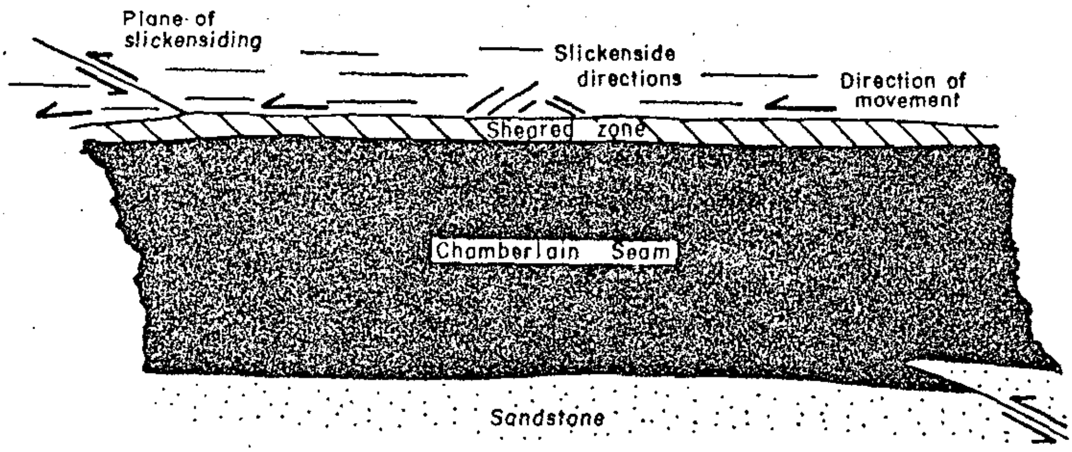


DIAGRAM B

Sketch only

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Figure 4

DATE January ,1973

responsible for this feature and that other structures could be related, in a time sense, to this movement sequence.

Further investigation of this phenomenon confirms the presence of the different movement directions. In fact, it can be seen by observing the strata in open rock bolt holes, that an adjustment to mining stresses is taking place along the bedding at different levels. However, this adjustment does not always take place in the same directions, i.e. different levels of the roof adjust to varying stresses by movement in different directions.

Observation of the slickenside directions in roof falls at different levels shows these different directions have been present prior to mining, since the slickenside surfaces are often composed of carbonate material. The suggestion that a time sequence can be attributed to these movement directions would thus appear to be invalid. It seems more probable that a complex sequence of these movements was taking place at the same time.

The mean bearing of these slickenside directions (214^{o}) in the rock bolt holes appears to be approximately the same as the average major direction of movement measured on one level, i.e. at the base of the laminite Chamberlain Seam roof.

2.3 THRUST FAULTS

Within the laminite roof of the Chamberlain Seam, planes exist throughout the underground exposures where thrust faulting has taken place. The thrust faults may be generated from any of the surface of bedding plane movement but most commonly are found to terminate at the bedding plane fault zone on the top of the Chamberlain Seam.

An analysis of 100 poles to these fault surfaces is included in Appendix B as Stereogram No. 1. Stereogram No. 1 shows that there are three concentrations of poles and one of the concentrations is much more strongly developed than the other two. The most strongly developed plane of these structures has an average strike of 114° and a dip of 26°S. Two other weaker distributions are present; the first forms a set of planes whose mean strike is 302° and dip is 13°N. The second set of planes strikes 207° and dips 52°E forming a reverse fault set.

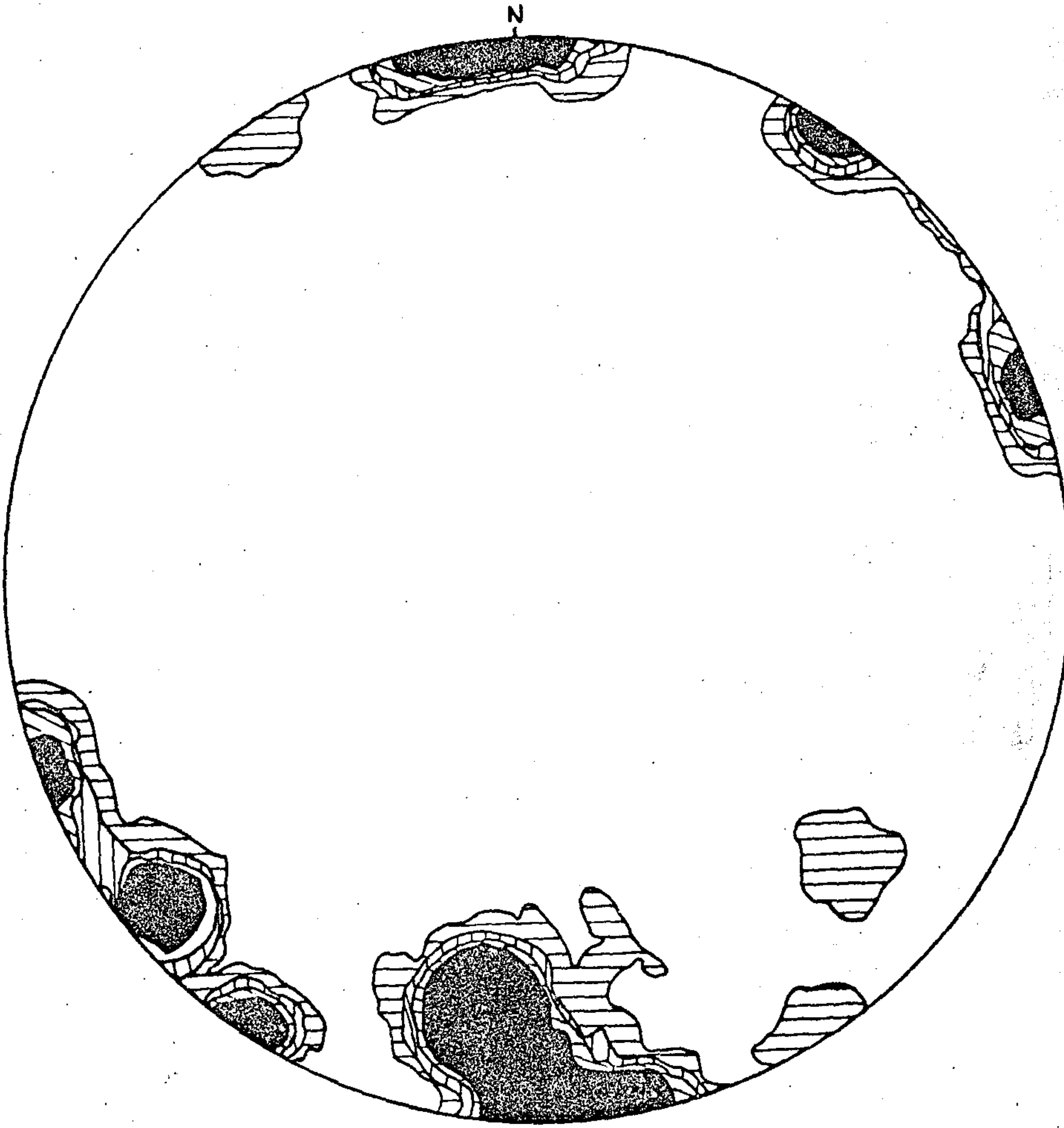
The first of these latter two sets is a conjugate to the major roof thrust set. The attitude of the major roof thrust set of structures and its conjugate indicates that the maximum principal stress had an azimuth of 206° at the time of formation of these structures. The dips of these structures indicate that the maximum principal stress acted in a nearly horizontal direction at this time.

The bearing of movement on the bedding plane fault, 214° (2.2, above), tends to confirm the 206° bearing for the direction of the maximum principal stress at the time of formation of these structures.

Drawing No. SKR 244 shows the trends, but not the strikes, of the roof thrusts encountered underground. Since the dip of these faults is often low and the dip of the seam is often half the dip of the thrust faults, the strike and trend of the thrusts can vary considerably. See also Drawing Nos. SKR 245 and 246.

In general, underground evidence from mining in the vicinity of the hinge line and the western limb of a south plunging anticline, indicates that the thrusts tend sub-parallel to the headings at the hinge and trend in a more westerly

AREA 'B' POLES TO ROOF JOINTS



MINE No. 1

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DATE: OCTOBER, 1973

STEREOGRAM No. 3

No. OF POLES: 150

PERCENTILE CONTOURS: 3, 6, 9, 12

Few fold structures and only one thrust fault have been encountered in the Chamberlain Seam floor. A discussion of the formation of these structures in the floor is included in Section 2.4. The single thrust fault in the floor trends parallel to the Area A structures.

In some localities gentle flexures of the Chamberlain Seam can be seen underground where, at the points of greatest curvature, a higher concentration of roof thrusts is often present. It is suggested that bedding plane faulting above the Chamberlain Seam continued to take place after the formation of these flexures. At the points of greatest curvature, disturbance of the stress field resulted in thrust faults being formed in a "ski jump" manner at these points.

Reference should be made to Appendix B-1 by Dr M.J. Rickard in the 1972 Supplement to the main geological report, (Wallis, McElroy & Bryan, 1973), which is a discussion of the development of flat thrusts and related structures. Specific reference is made to the Eastern Foothills, paying particular attention to rocks showing the physical characteristics of those rocks considered in this report.

2.4 SIGMOIDAL LAMINITE ZONES

An unusual tectonic structure, termed a 'sigmoidal laminite zone', has been observed in bore cores and in surface and underground exposures.

The structure consists of 'slices' of laminite rock, each 'slice' having a pronounced 'S' shape, separated from the next 'slice' by a small thrust zone. These zones are confined to a single stratum i.e. the zones are non-transgressive with respect to the surrounding laminite strata. These zones can be recognised in bore cores.

In the 1972 Geology Supplement it was suggested that these structures form by a process in which "slices of laminite are scraped off during bedding plane faulting and are stacked against..." an obstruction or irregularity on the fault plane.

Dr Rickard (op. cit.) proposes a very similar mechanism for the formation of these structures (termed 'Schuppen Lenses') and, in the discussion, he suggests a theory of compaction to explain the characteristic 'S' shape of the slices in the structure. Dr Rickard further suggests that this mechanism can explain the formation of some larger scale imbricate structures observed at Sukunka.

Further field work has indicated how these structures are distributed both laterally and vertically. In the underground exposures some of the sigmoidal laminite structures can be observed in fallen roof areas, while other occurrences can be inferred by the physical characteristics of the roof during drilling for roof bolting.

From this study the properties of the roof can be divided, in general, into three categories:

(i) bad roof,
(ii) good roof, and
(iii) apparently good roof.

The good roof conditions are relatively stable underground, while both of the other two classes are less stable. Rock drilling within the areas of apparently good roof indicates that there are zones of sigmoidal laminite at one or more levels within the first 8 feet of the Chamberlain Seam roof i.e. within the thinly laminated sequence. In surface exposures, drill cores and underground exposures, the presence of these structures can be seen to be confined to the thinly bedded strata. They are not present in massive bedded rock units such as the siltstone above the laminite of the Chamberlain Seam roof, nor in the massive sandstone of the seam floor.

It is suggested that these structures are generated and confined to the laminite or similar units higher in the sequence as a result of failure during a period of shortening. This period of shortening was the deformation phase during which the thrust and bedding plane faults were generated. The amount of shortening and thickening that a unit of rock can undergo before failure is controlled by the thickness of that unit; a thick unit will undergo a greater amount of shortening and thickening before failure than a thinly laminated unit. The laminite roof of the Chamberlain Seam is a thinly layered sequence of rock confined within two massive units; the overlying siltstone and underlying seam and its sandstone floor.

The failure of the laminite with the generation of these structures allowed a regular lateral thickening of this unit to take place. As opposed to this, a local change caused by a single thrust fault with an equal amount of shortening would require that at least one of the surrounding rock units also be significantly deformed.

Apparently the contrast in mechanical properties of the surrounding rock units, and the physical conditions existing at the time of deformation, were such that deformation of the massive rock units could not easily take place.

Other sigmoidal laminite structures developed on different levels together with small scale thrusts, so that the whole of the unit was deformed regularly throughout on all levels and over a wide lateral area.

In general, the presence of bad or apparently good roof conditions indicates the presence of a domain similar to that described above. This domain is observed to be separated from a good roof domain by either:

(a) folded zones,
(b) reverse faults, or
(c) brecciated strata.

Figure 5 shows diagrammatically the relationship between these domains. The transition zone between domains of different amounts of shortening and thickening is not as distinct as the sketch indicates. In addition, it is generally observed that the thickness of the sigmoidal laminite zone increases towards the axis of the anticlines and thins on the limbs. Figure 6 shows the relationships that exist near the margins of the sigmoidal laminite structures.

2.5 SLIP WEDGE STRUCTURES

Another unusual tectonic structure has been observed at Sukunka lying within the laminite of the Chamberlain Seam roof strata. This structure has been termed a 'slip wedge'.

Only two structures of this type have been observed; one is exposed at the surface exposure of Mine No. 1 and the other is located in the underground workings of Mine No. 1. The structure exposed at the surface exists as a separate slab

DIAGRAMMATIC RELATIONSHIP BETWEEN ZONES WITH SIGMOIDAL LAMINITE STRUCTURES and RELATIVELY UNDEFORMED ADJOINING STRATA

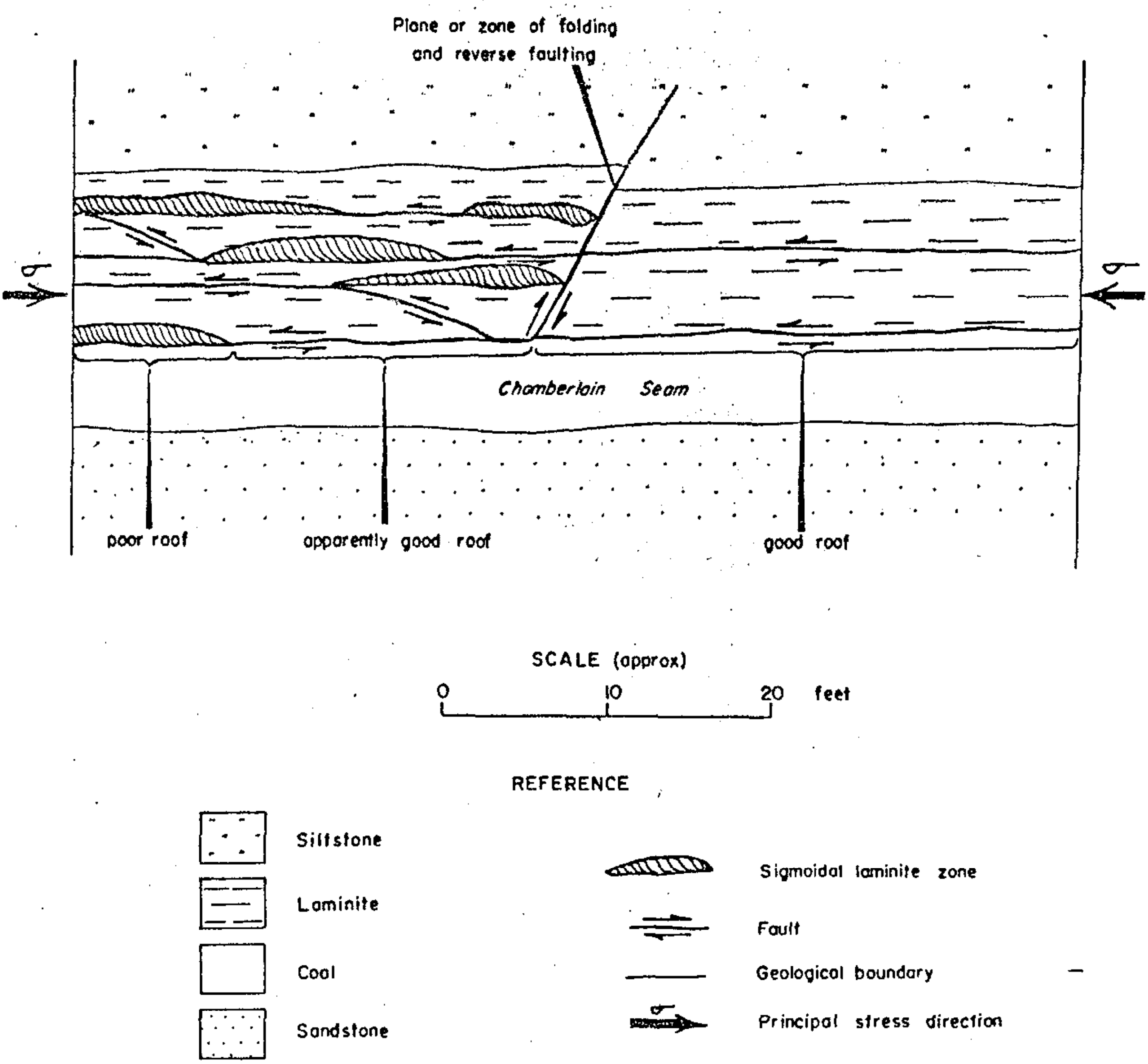

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Figure 5

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RELATIONSHIPS AT FRONT OF SIGMOIDAL LAMINITE

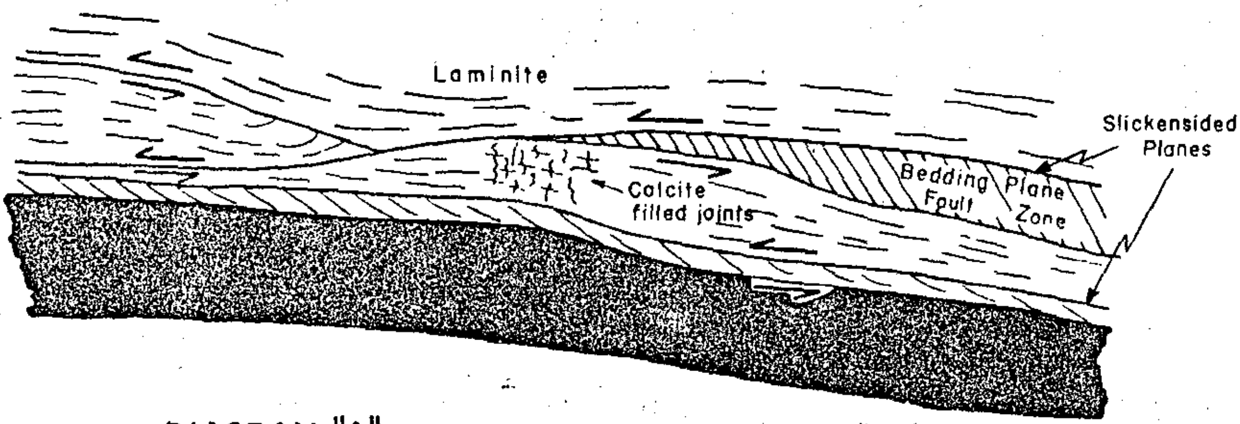

DIAGRAM "A" SCALE: 1" = 2'

