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In Situ Horizontal Stress Determinations in the Yampa Coalfield, Northwestern Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR

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Donald Paul Hodel, Secretary

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David S. Brown, Acting Director

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

deg	degree	μin	microinch
ft	foot	psi	pound per square inch
in	inch	sp gr	specific gravity

IN SITU HORIZONTAL STRESS DETERMINATIONS IN THE YAMPA COALFIELD, NORTHWESTERN COLORADO

By D. L. Bickel[1] and D. A. Donato[2]

ABSTRACT

This report presents a Bureau of Mines study intended to determine if horizontal stress trends exist and if the stresses can be projected for improved mine design in a selected coalfield. The horizontal stresses were determined in three mines in the Yampa Coalfield and one mine in the adjacent Danforth Hills Coalfield of northwestern Colorado. Stresses were determined from stress-relief measurements using a three-component borehole deformation gauge and overcoring techniques developed by the Bureau. A least-squares method of calculating the average rock stress components in the horizontal plane was performed. Physical properties of the rock from the test sites are also included.

For the Yampa Coalfield, the maximum horizontal compressive stress in the floor ranged from 363 to 1,956 psi, and the maximum horizontal compressive stress in the roof ranged from 235 to 875 psi. For the Danforth Hills Coalfield, the maximum horizontal compressive stress in the floor ranged from 360 to 1,494 psi, and the maximum horizontal compressive stress in the roof was 1,033 psi.

Results indicated a trend of low horizontal stresses in the Yampa Coalfield that have not impacted ground control conditions in mines less than 1,000 ft deep.

[1]Physical scientist.
[2]Mining engineer.
Denver Research Center, Bureau of Mines, Denver, CO.

INTRODUCTION

Many underground coal mines in the United States are experiencing ground control problems that are the result of the horizontal state of stress. However, there are coalfields in the United States where the horizontal state of stress is unknown. The purpose of this Bureau of Mines investigation was to locate a developing western coalfield where the horizontal state of stress was unknown, to measure the horizontal stresses in all operating underground mines in that coalfield, and to determine if the stresses were contributing to ground control problems and showed a stress trend that could be incorporated into more effective mine design. Previous Bureau research (3-5, 7)[3] has shown a correlation between high horizontal or high differential horizontal stresses and several types of coal mine ground control problems, such as shear (cutter) roof failure and floor heave. Past research has also shown that horizontal