DETAIL OF SIGMOIDAL LAMINITE

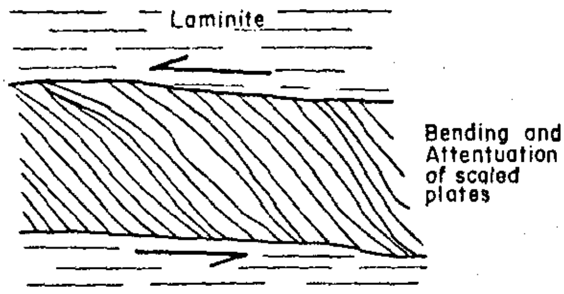

DIAGRAM "B" SCALE: 1" = 1'

TERMINATION OF SIGMOIDAL LAMINITE

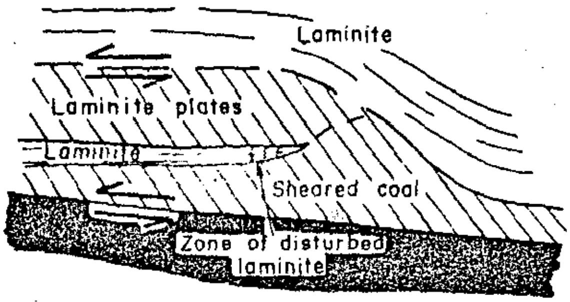

DIAGRAM "C" SCALE: 1" = 2'

MARGIN OF SIGMOIDAL LAMINITE

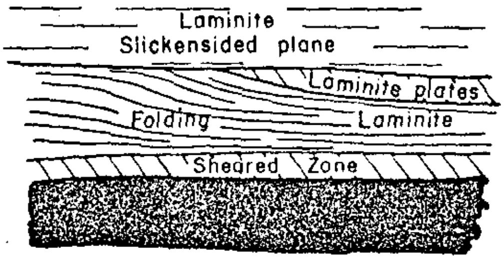

DIAGRAM "D" SCALE: 1" = 2'

MARGIN OF SIGMOIDAL LAMINITE

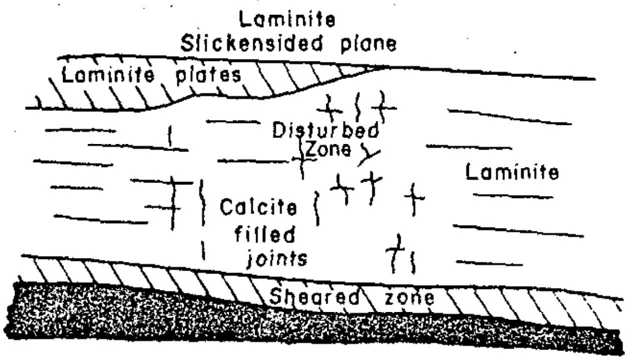

DIAGRAM "E" SCALE: 1" = 2'

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COALITION MINING LIMITED

DATE: January, 1973

Figure 6

of laminite strata over which the laminite roof of the seam has moved during the phase of bedding plane faulting. Marker beds and a plane of slickensiding which diverge from the bedding at the top of the seam and finally return to the original level allow identification of this feature to be made; see Figure 7.

The presence of a sheared layer below the laminite wedge indicates that much bedding plane faulting had taken place prior to the formation of this structure.

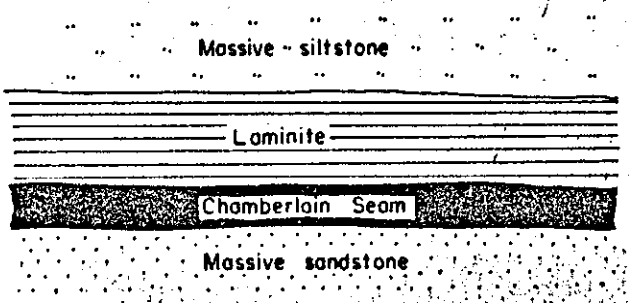
The underground structure could only be identified by study of accretion steps on the slip planes since the wedge material formed a roof fall. The criteria of Norris and Barron (1969), regarding accretion steps on slickensided planes, indicated that movement on one side of the fallen structure was at a low angle to the bedding but movement took place in the sense of a normal fault. Thrust faulting took place on the other side of the structure.

It is suggested that slip wedge structures form as a result of two distant stages.

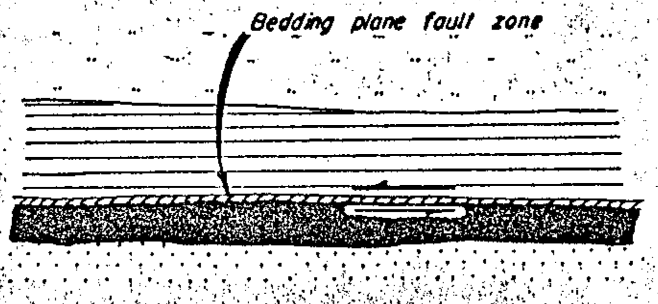
(1) Failure of the laminite takes place with the formation of a thrust and a conjugate to this thrust in a favourable location in the laminite strata.

(2) Movement of the surrounding and overlying strata takes place along the thrust, its conjugate and a bedding plane. This leaves the slip wedge as an isolated block of strata. This sequence is shown diagrammatically in Figure 7.

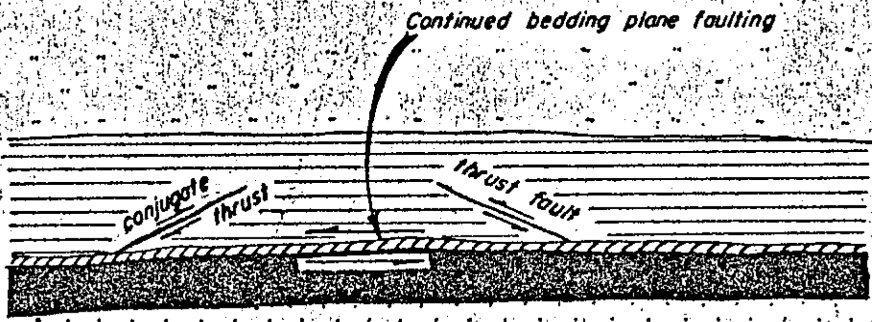
DEVELOPMENT OF A SLIP WEDGE



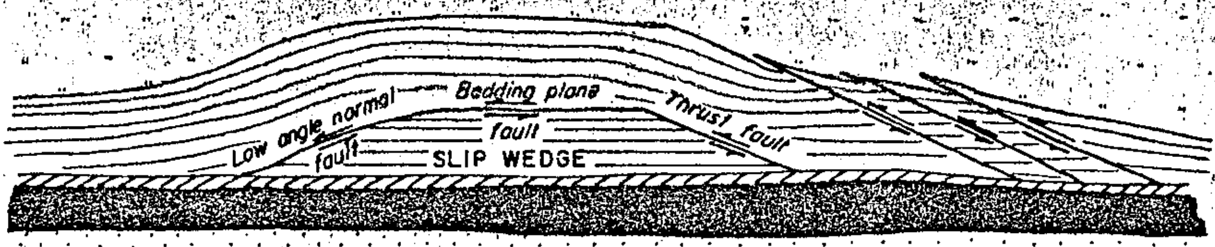
STEP 1 : PRE BEDDING PLANE FAULTING



STEP 2 : BEDDING PLANE FAULTING



STEP 3 : LAMINITE FAILURE



STEP 4 : SLIP WEDGE FORMATION

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Figure 7

DRAWN BY K.W.

DATE: OCTOBER, 1973

SECTION 3

JOINT ANALYSIS

3.1 INTRODUCTION

An analysis of jointing in the coal and laminite roof of the Chamberlain Seam measured at several surface exposures and in the underground workings of Mine No. 1 is presented in this section.

Much of the area to be mined within the Sukunka Project area is covered by greater than 1000 feet of overburden. Such deep seam coal mining in the Southern Coalfield of New South Wales, Australia, has shown that problems such as roof instability, floor heave and pillar crushing can become economically restrictive.

However, studies in that area by Connelly (1967, 1970) indicate that large latteral compressive stresses are present. In some cases, reasonable control of these problems can be gained by directional mining techniques.

As part of a study to determine mining directions at Sukunka, in anticipation of similar problems, a joint analysis has been carried out.

3.2 LOCATION OF AREAS STUDIED

Since this analysis concerns the influence of geological discontinuities upon mining, the ten feet of strata forming the immediate roof, and the coal of the Chamberlain Seam were investigated.

Figure 1 shows the location of these areas. At Adit No. 2 and Mine Site 4, 100 joints were measured in both the coal and roof strata. At Mine Site No. 2, 100 joints were measured in the coal and 100 joints were measured in the roof strata on either limb of the anticline at this site.

The purpose of the studies on either limb was to investigate the effect of changes in dip of the strata upon joint orientation.

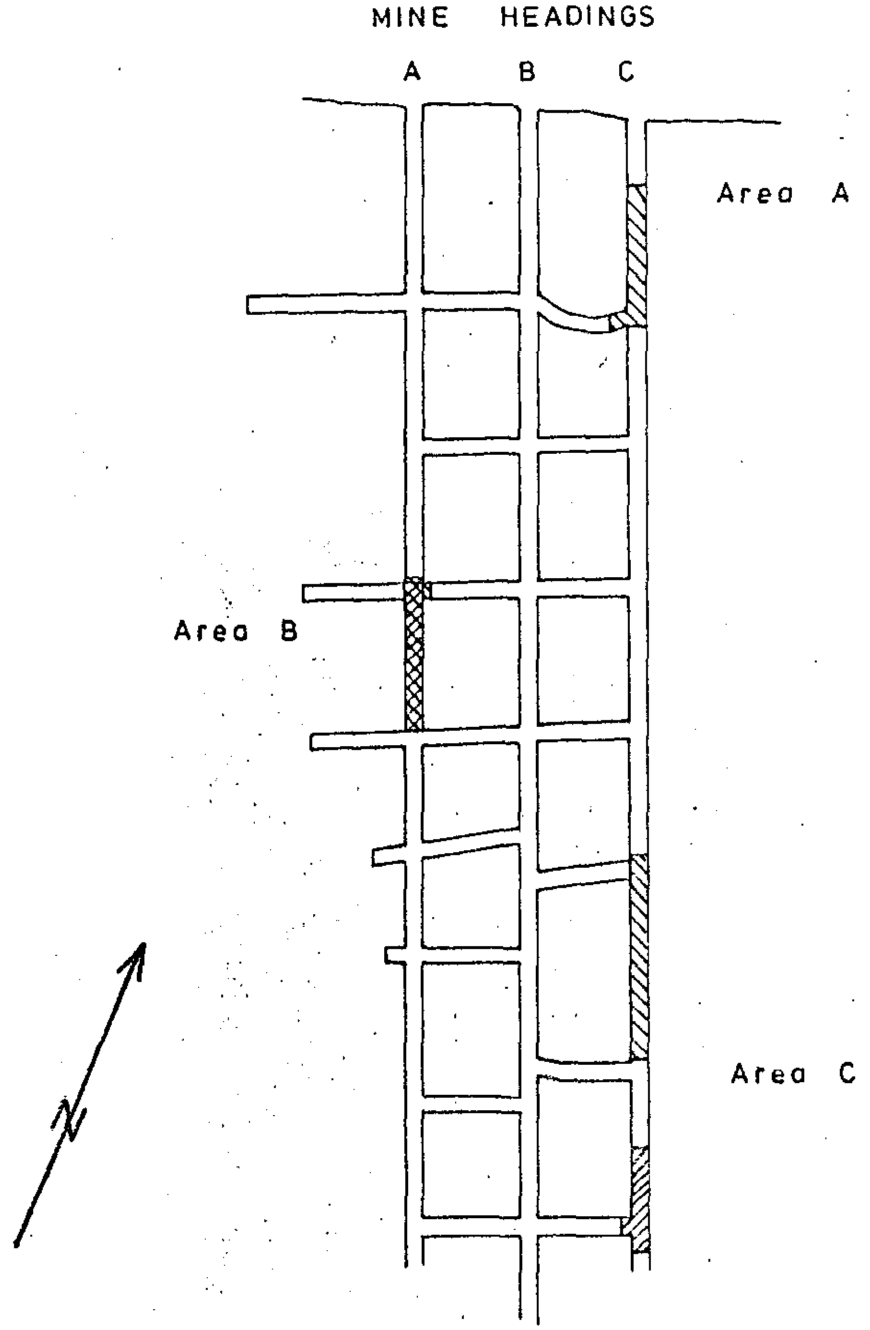
Similarly, 100 joints were measured at Mine Site No. 2 at three different stratigraphic levels in the immediate roof of the Chamberlain Seam to investigate the effect of stratigraphic elevation upon joint orientation.

Finally, three separate areas were selected for study in Mine No. 1 as shown on Figure 8.* Two areas, A and C, are situated as close to the axis of the anticline and as far distant from each other as possible. The third area, B, is equidistant from A and C and close to the steepest part of the western limb of the anticline.

In addition, Area C was located within one of the zones of relatively bad roof conditions, while Area A was located in a region of good roof. At each of these localities 150 joints were measured in the roof strata. A similar analysis was then made of joints within the coal seam at Areas A and B.

*See Also DWG No. SKR 244

JOINT ANALYSIS LOCATIONS
MINE No. 1.



SEE ALSO DRAWING NO. SKR 244

SCALE : 1"=200'

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Figure 8

The poles to these joints were plotted stereographically and are presented as Stereograms 2 to 16, Appendix A. Each diagram has the 2, 4, 6 and 8 percentile contours shown. Greater concentrations are contoured when justified by the density of data. A general indication of point frequency can be gained from the densities shown on the stereograms.

In the joint analysis the joint pairs are discussed using inverted commas and numerical values in the third and fourth degree quadrants i.e. between "180^{o}" and "360^{o}". Each plane of the set (pair) is described in the first and second degree quadrants i.e. between 0^{o} and 180^{o} and are shown without inverted commas.

3.3 JOINTS IN THE CHAMBERLAIN SEAM ROOF

In the following discussion, the roof joints studied at Mine No. 1 will be treated first. The results from the other areas will then be compared with the pattern that exists at Mine No. 1.

The plots of roof joints at Areas A and C in Mine No. 1 (Stereograms 2 and 4) show that there is a close relationship between the distribution of roof joints in these two localities.

The roof joints are normal to the bedding. Thus, in Areas A and C, the various sets dip between vertical and 80^{o} in a northerly direction. The joint patterns presently consist of four planes forming two orthogonal sets. These four planes are termed the '042', '136', '097', '178' sets respectively depending on the strike of the structures.

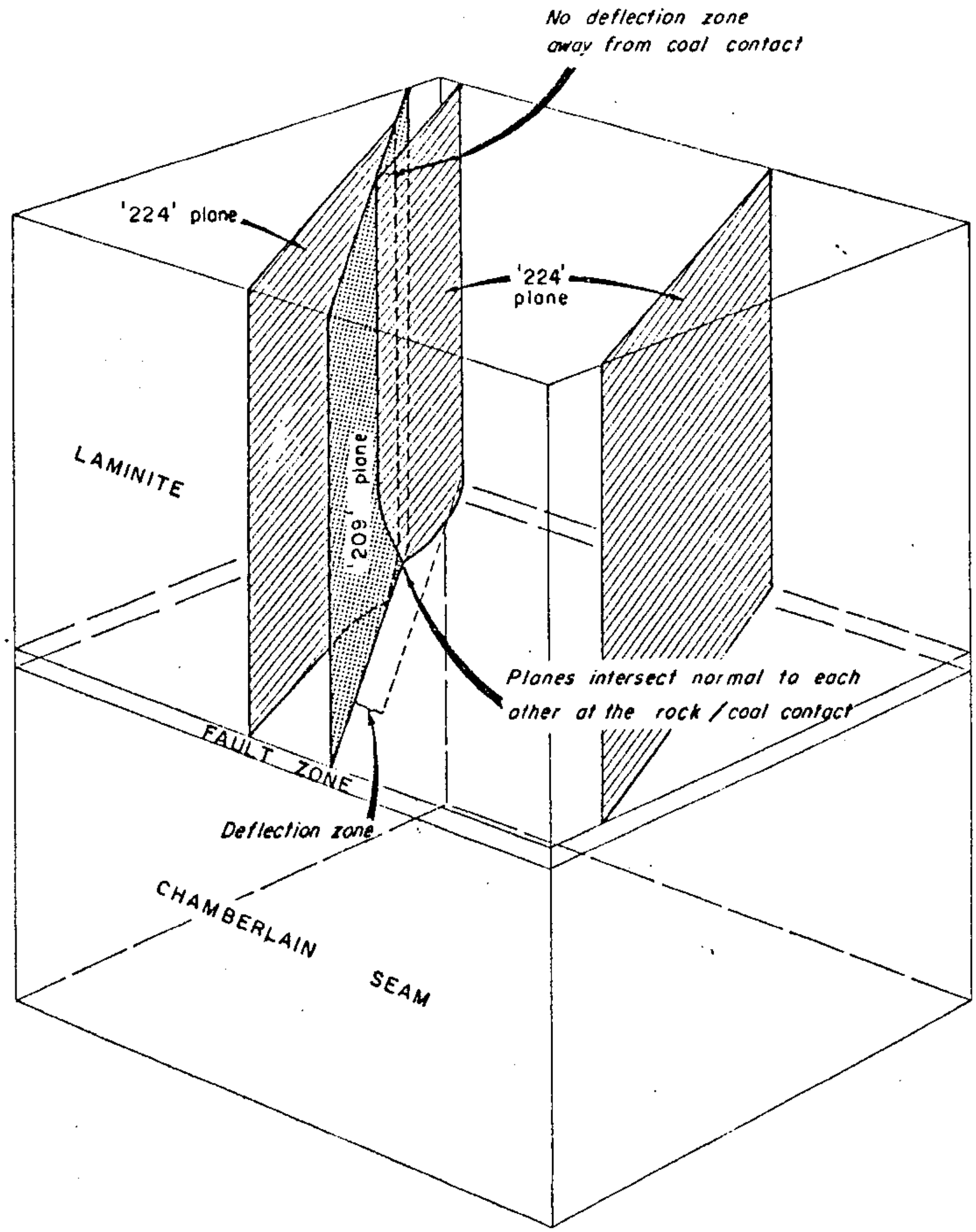
3.3.1 DIHEDRAL ANGLE BETWEEN JOINT PLANES

Apart from the four joint sets described above, for Areas A and C, the stereograms show that each of the distributions representing a set is bilaterally symmetrical through a small dihedral angle of 10° to 20°. However, individual concentrations in each diagram may not show bilateral symmetry. This feature is absent from concentrations with few measured poles. A greater number of measurements for these attributions at joints show a small dihedral angle in all cases. This can be seen on other plots of the same joint set.

Examples of the physical relationships that exist between planes of a joint set having a small dihedral angle were studied underground and at the surface exposures of Adit No. 2 and Mine Site 2.

In Mine No. 1 an area of well developed '042' joints can be observed. Here, two principal planes of this set exist: the 209 and 224 planes. The 209 plane is most strongly developed with joints continuing across the heading. However, the density of these planes is lower than those of the 224 group. The planes of the 224 group trend parallel outside a 6 inch zone along either side of each of the 209 planes. As each of the 224 planes approaches the 209 plane within this zone, the 224 plane is deflected, in most cases, into the 209 plane.

Additionally, the junction of these planes at the contact between rock and coal is almost perpendicular and the dip of the 224 planes becomes shallow within the zone of deflection into the 209 planes. These relationships are shown in Figure 9.



Block diagram showing relationship between '209' joint plane and '224' joint plane.

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At the coal/rock contact, the joint planes tend to be deflected, whereas as little as 2 feet away from the contact, deflection does not occur. A time sequence for the generation of these planes can be inferred. No displacement along these joints can be observed, but the lack of 224 planes cutting across 209 planes, and the deflection of the 224 planes as they approach the 209 planes, indicates that the 209 planes were present at the time of formation of the 224 planes.

The presence of the 209 planes in the rock, modified the stress field such that the 224 planes, during propagation, were deflected and terminated at these discontinuities and near the coal/rock interface. Similar time relationships are expected to exist between other planes of joint sets having a small dihedral angle.

3.3.2 ROOF JOINTS - AREA 'B', MINE NO. 1

At Area 'B' in Mine No. 1 the same joint sets that were identified at Areas A and C can be seen on Stereogram 3. Concentrations with larger numbers of contoured poles also display a small dihedral angle between sets.

One distinct difference exists between the stereographic plots of normals to joints measured at Area B and at Areas A and C, this being a rotation of the concentrations in the plot for Area B compared with those for Areas A and C.

A similar rotation can be seen in the plots of poles to joints measured on opposite sides of the anticline at Mine Site 2. The same situation also applies to other plots of poles to joints measured in strata which dip in different directions from plot to plot. This rotation is a function of the tectonic structures upon which the plots have been taken. Since all the plots have been made on the crest of one or both of the limbs of south plunging anticlines and thus the joints tend to be formed normal to the bedding, the strike of the joints on either limb of the plunging anticline will not be parallel. The strike of a joint set on one limb will appear to be rotated from the same joint set on the other limb. The amount of rotation will be controlled both by the amount of plunge of the fold and by the angular relationship, measured in a plane normal to the limbs of the fold, between the positions from which the measurements were made on the limbs of the fold.

3.3.3 GEOMETRICAL RELATIONSHIP OF JOINTS TO TECTONIC STRUCTURES

Geometrically, the '042' group of joints represents A - C joints and the '136' group are B - C joints with respect to the anticline on which they are developed.

Price (1966) has suggested a mechanism by which the geometry of various joint sets is related to the tectonic structures on which they are located and to a residual stress from the tectonics responsible for the folding and faulting phases. In his mechanism for the formation of joints in strata possessing such a residual tectonic stress, Price suggests that, after shear joints form, B - C (longitudinal) joints are more likely to form than A - C joints. He states that the B - C joints would be propagated first, forming 'main' joints. The A - C joints would probably form as 'cross' joints. At Sukunka the reverse situation is found; the '042' group of joints are 'main' joints and the '130' group are 'cross' joints.

Price's statements regarding the probable time sequence of joint formation were based on the presence of an earlier formed shear joint set and the possibility of movement taking place along these planes rather than the stresses being relieved by the formation of a new set of joints. This imposed fairly rigid angular relationships between the different joint sets for their formation by this mechanism.

The physical characteristics of the '042' and '136' sets of joints, as well as their geometric relationship to the tectonic structures, suggests that these joint sets are extensional. Whether the '097' and '178' sets are shear or extensional has not been established.

The normal '136' set of joints is similarly mineralised. In addition, both the '042' group and its complement, the '136' group, have some examples displaying horizontal slickensides and polished surfaces. Only one example of this movement and polishing is recorded for the '097' set.

3.3.4 ROOF JOINTS - MINE SITE 4

At Mine Site 4 the stratigraphic plot of the roof joints, Stereogram No. 5, is very similar to the plot of roof joints at Area B in Mine No. 1, Stereogram No. 2. The structural setting of these two areas is similar; they are both situated in a similar part of a broad anticline.

The differences in the plots arise from difficulties of identification of joints developed parallel to the exposure, as the joints trending into the face are easily measured, while those trending parallel are irregular weathered surfaces. Due to the geological similarity of Mine Site 4 to Mine No. 1

and the probable similarity of the residual tectonic stress component of the existing stress field, mining recommendations made and successfully tested at Mine No. 1 would apply directly to Mine No. 4.

However, it is observed that the angular relationship between the planes is in the opposite sense for shear joints formed as a product of a residual tectonic stress. The acute angle lies between the '097'/'178' sets and the '136' or B - C joints and not the A - C joints as is required for shear joints formed by Price's mechanism.

The observed situation would require that the angle of internal friction be negative. Such a situation is impossible for a homogeneous rock mass and makes the suggestion very tenuous that the '097'/'178' joint sets are shear joints. The bilaterally symmetrical nature of the joint sets show that the situation is complex and it may be impossible to establish a simple classification for these joint sets.

Observation of the physical characteristics of the various joint sets has shown that the '097' joints are widely spaced and tend to be discontinuous. Where these joints are present, they are characterized by the presence of plumose structures. On the other hand, the '042' set of joints contains the 209 and 224 planes which are mineralised with carbonate material.

3.3.5 ROOF JOINTS - ADIT NO. 2

At Adit No. 2 the lithology of the roof strata is essentially the same as the roof at Mine No. 1 and Mine Site 4. The roof strata at Adit No. 2 appears to have been tectonically deformed to a lesser extent than Mine No. 1. Although a sigmoidal laminite zone can be observed in the roof, for the most part, there is no bedding plane fault at the top of the Chamberlain Seam and very few thrust faults are recorded which are generated from the seam level cutting the roof strata.

Similarly, fewer distinct joint sets appear to be developed in this area, as can be seen on the stereogram of poles to joints, Stereogram No. 11. This diagram shows that there are two principal joint sets both of which show the same small dihedral angle of two planes for the set, as can be seen in the areas studied at the northern end of the property. By comparison with Area A at Mine No. 1, these joints are the '097' and '042' sets. The stereogram shows that the 224 plane of the '042' site is more strongly developed than the 209 plane and a similar situation applies to the '097' set of joints. A discussion of the formation of these joint sets is included in Section 3.5.

3.3.6 ROOF JOINTS - MINE SITE 2

The coal of the Chamberlain Seam and the roof strata are fully exposed across a broad anticline at Mine Site 2. This exposure provided the opportunity to study lateral and vertical changes in the orientation of roof joints, in order to establish control for measurements taken at less complete exposures.

Firstly, joints in the roof were measured on either limb of the anticline, at the same stratigraphic level, to study changes in dip of the bedding on joint orientation. (See Stereograms 6 and 7). The results of this study have already been discussed in Section 3.3.2.

The second study at Mine Site 2 involved the measurement of joints at three different stratigraphic levels on the same limb of the anticline; the data from this study is presented as Stereograms 8 to 10. The lower stratum comprises the 4 feet of rock immediately above the Chamberlain Seam, being overlain by central stratum comprising the next 2.5 feet of the sequence. The upper and lower strata appear to be lithologically very similar, while the central lithology appears to have a more massive nature. Bedding in this stratum is still easily observed.

Field observations indicated that joints characteristic of the upper stratum were not readily observed in the lower stratum. The stereographic plots confirm this observation. However, there is a close correlation between the plots when one of the stereograms is rotated through 10^{o} with respect to the other. This rotation cannot be explained by a change in dip of the strata at two points of measurement and, to date, positive explanation is not yet available.

The upper stratum is adjacent to a sigmoidal laminite zone and the orientation of this structure at the time of joint formation may have modified the stress field producing a change in strike of the joint planes. The strike of the joints in the central lithology tends to be randomly oriented and a more detailed investigation of one set of planes showed that the strike of these joints gradually changed from 177° on the limb to 215° at the crest of the anticline.

It is considered that this unit of rock with its particular lithology and physical characteristics, at the time of tectonic deformation acted in a varying ductile manner. Microseismic activity possibly took place to a greater extent where curvature of the beds was strongest, that is, at the crest of the anticline. This activity was less pronounced with increased distance away from the crest of the fold. The deformation imposed a series of oriented 'Griffith' cracks or microfractures most strongly developed at the crest of the fold and progressively less prominent along the limbs.

Consequently, at the time of formation of the first joint set, the presence and density of these oriented cracks and small fractures tended to modify the trends of the joints. The presence and orientation of the first set of joints would similarly modify the trend of subsequent joint sets. This feature is not observed in the surrounding strata. Its absence may indicate that the surrounding strata had different physical properties. Under the conditions that existed at the time of tectonic deformation, they did not behave in a transitional manner, but were uniformly deformed from the hinge to the limb of the fold. Hence, there is no rotation of joint planes across the fold.

Superimposing stereographic plots from the centre and lower lithologies produces identical results to those obtained from joint measurements on the western limb of the anticline. The poles are scattered, and this scatter reduces the intensity of the concentrations.

Consequently, all plots of joints are more useful for comparative studies when they are measured at the same stratigraphic horizon.

3.4 JOINTS AND FAILURE PLANES IN THE CHAMBERLAIN SEAM

These structures, commonly termed rib joints, were studied at two areas, A and B (See Figure 8), at Mine No. 1, as well as the exposures of the seam at Mine Site 2 and Adit 2. The nature of the seam discontinuities was most easily observed at the surface exposure of Mine Site 4 and the other areas are compared with this. Stereograms 12 to 16 refer.

Two types of structures could be distinguished; (i) closely spaced and steeply dipping cleats, and (ii) shallowly dipping and widely spaced failure planes. Comparison of the cleat structures with the roof joint plots shows a close similarity of trends; the '136', '178' and '042' groups are present. The strike of the '097' set is not well developed and this set may be obscured as a result of surface weathering. In the underground areas, some of these trends can be seen on the stereogram however the cleat commonly is either not well developed or is obscured.

In general, the cleats would appear to be structures generated in the seam under the same stress conditions existing at the time of joint formation in the seam roof. The only difference would appear to be a slightly shallower dip in the seam than in the roof structures. This may be a function of the different properties of the two materials and orientations with respect to tectonic structures, i.e. a feature similar to cleavage refraction in a low grade metamorphic terrain.

The low angle structures developed in the seam do not have any parallel joint structures developed in the seam roof. However, these seam discontinuities are paralleled in the roof by the two weakly developed small scale thrust fault trends discussed in Section 2.4.

In some cases, coal along the planes of the seam discontinuities is sheared and small scale fold structures similar to kink bands are formed. Consequently, it is felt that these seam discontinuities are a product of shear failure taking place in the seam at the time when tectonic deformation was generating the roof thrust planes.

It should be noted that both concentrations of the cleats at Mine Site 4 strike parallel to one of each of the shear plane concentrations. Also, the parallel trending shears and cleats have the same angular relationship between their planes. The parallel trending cleats and shear planes are separated by approximately 62° in both cases.

The close relationship between the trends of these two structures which are formed at different times, lends strong support to a mechanism of a stress field sympathetic with the tectonic stresses generating the cleats and roof joints. It is interesting to note that the bilaterally symmetrical nature earlier noted for the groups of roof joints appears to be present in the cleats and the seam shear planes.

At Area B in Mine No. 1 a similar situation to that for the seam shear structures can be seen at both Area A and at Mine Site 2; however, the data collection procedures may have emphasised some planes at the expense of others.

At Adit No. 2 the reduced amount of tectonic deformation of the roof, as discussed in Section 3.3.5, also applies to the coal seam. At this location, towards the southern end of the property, no shear planes are present in the coal, only the cleats being present. Further along the exposed outcrop of the Chamberlain Seam, to the east of Adit No. 2, some widely spaced low angle planes occur in the coal including one zone having a high density of low angle shear planes. The latter zone, which occurs over a distance of approximately 20 feet, is associated with a small thrust fault which has a throw of 0.7 feet in the coal and 1.6 feet in the roof strata.

The average density of low angle shear planes in the coal in the Chamberlain Creek area is approximately one per 5 to 10 feet compared with one per 0.5 or less feet at all of the northern exposures of the seam.

3.5 JOINT FORMATION - AGE AND ROCK FAILURE

In this section current ideas regarding the formation of joints and the application of these ideas to the Sukunka project is discussed.

As may be anticipated, it is frequently observed that the joints have a consistent geometrical relationship to the tectonic structures on which they are located. Price (1959) introduced an hypothesis to explain the formation of the joints and the geometrical relationship to tectonic structures. Price (1959) suggested that after the phase of active deformation the rocks retain a residual stress field which has the same orientation as the original tectonic stress field.

At Sukunka, many of the fault and fold structures formed during tectonic deformation indicate that the maximum principal stress acted in a horizontal direction and the minimum principal stress was vertical. Observation of joint patterns and their physical characteristics has indicated that some of the structures are the product of shear failure and others are the product of brittle failure in extension. However, the joints are commonly vertical, thus roation of the stress field is required to explain failure planes formed in this orientation from residual tectonic stresses.

Price (1959) explained this rotation by suggesting that crustal extension during uplift preferentially reduced the horizontal stresses with respect to the vertical stresses. Consequently, the vertically acting minimum principal stress becomes the intermediate principal stress at higher levels in the crust and, further, is horizontally oriented. In this orientation vertical shear joints can form.

The development of these joints will tend to reduce the maximum principal stress and increase the minimum principal stress. Thus, the vertical load may now become the greatest principal stress.

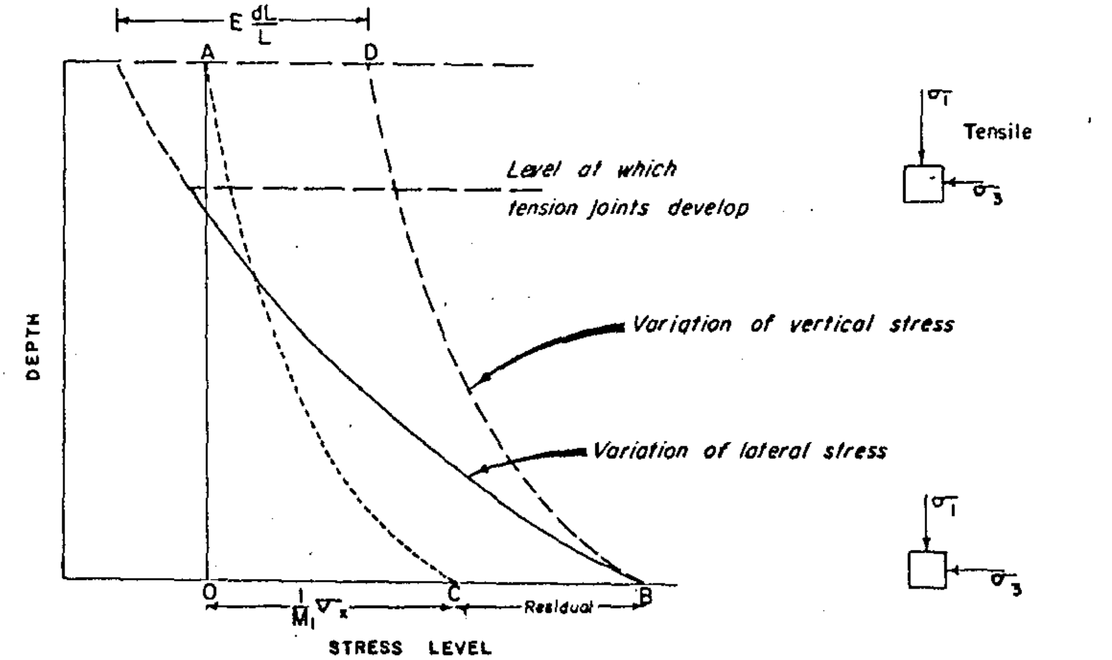
Price (1959) states "Further uplift may cause the rock to pass into tension with the possible subsequent development of a system of tension joints."

Figure 10 shows the relationship which exists between stress level and depth of burial, for the formation of shear and tension joints by this mechanism. This hypothesis explains the formation of shear joints, but objections have been raised to the rock passing into a state of absolute tension before the formation of tension joints.

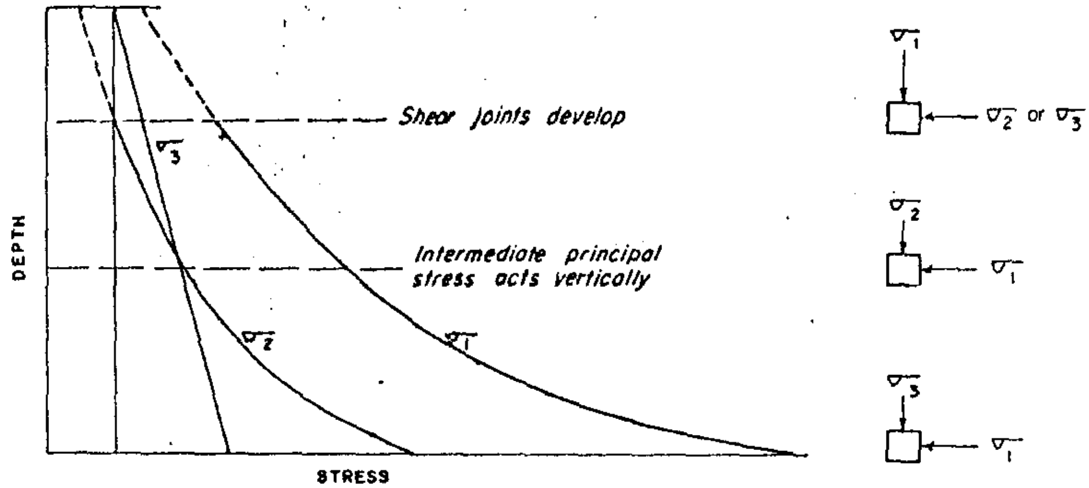
Secor (1968) introduced a mechanism explaining the formation of tension joints at depth. He suggests that the stresses involved in tension joint formation are effective stresses i.e. the difference between the absolute stress field and the pore water pressure. Further, he concluded "when natural fracturing occurs at depth in the earth's crust in the presence of high pore pressures, macroscopic fracture growth is a slow process consisting in detail of numerous brief episodes of fracture propagation interspersed with longer periods of quiescence during which pore fluid from the surrounding rock percolates into the crack and wedges it open". In addition, "most rocks appear to have porosites adequate for the development of the joint patterns observed in them."

This mechanism allows failure and extension fractures to form under effective tension stresses and not under absolute tension. Experimental evidence of Brace (1964) shows that both extension fractures normal to the axis of least

ROOF JOINT FORMATION — STRESS VARIATIONS WITH UPLIFT



Variations in stress due to uplift from an initial condition of near hydrostatic pressure



Variations in stress due to uplift from an initial condition in which the ratio of greatest to least principal stress, σ_1/σ_3 is large

After PRICE (1966)

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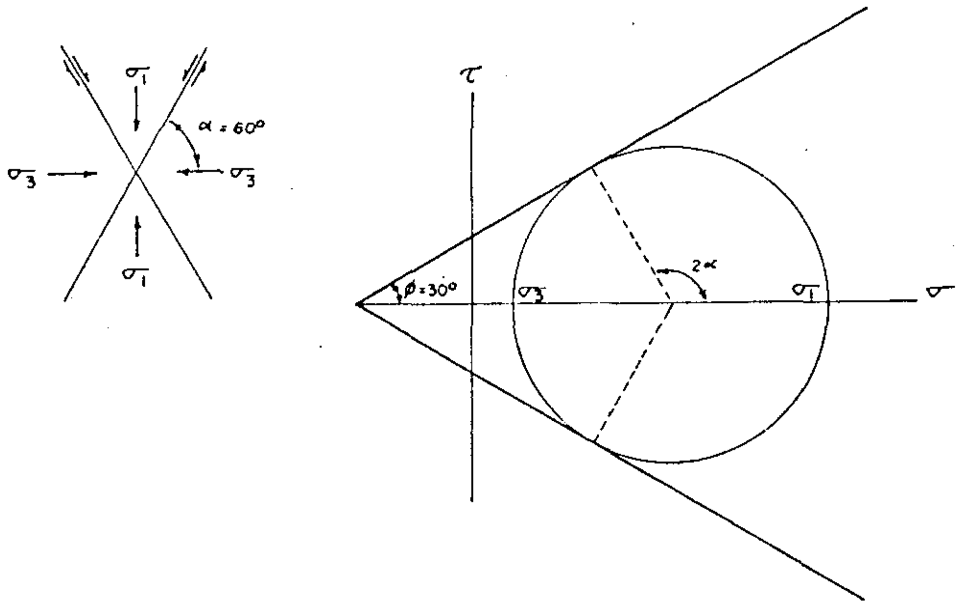
Figure 10

compressive stress, and shear fractures oriented at 70° to 90° to this axis, occur. He also indicates that shear and extension fractures are members of a continuous series, hence effective stesses would control the formation of shear joints as well as tension joints.

At Sukunka, the joint systems are characterised by the presence of a small dihedral angle between conjugate planes. Parker (1942) described a single joint set of this type and explained its formation as a set of conjugate shears formed under the influence of normally oriented compressive and tensile stresses.

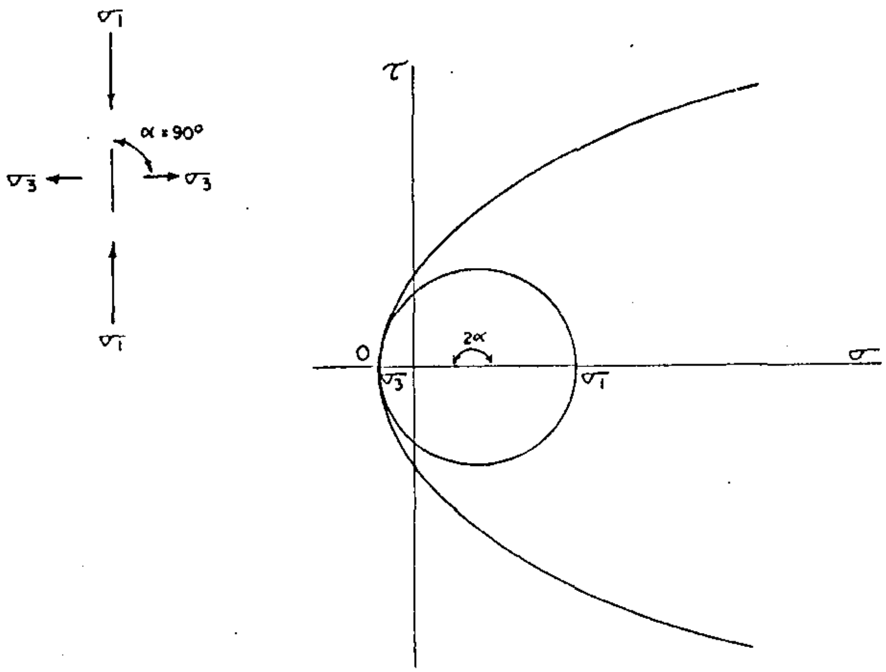
Nickelsen and Hough (1967), working in the same areas as Parker, argued that these planes with a small dihedral angle represented the overprinting of two joint sets. The overprinting occurred at the junction of two areas, each of which possessed a promininent joint set. At Sukunka, the Nickelsen and Hough explanation seems unlikely, since each of four joint planes would have to be overprinted. No data is available from surrounding areas to determine whether some overprinting of joint sets may have occurred.

Muehlberger (1961) described the Mohr envelope and discussed the failure criterion required to form a conjugate joint set with a small dihedral angle. In his discussion, Muehlberger considered the typical Coulomb Law straight line envelope shown in Figure No. 11. He states "The confining pressure becomes less as the tension side of the graph is approached, until ultimately it may be possible to have the entire body under tension in all principal stress directions." The shear failure angle predicted from this diagram is constant and independent of the 'confining pressures'.



(a) Coulomb-law Mohr envelope with critical stress circle

After Muehlberger (1961)



(b) Leon modification of Mohr envelope.

After Muehlberger (1961)

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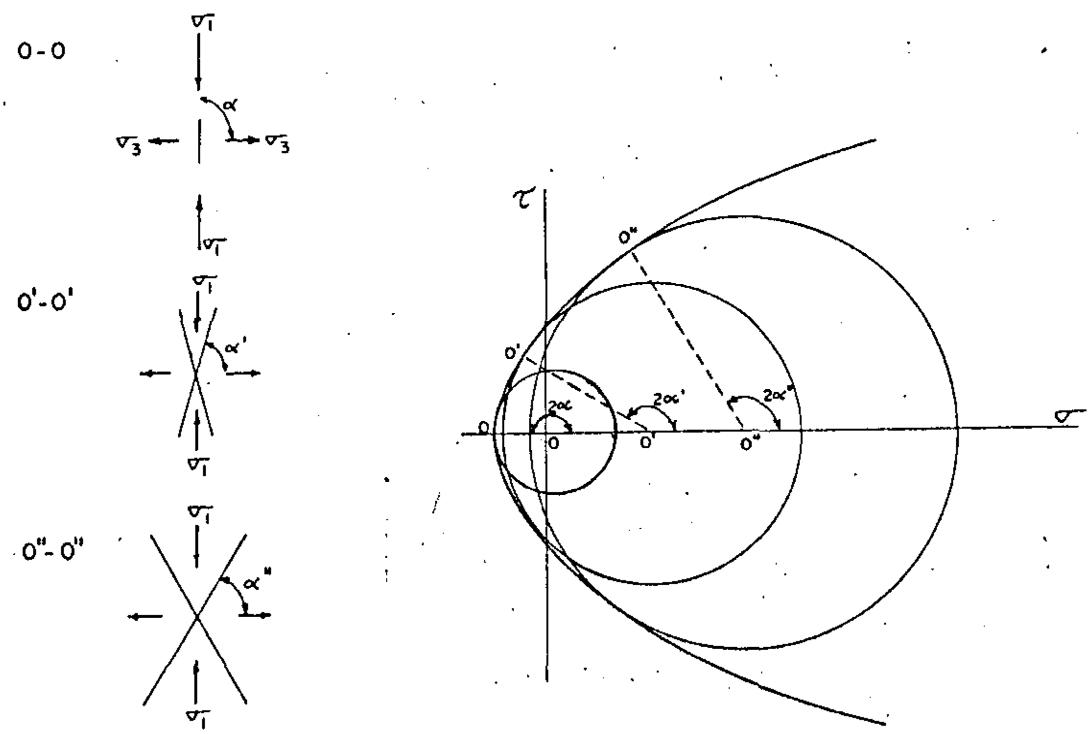
Figure 11

Figure No. 11 also shows Leon's modification of the Mohr fracture envelope intersecting the normal stress axis at right angles in the region of the low values of the confining pressures. With this envelope a critical stress circle, with a smaller or equal radius of curvature than the envelope at O, can become tangent to the envelope at the point O on the normal stress axis and thus a single plane of failure is predicted." The type of structure produced is termed a tension joint or extension fracture.

Muehlberger (op. cit.) shows that, under slightly higher 'confining pressures', planes of failure with a small dihedral angle can be produced under the Leon modification of the Mohr failure envelope. He suggests that conditions of failure, discussed above, producing the single plane normal to the minimum 'confining pressure' and the small dihedral angle conjugate pair of joints, implies formation at shallow depths of burial. This is illustrated in Figure 12.

Muehlberger then applies these failure relationships to a theory of joint formation at the time of folding, in which stresses near or at tensile values exist at the crest of anticlines. This would allow such small angle conjugate shears to form in these regions. However, Price has argued that similar fractures produced during the phase of active deformation would probably produce wrench or normal faults.

At Sukunka, the folding was of such an order of intensity as to suggest that plastic deformation or cataclastic flow mechanisms were significant at this time. No increase in joint intensity at the crest of the folds is obvious. The formation during this period of such structures as the sigmoidal laminite zones confined to particular stratigraphic levels, tends to suggest relatively high confining pressures existed at that time.



Summary Mohr diagram with Leon-modified envelope showing three successive steps in increasing stress difference with corresponding conjugate fracture sets of increasing dihedral angle.

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Figure 12

3.6 DETERMINATION OF MINING DIRECTIONS

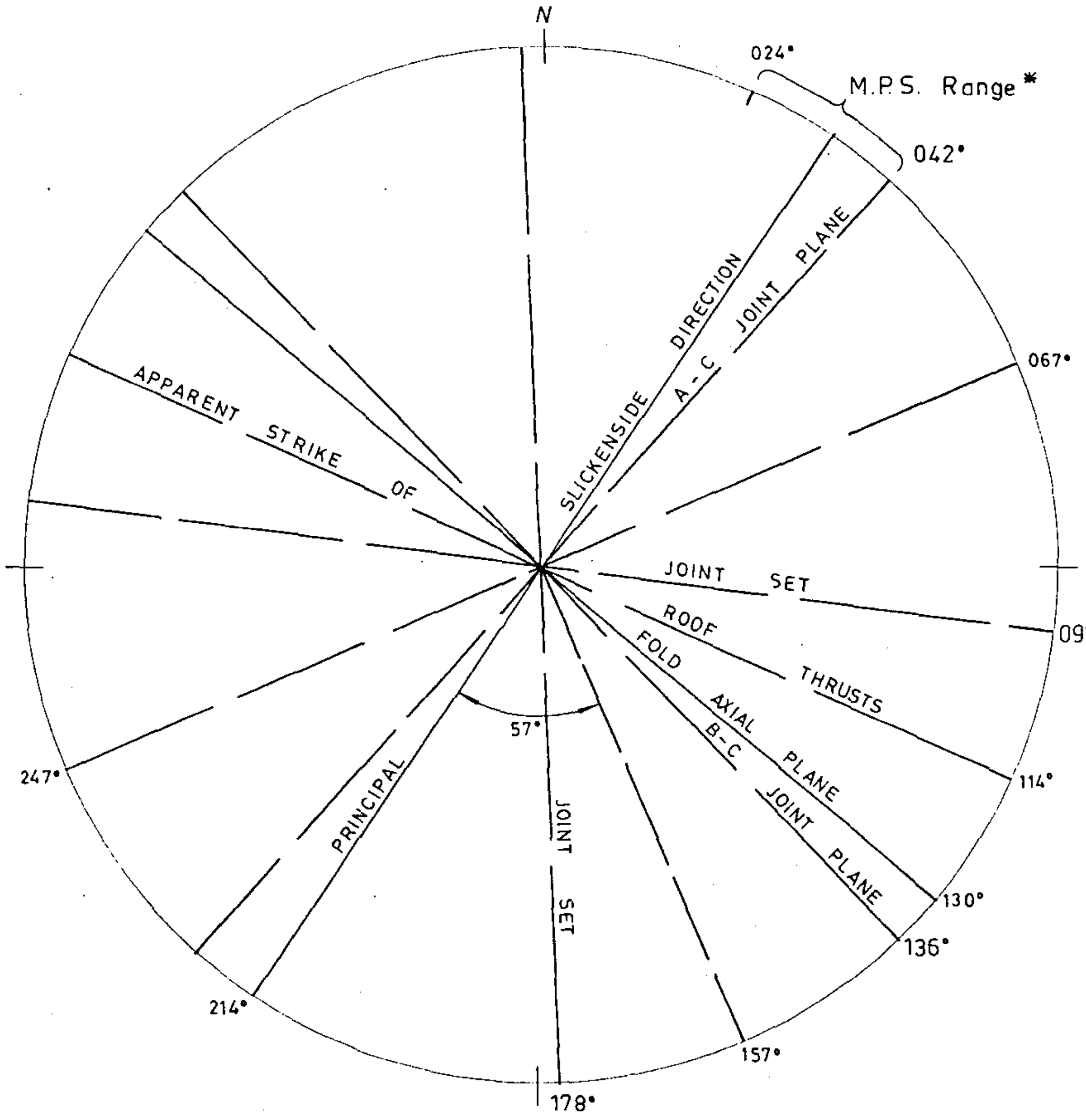
(Note: Since mining is not current in the Chamberlain Seam in Mine No. 1 the following recommendations are not readily tested. The basic principles employed in the analysis, and the results therefrom, are however applicable to other areas of the Sukunka Property.)

The following section takes into account the data included throughout this report, for example Section 2.3 - Thrust Faults, Section 3.3 - Joints in the Chamberlain Seam Roof, and in Section 4.3.6 (Analysis of Sub Surface Structures) of the 1972 Geological Supplement, Wallis, McElroy and Bryan, (1973). Figure 13 illustrates the generalised directions of the significant structural elements under consideration.

The residual stress field in the Sukunka area is inferred to be such that the maximum residual stress (M.R.S.) is near the horizontal. Further, the M.R.S. is most probably oriented approximately in a similar direction to the maximum principal stress (M.P.S.) that prevailed during the period of deformation of the strata. From the analysis of the structural elements discussed above the M.P.S. is interpreted as lying within the range 024° to 042°. From Figure 13 it can be seen that the M.P.S. range is parallel to the slickenside direction (214°) and approximately perpendicular to the trend of the roof thrusts (114°). Thus the most unstable area at the downward termination of the roof thrusts is passed in the minimum distance when driving parallel to the M.P.S.

It is recommended that driving parallel to the M.P.S., that is 214°, be tested in order to minimise the effects of the thrust structures. While the main headings are controlled by the intra-plate faults, a modification of the cross-cut directions should be possible, within the normal constraints of mine layout and machine manoeuverability.

GENERALISED DIAGRAM OF
STRUCTURAL ELEMENT DIRECTIONS



* Range of azimuths for
MAXIMUM PRINCIPAL STRESS = PREFERRED DIRECTION OF CROSS CUTS

PRESENT HEADING DIRECTION 157°

PRESENT CROSS-CUT DIRECTIONS 067° - 247°

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COALITION MINING LIMITED

Figure 13

DRW BY G.W. DATE: JANUARY, 1976

Prior to the cessation of activity in the Chamberlain Seam in Mine No. 1 a trial mining direction of 212^{o} in the B heading to the A heading cross-cut was tested with some amelioration of bad roof. Insufficient testing, prior to cessation of mining this seam, was carried out to provide any conclusive results, however.

It is stressed that any predictions based on the fore-going structural analysis must be regarded as tentative until tested over a greater spatial area. Continual observation and evaluation of features revealed in mine openings is essential if a more complete understanding of the significant structural elements affecting mine stability is to be gained. None-the-less the basic principles will be applicable to other areas on the property.

G.R. Jordan

B.Sc., A.M.Aus.I.M.M.

SELECTED BIBLIOGRAPHY

BIELENSTEIN, H.U., & BARRON, K., 1971 : In Situ Stresses; 7th Canadian Rock Mechanics Symposium.

BRACE, W.F., 1964 : Brittle Fracture of Rocks. Pub. in Proc. Int.Conf. of State of Stress in the Earth's Crust. Ed. W.R. Judd. Elsevier & Co.

__________ 1969 : The Mechanical Effects of Pore Pressure on the Fracturing of Rocks; Proceedings, Conference on Research in Tectonics. Geol.Surv.Can.Paper 68-52, 113-123.

BURK, C.F., Jr. 1963 : Structure, Isopach and Facies Maps of the Upper Cretaceous Marine Succession, West Central Alberta and Adjacent British Columbia; Geol. Surv. of Can. (Dept. Min. and Tech. Sur.), Paper 62-31.

CHARLESWORTH, H.A.K., 1969 : Some Observations on the Age of Jointing in Macroscopically Folded Rocks; Proceedings, Conference on Research in Tectonics, Geol. Surv. Can. Paper 68-52, 125-134.

CONNELLY, M.A., 1966 : The Uses of Geological Structural Analyses in Predicting Roof Conditions in Coal Mining; Symposium on "Stress and Failure Around Underground Openings"; Paper No. 13.

__________ 1967 : Structural Investigation into Directional Mining Eyre Panel - Nebo Colliery; Australian Iron & Steel Pty. Ltd., Coal Geology Report, Unpublished.

_______________ : A Geological Structural Assessment at Appin Colliery with Reference to Roof Failure and Directional Mining: Proc. Aust. Instit. Min. Met. June, 1970, 234:17.

CROSBY, G.W., : Stress Reorientation During Folding; Geologische Rundschau, Ed. 61.

GAY, N.C., 1972 Virgin Rock Stresses at Doornfontein Gold Mine, Carletonville, South Africa; Journal of Geology, Vol. 80.

HEIDECKER, E., 1964 : Estimation for Engineering Design Purposes of the Principal Stress Directions in Rocks Containing Residual Strains; Proc. Aust. Instit. Min. Met. March, 1964, 209:167.

_______________ 1965 : Recognition, Interpretation, and Use of Mutually Perpendicular Lineations in Rocks; Proc. Aust. Instit. Min. Met., March, 1965, 213:65.

HUGHES, J.E., 1964 : Jurassic and Cretaceous Strata of the Bullhead Succession in the Peace and Pine River Foothills: B.C. Dept. of Mines and Petroleum Resources, Bulletin No. 51.

_______________ 1967 : Geology of the Pine Valley; B.C. Dept. of Mines and Petroleum Resources, Bulletin No. 52.

IRISH, E.J.W., 1968 : Structure of the Northern Foothills and Eastern Mountain Ranges, Alberta and British Columbia, between latitudes 53°15' and 57°20'; Geol. Surv. Can. (Dept. of Energy, Mines and Resources), Bull. 168.

JAEGER, J.C., 1960 : Shear Failure of Anisotropic Rocks; Geol. Magazine, Vol. 97.

——————— & COOK, N.G.W., 1969 : Fundamentals of Rock Mechanics; Chapman and Hall Ltd. and Science Paperbacks.

LATOUR, B.A., 1970 : The Coal Deposits of Western and Northern Canada; Geological Survey of Canada, Presented to 22nd, Canadian Conference on Coal, Vancouver 1970.

MENZIES, R.A., 1969 : Roof Support in Coal Mines; Bulletin of the Coal Mines Safety Committee, N.S.W.

MORGENSTERN, N.R., 1971 : Role of Effective Stresses in Earth Behaviour; Proceedings of the 7th Canadian Rock Mechanics Symposium.

MUEHLBERGER, W.R., 1961 : Conjugate Joint Sets of Small Dihedral Angle; Journal of Geology 69: 211 to 219.

McCURDY, R., (in press) : Structural Geology at the Cardinal River Mine, Alberta.

McELROY, C.T., & WALLIS, G.R., 1972 : Sukunka Coal Project Geological Report; Unpublished Report by Clifford McElroy and Associates to Coalition Mining Limited.

McKELVIE, D.L., (in press) : Practical Geology in the Smoky River Coalfield.

MICKELSEN, R.P., & HOUGH, V.N.D., 1967 : Jointing in the Appalachian Plateau of Pennsylvania; Geol. Soc. America Bull., 78: 609-629.

MORRIS, D.K., & BARRON, K., 1969 : Structural Analysis of Features on Natural and Artificial Faults; Proceedings, Conference on Research in Tectonics, Geol. Surv. Can., Paper 68-52 : 136-167.

PARKER, J.M., 1942 : Regional Systematic Jointing in Slightly Deformed Sedimentary Rocks; Bull. Geol. Soc. of America, 53 : 381-408.

PARSONS, R.C., & DAHL, H.D., 1971 : A Study of the Causes of Roof Instability in the Pittsburgh Coal Seam; Proceedings of the 7th Canadian Rock Mechanics Symposium.

PHILLIPS, F.C., 1960 : The Use of Stereographic Projection in Structural Geology; Edward Arnold (Publishers) Ltd.

PRICE, N.J., 1959 : Mechanics of Jointing in Rocks. Geol. Mag. 96:149.

__________ 1966 : Fault and Joint Development in Brittle and Semi-brittle Rock; Pergamon Press.

PUGH, D.C., 1960 : The Subsurface Gething and Bluesky Formations of Northeastern British Columbia; Geol. Surv. Can. (Dept. Min. and Techn. Surv.), Paper 60-1.

SECOR, D.T., 1965 : Role of Fluid Pressure in Jointing; Am. Jour. Sci., 263 (8): 633-646.

__________ 1969 : Mechanics of Natural Extension Fracturing at Depth in the Earth's Crust; Proceedings, Conference on Research in Tectonics, Geol. Surv. Can. Paper 68-52 : 3-47.

STEARNS, D.W., 1969 : Fracture as a Mechanism of Flow in Naturally Deformed Layered Rocks; Proceedings, Conference on Research in Tectonics. Geol. Surv. Can. Paper 68-52, 79-90.

STOTT, D.F., 1968 : Lower Cretaceous Bullhead and Fort St. John Groups, between Smoky and Peace Rivers, Rocky Mountain Foothills, Alberta and British Columbia; Geol. Surv. Can. (Dept. Energ., Min. and Res.), Bull. 152.

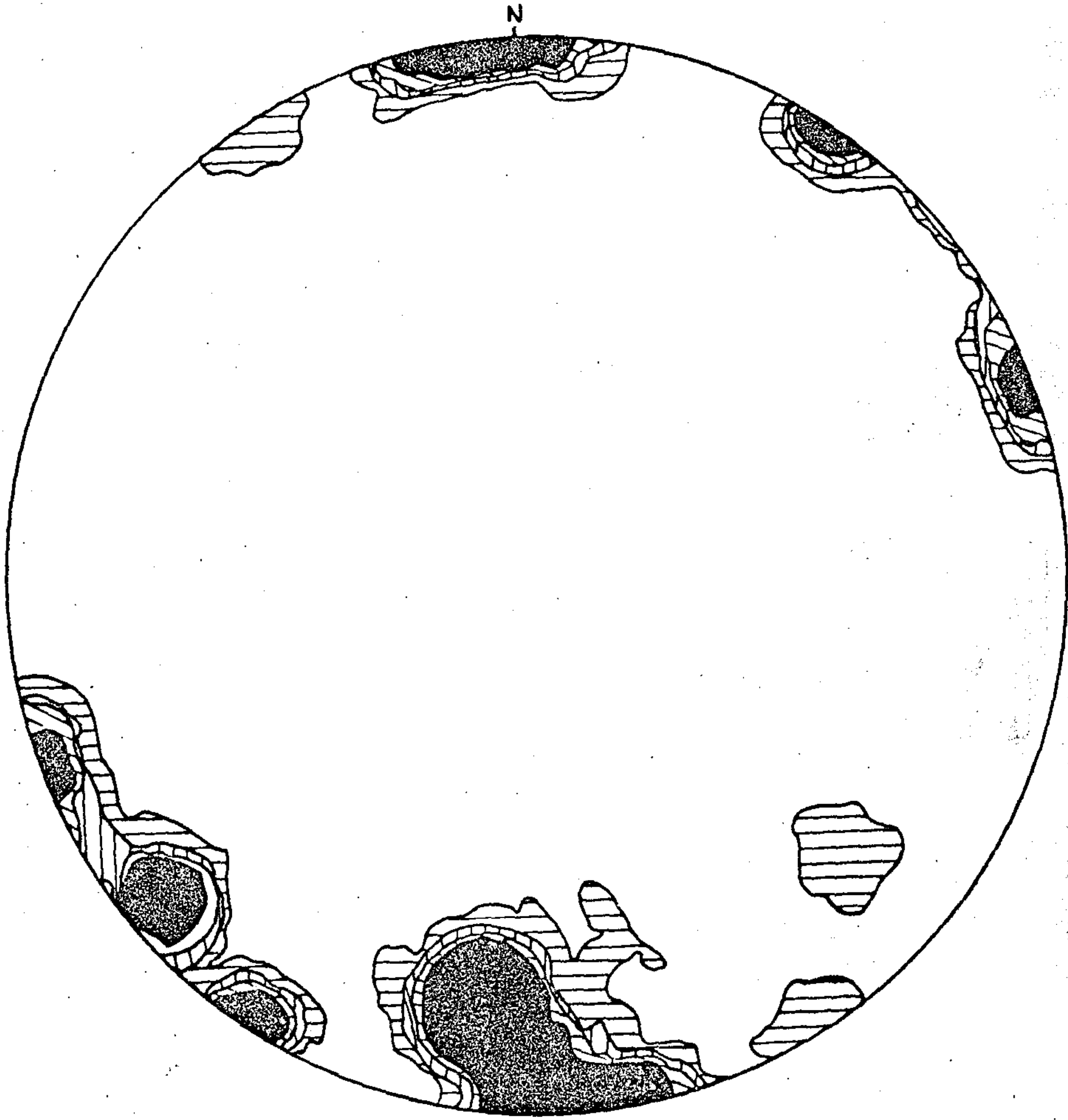
WALLIS, G.R., McELROY, C.T., & BRYAN, J.H., 1973 : Sukunka Coal Project Geological Supplement; Unpublished Report by Clifford McElroy and Associates to Coalition Mining Limited.

WALLIS, G.R., & JORDON, G.R., 1975 : The Stratigraphy and Structure of the Lower Cretaceous Gething Formation of the Sukunka River Coal Deposit, British Columbia. Bull. Can. Instit. Min. & Metall.

APPENDIX A

STEREOGRAMS 1 TO 16

AREA 'B' POLES TO ROOF JOINTS



MINE No. 1

Prepared by :
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for
COALITION MINING LIMITED

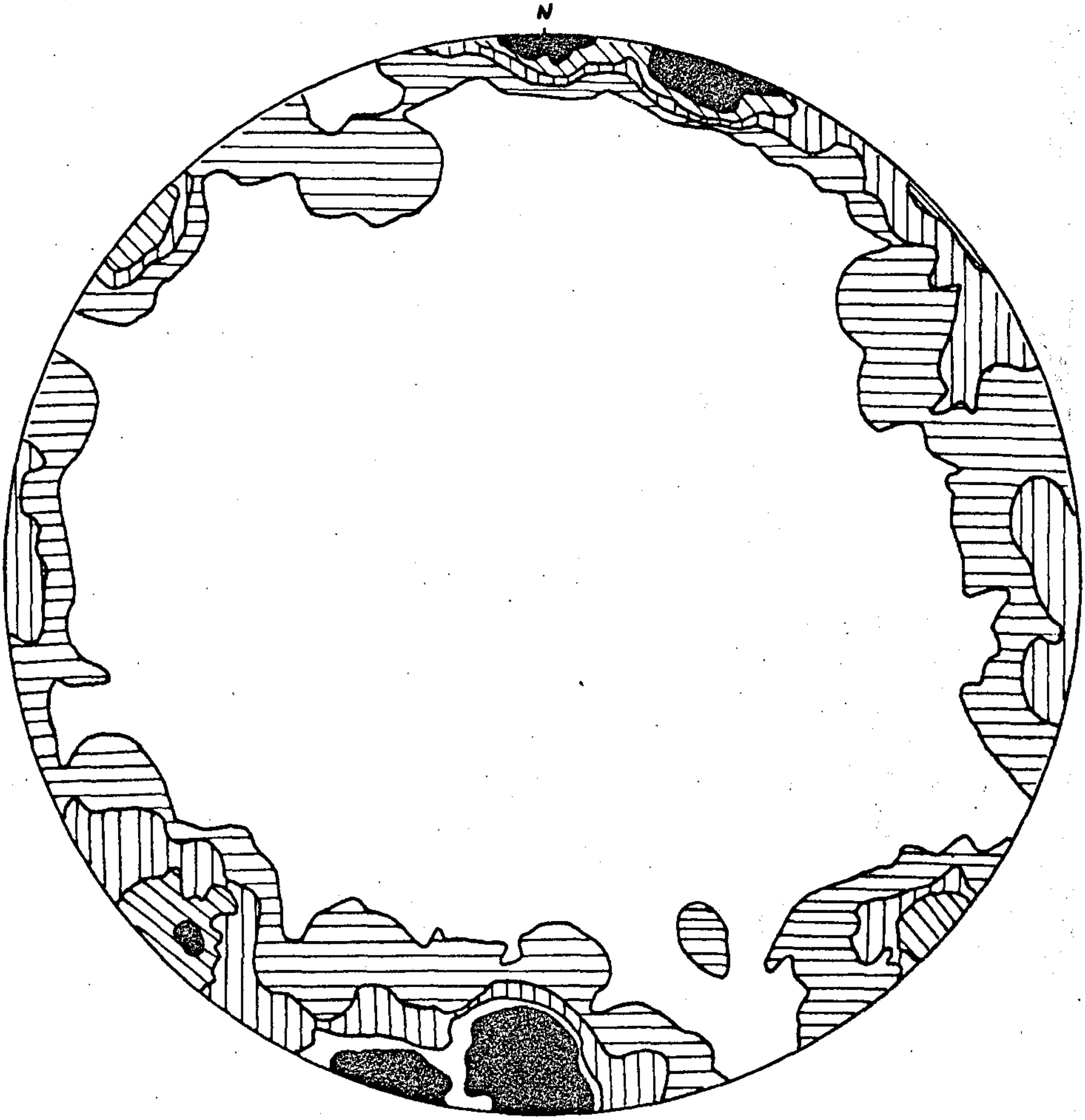
DATE: OCTOBER, 1973

STEREOGRAM No. 3

No. OF POLES: 150

PERCENTILE CONTOURS: 3, 6, 9, 12

AREA 'C' POLES TO ROOF JOINTS



MINE No. I

Prepared by :
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for
COALITION MINING LIMITED

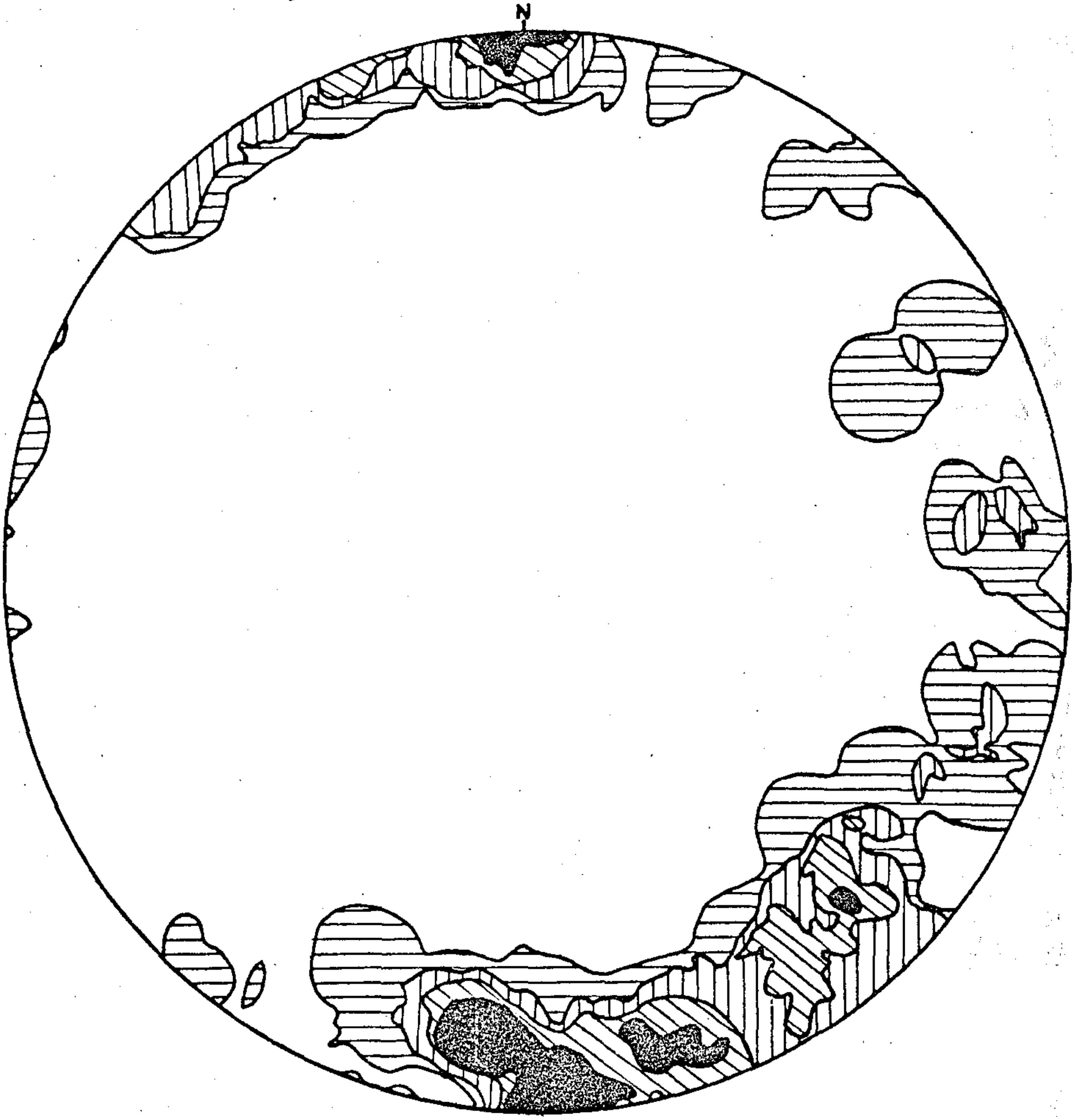
DATE: OCTOBER, 1973

STEREOGRAM No. 4

No. OF POLES: 150

PERCENTILE CONTOURS: 3, 6, 9, 12

MINE SITE 4 POLES TO ROOF JOINTS



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for
COALITION MINING LIMITED

DATE: OCTOBER, 1973

STEREOGRAM No. 5

No. OF POLES: 100

PERCENTILE CONTOURS: 2,4,6,8

MINE SITE 2 POLES TO ROOF JOINTS – EAST LIMB

Prepared by :
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for
COALITION MINING LIMITED

DATE: OCTOBER, 1973

STEREOGRAM No. 6

No. OF POLES: 100

PERCENTILE CONTOURS: 2, 4, 6, 8

MINE SITE 2 POLES TO ROOF JOINTS – WEST LIMB

Prepared by:
CLIFFORD McELROY & ASSOCIATES PTY LTD
for
COALITION MINING LIMITED

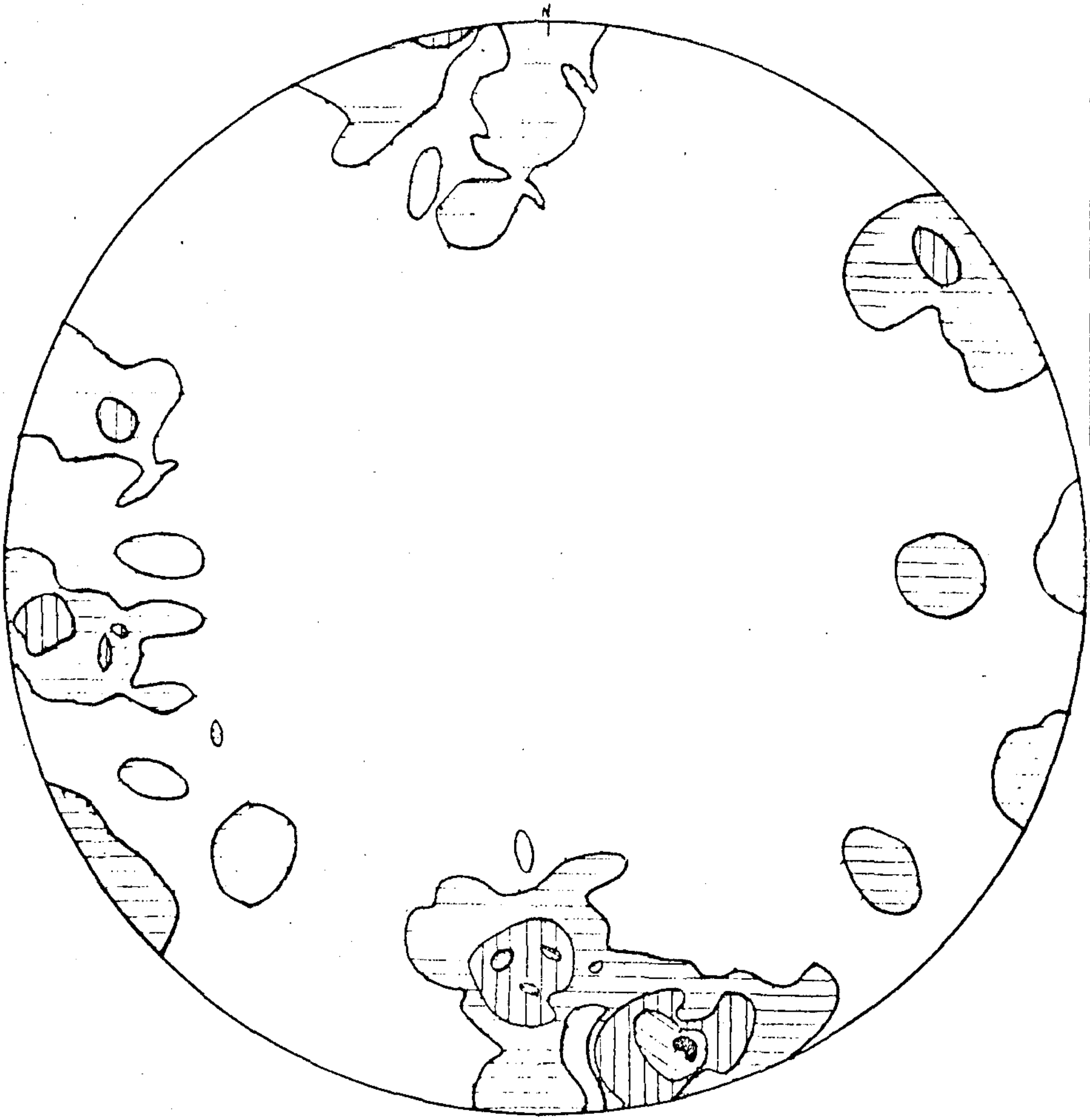
DATE OCTOBER,1973

STEREOGRAM No. 7

No. OF POLES: 100

PERCENTILE CONTOURS: 2,4,6,8

MINE SITE 2 POLES TO ROOF JOINTS – TOP LITHOLOGY



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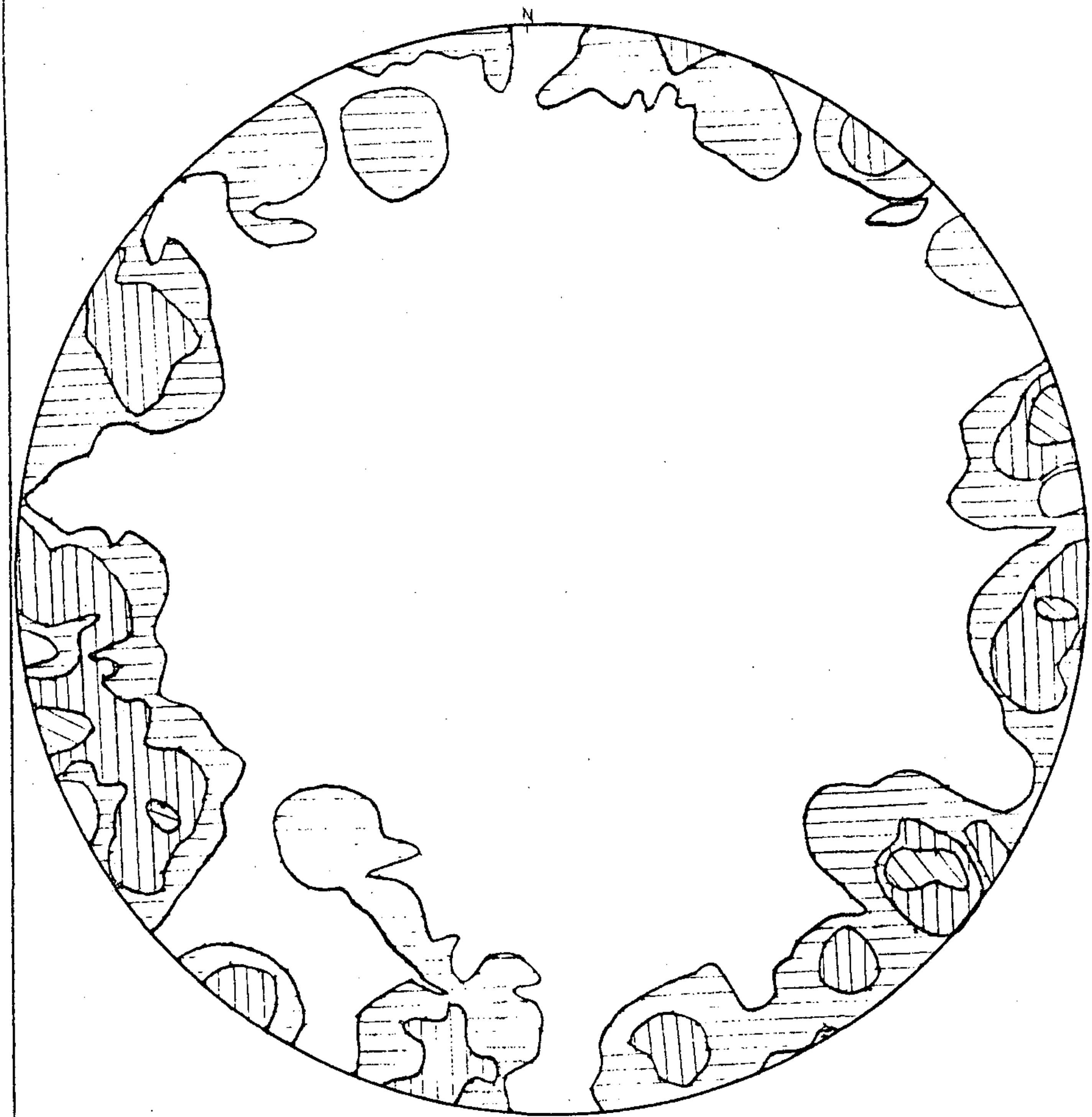
DATE: OCTOBER, 1973

STEREOGRAM No. 8

No. OF POLES: 100

PERCENTILE CONTOURS: 2,4,6,8

MINE SITE 2 ROOF JOINTS - CENTRE LITHOLOGY



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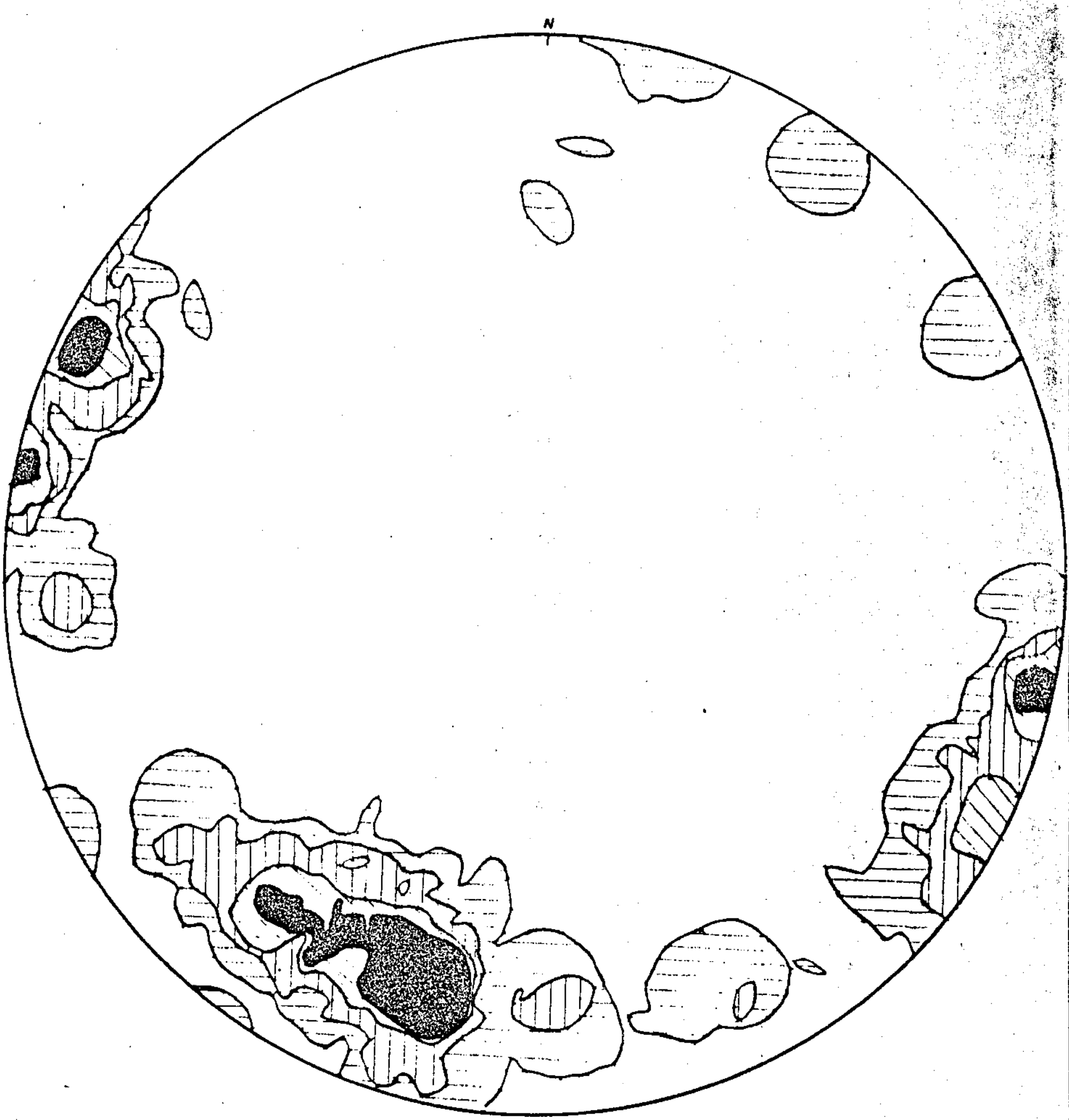
DATE OCTOBER, 1973

STEREOGRAM No. 9

No. OF POLES : 100

PERCENTILE CONTOURS : 2, 4, 6

MINE SITE 2   POLES TO ROOF JOINTS-LOWER LITHOLOGY



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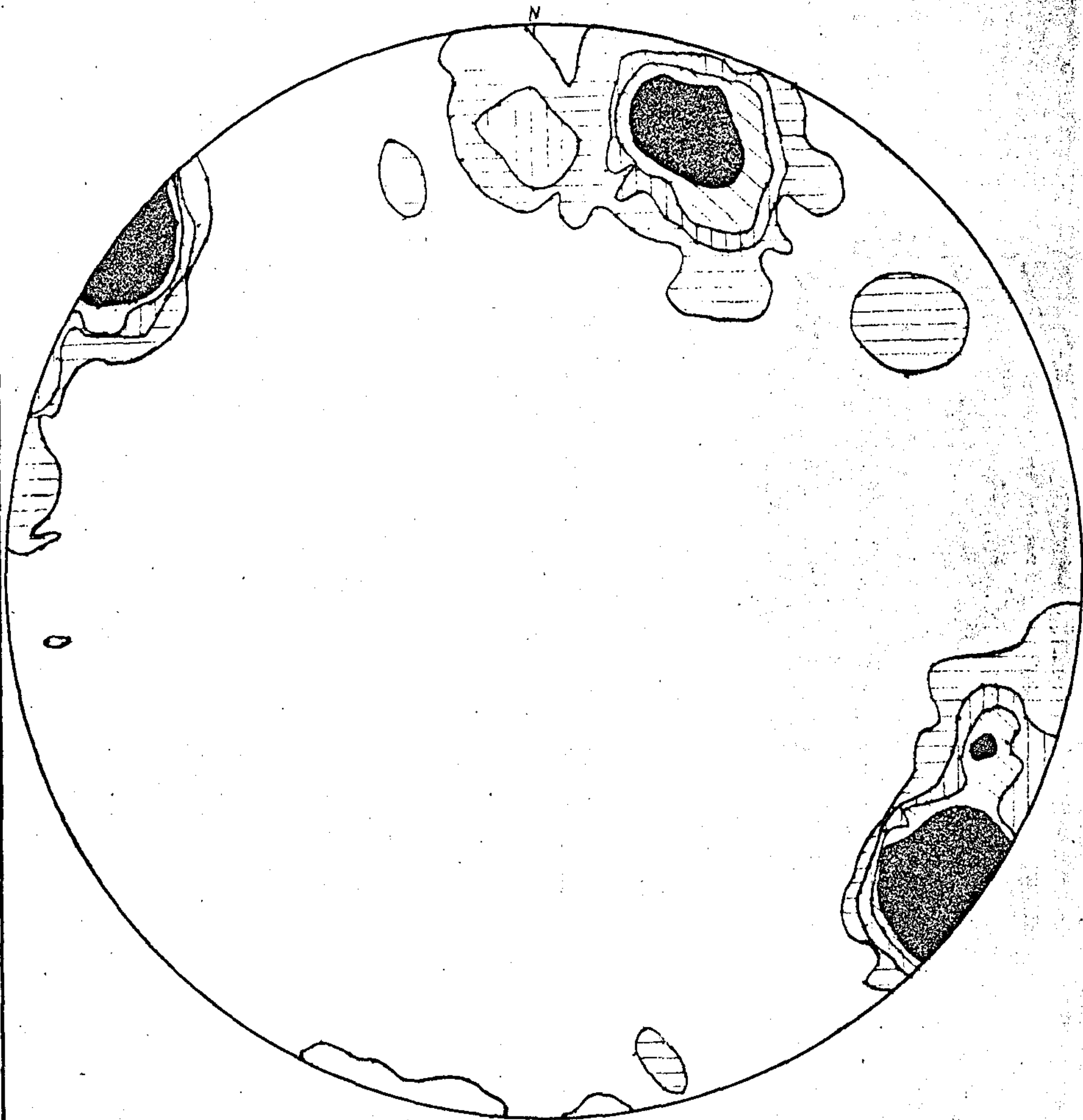
DATE OCTOBER, 1973

STEREOGRAM No. 10

No. OF POLES: 100

PERCENTILE CONTOURS: 2,4,6,8

ADIT No. 2 POLES TO ROOF JOINTS



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for
COALITION MINING LIMITED

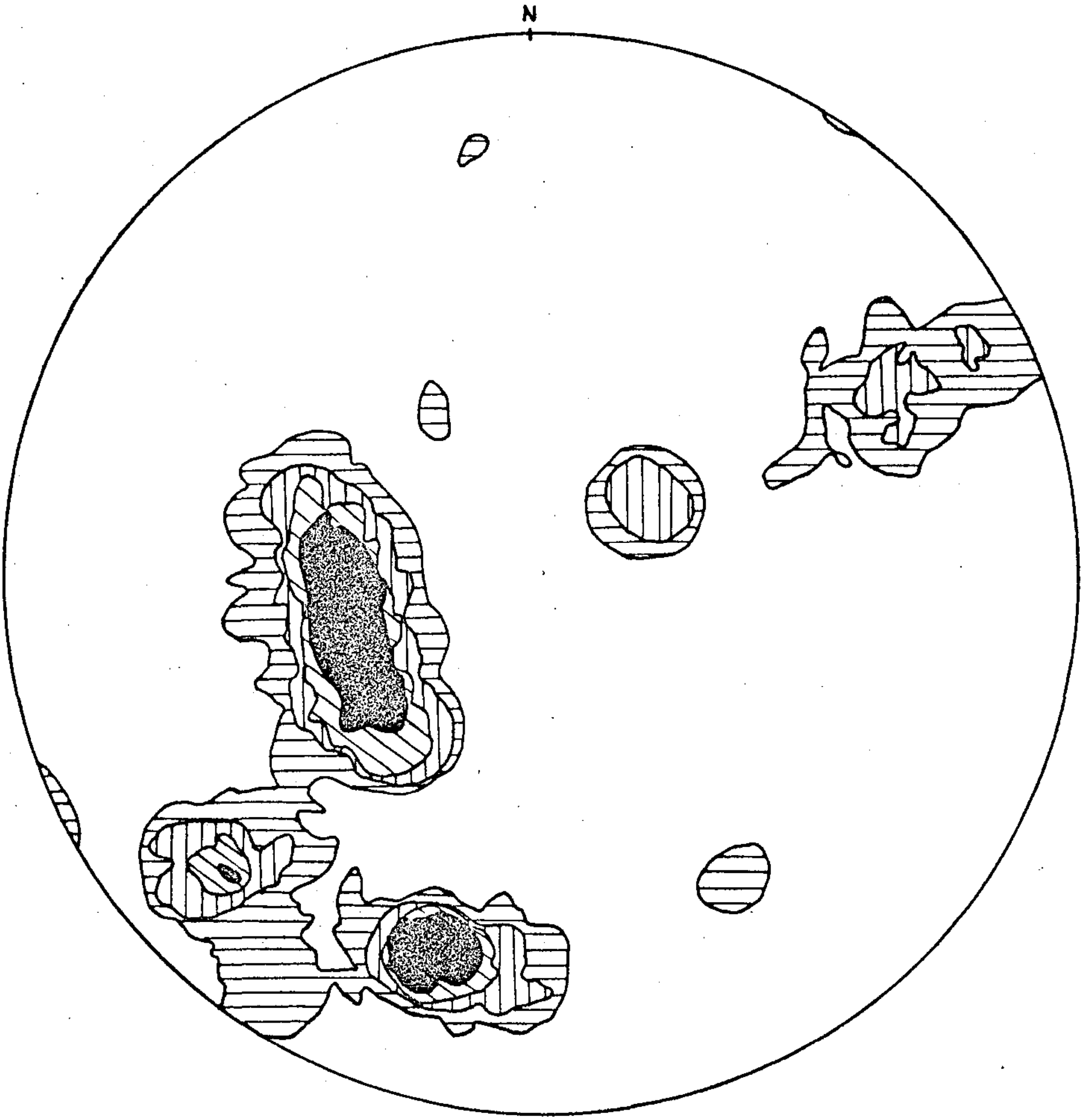
DATE: OCTOBER, 1973

STEREOGRAM No. 11

No. OF POLES : 100

PERCENTILE CONTOURS : 2, 4, 6, 8

AREA 'A' POLES TO JOINTS IN RIB



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for
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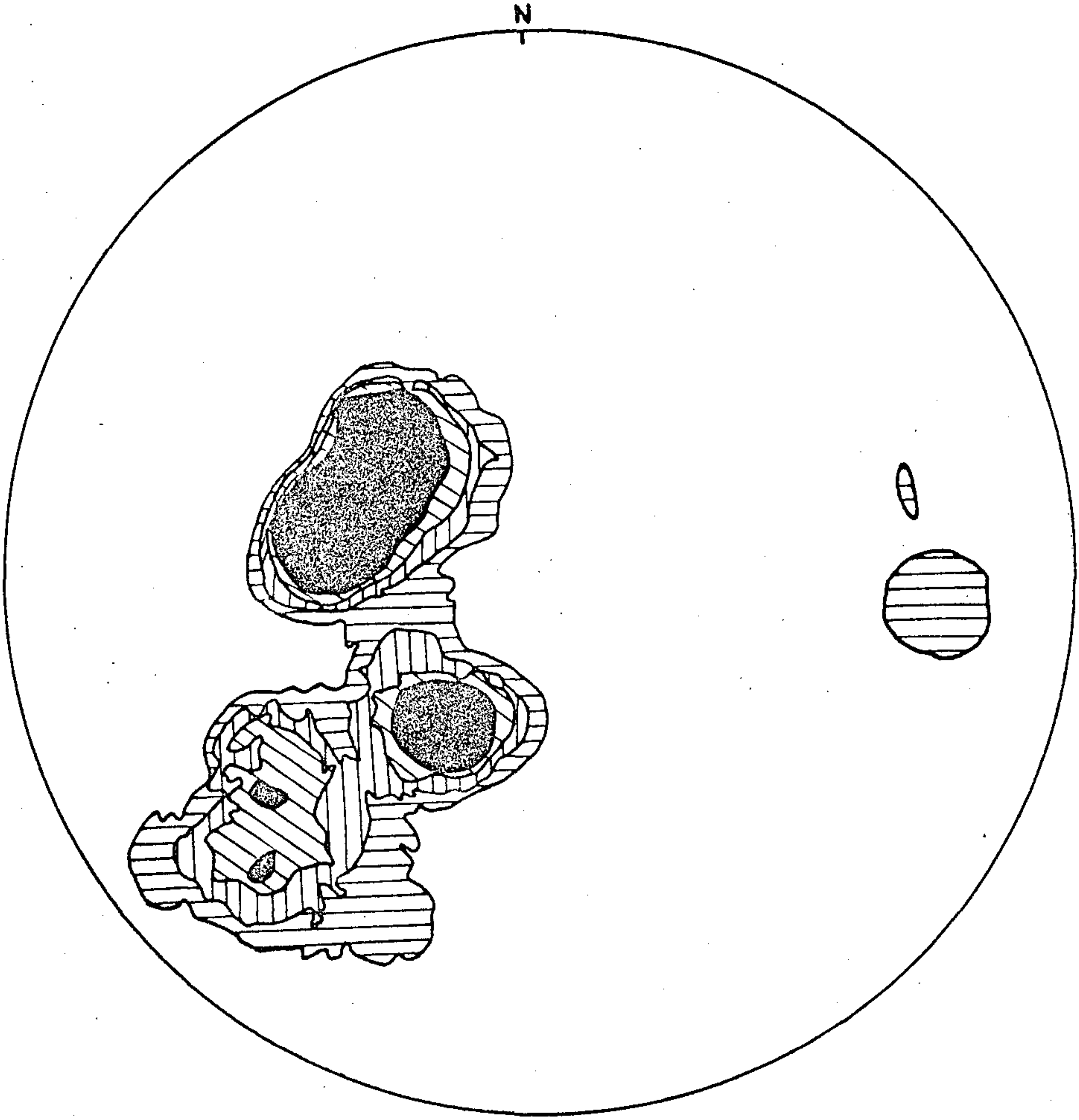
DATE: OCTOBER, 1973

STEREOGRAM No. 12

No. OF POLES : 150

PERCENTILE CONTOURS : 3, 6, 9, 12

AREA 'B' POLES TO RIB JOINTS



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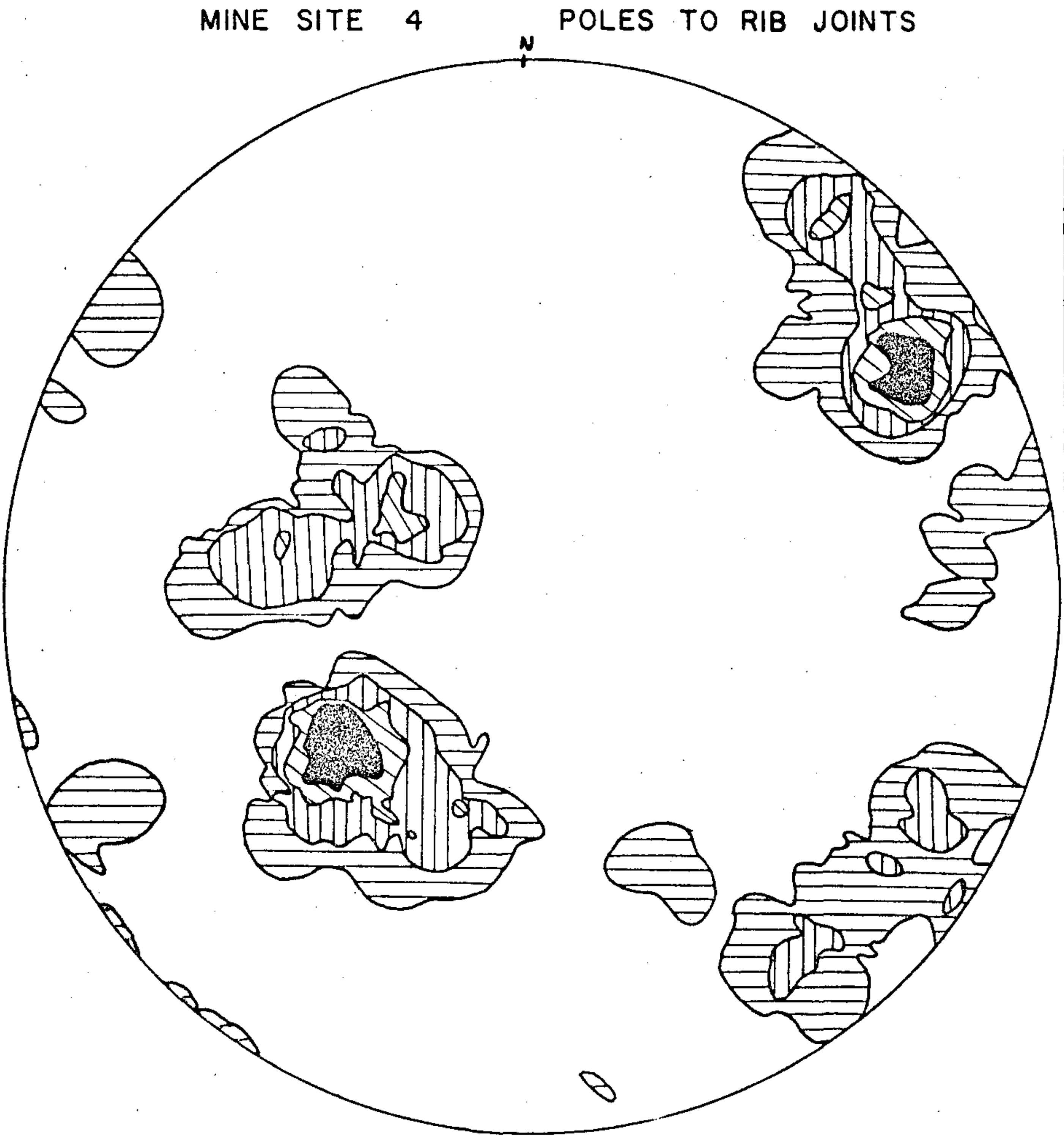
DATE: OCTOBER, 1973

STEREOGRAM No. 13

No. OF POLES: 150

PERCENTILE CONTOURS: 3, 6, 9, 12



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for
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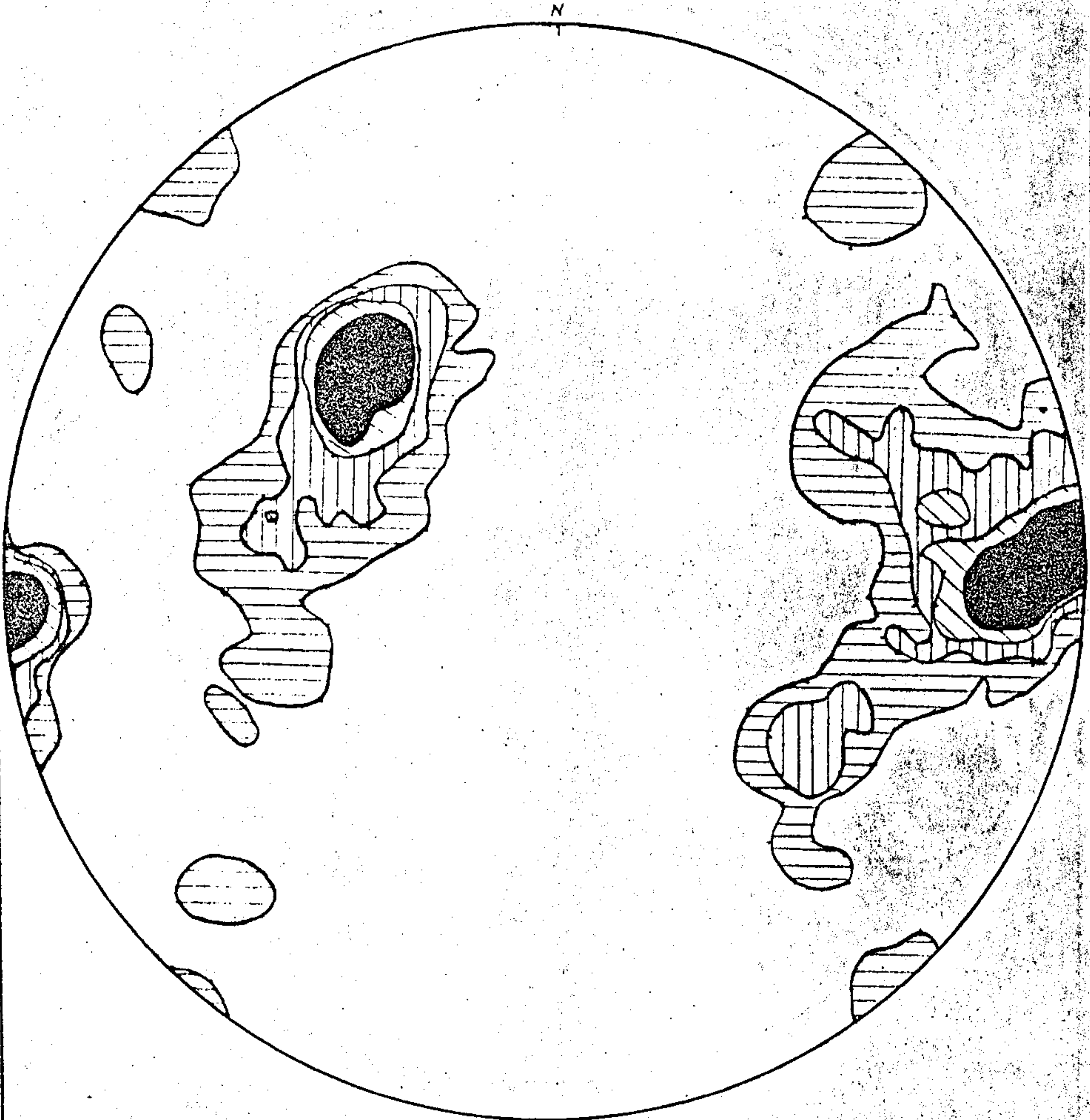
DATE: OCTOBER, 1973

STEREOGRAM No. 14

No. OF POLES: 100

PERCENTILE CONTOURS: 2, 4, 6, 8

MINE SITE 2 POLES TO RIB JOINTS



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for
COALITION MINING LIMITED

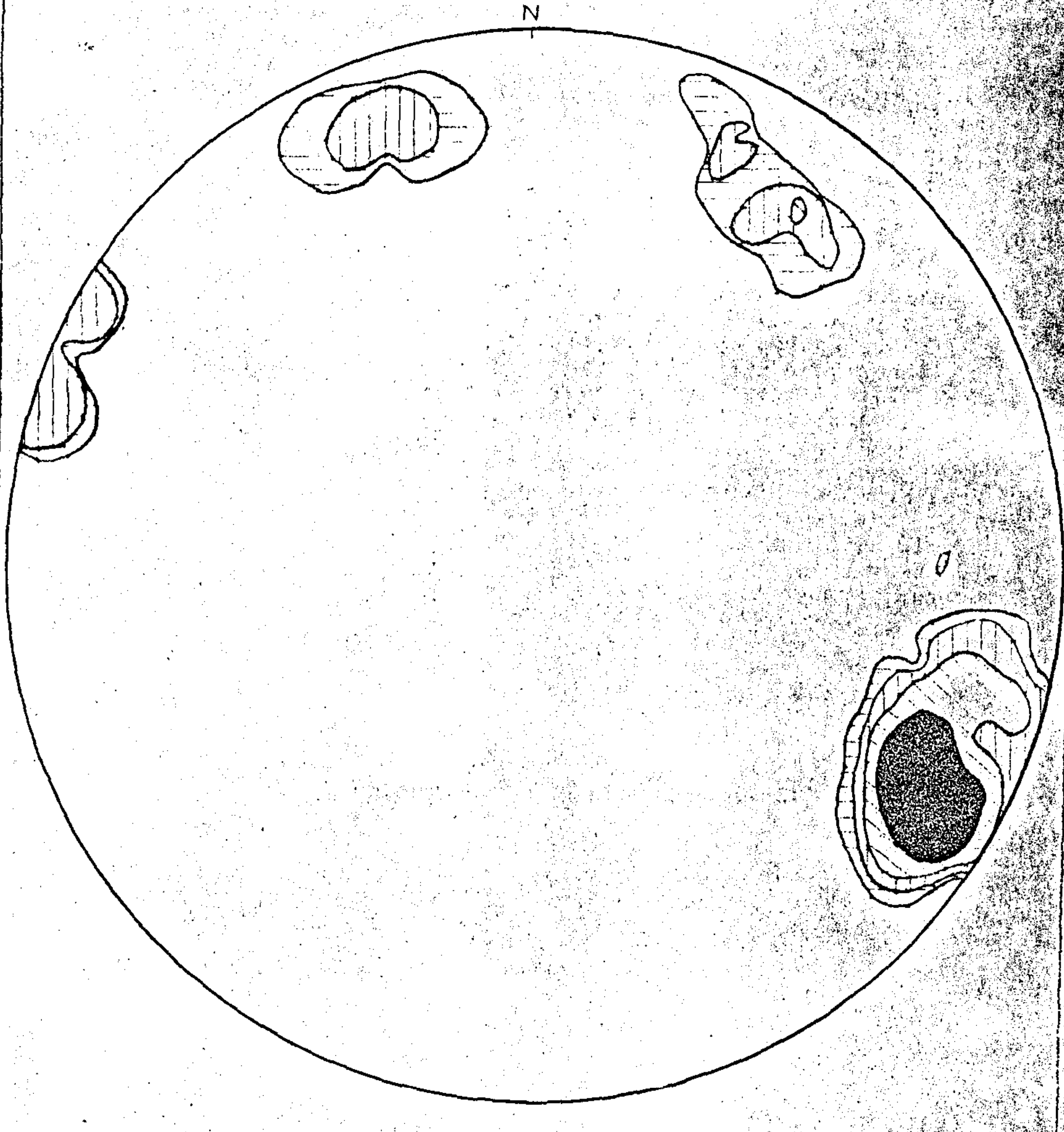
DATE: OCTOBER, 1973

STEREOGRAM No. 15

No. OF POLES: 100

PERCENTILE CONTOURS: 2, 4, 6, 8

ADIT No. 2 POLES TO RIB JOINTS



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for

COALITION MINING LIMITED

DATE: OCTOBER, 1973

STEREOGRAM No. 16

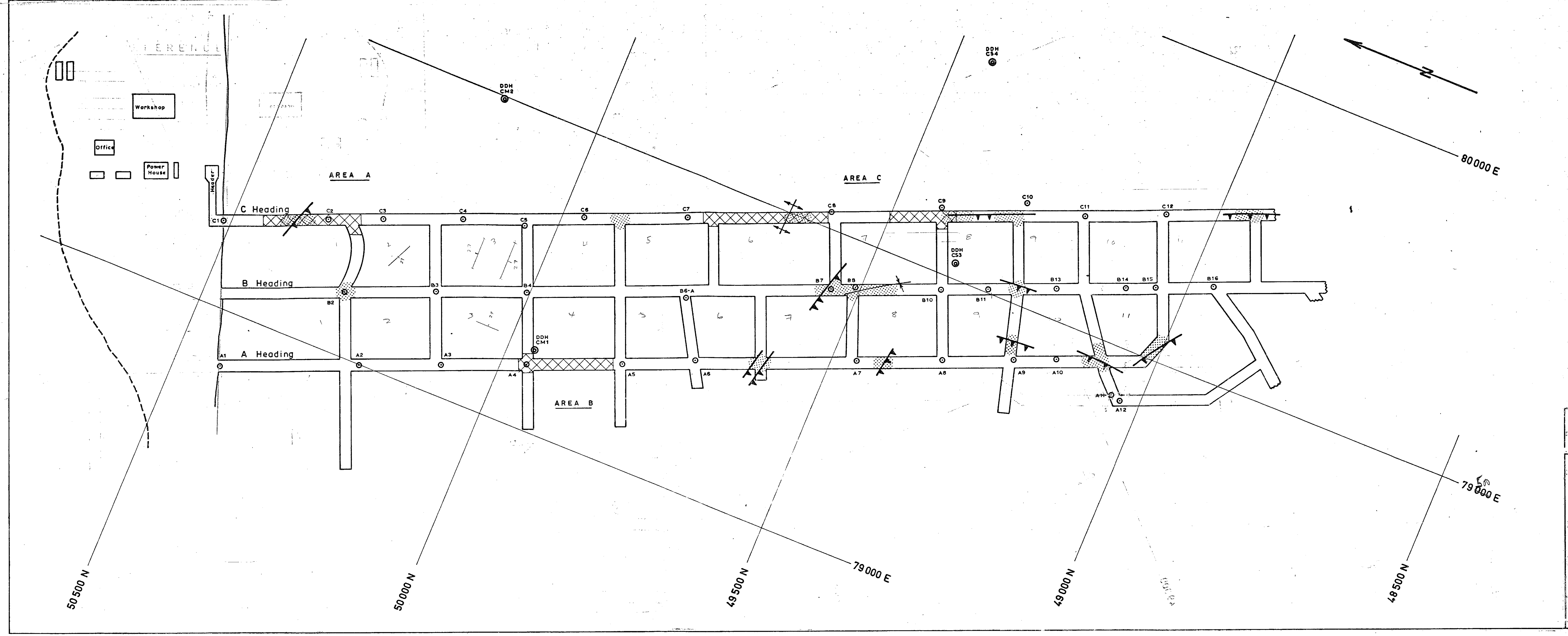
No. OF POLES: 100

PERCENTILE CONTOURS: 2, 4, 6, 8

ROOF CONDITIONS.

CLASS	MAP SYMBOL	
VERY GOOD	(1)	The roof is planar, generally slickensided; joints widely spaced, usually in excess of 6 feet. Roof bolting on 4 foot centres, timber sets not normally required but sometimes used on a 6 foot centre.
GOOD	(2)	May be planar but often contains minor unevening features, for example scallops; slickensides present; jointing close, usually 1.5 feet apart. Roof bolting and timber sets at 4 foot centres.
POOR	(3)	Used when less than 0.5 feet of the roof above the shear coal and rock has fallen of its own accord. Joint spacing very close and irregular; slickensides and related numerous small thrust faults causing cuspate shaped indentations.
FALLEN	(F)	Collapse of roof over full width of roadway in excess of 0.5 feet.

LEGEND TO ACCOMPANY DRAWINGS SKR 245 & 246



REFERENCE

Mine roadway (Development to June 1973).

Significant roof falls.

AREA A — Joint Analysis (see Section 3 of Report 1/4/24).

Thrust Fault.

Synclinal, Anticlinal Axis.

Survey Point.

Diamond Drill Hole.

Property Grid, see Map 1 (Geological Map) 1972 Report for details of grid.

SCALE 1" = 100 Feet

SURVEY DATA SUPPLIED BY COALITION MINING LTD.

TO ACCOMPANY REPORT № 1/4/24

PREPARED BY CLIFFORD McELROY & ASSOCIATES PTY. LTD.

COALITION MINING LTD.
SUKUNKA COAL PROJECT

PR-SUKUNKA 75(1)B

UNDERGROUND WORKINGS

MINE №1.

SHOWING GENERALISED THRUST FAULT DIRECTIONS

658

DATE October 1973 DWG No. SKR 244

REFERENCE

ROOF CONDITIONS
- ① Very good
- ② Good
- ③ Poor
- Ⓕ Fallen
- Boundary between areas of differing roof conditions

SEAM THICKNESS
- S 0·55 — Thickness of sheared zone (in feet) } where present
- B 0·1 — Thickness of bone layer (in feet) }
- 5·54 — Thickness of coal below sheared zone (in feet)

DIP OF SEAM
- 260° / 6° — Showing dip and strike of roof

SLICKENSIDES
- 214° — Direction of slickensides in roof strata

JOINTS
- 192° / 56° — Joint in coal measured in rib showing dip and strike
- 115° — Vertical joint in roof showing strike
- 315° / 55° — Joint in roof showing dip and strike

B·2 — Survey point

NOTES :
1. All bearings are relative to True North
2. Data included up to December 19, 1972
3. See separate legend for description of Roof Condition Symbols.

T. N.

FEET 20 0 20 40 60 FEET

PREPARED BY CLIFFORD McELROY & ASSOCIATES PTY. LTD.

COALITION MINING LIMITED
SUKUNKA COAL PROJECT

UNDERGROUND WORKINGS
Nº 1 MINE

PR-SUKUNKA 75(1)A.

658

DATE: 9-11-73 DWG. Nº SKP: 265

REFERENCE

ROOF CONDITIONS
- (1) Very good
- (2) Good
- (3) Poor
- (F) Fallen
- Boundary between areas of differing roof conditions

SEAM THICKNESS
- S 0·55 Thickness of sheared zone (in feet) } where present.
- B 0·13 Thickness of bone layer (in feet) } where present.
- 5·54 Thickness of coal below sheared zone (in feet)

DIP OF SEAM
- 260° / 6° Showing dip and strike of roof

SLICKENSIDES
- 214° Direction of slickensides in roof strata

JOINTS
- 192° / 56° Joint in coal measured in rib, showing dip and strike
- 115° Vertical joint in roof showing strike
- 315° / 55° Joint in roof showing dip and strike

B·2 Survey point

NOTES : 1. All bearings are relative to True North
2. Data included up to December 19, 1972
3. See separate legend for description of Roof Condition Symbols.

T.N.

FEET 20 0 20 40 60 FEET

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COALITION MINING LIMITED
SUKUNKA COAL PROJECT

UNDERGROUND WORKINGS
Nº 1 MINE

PR-SUKUNKA 75 (1) B.

658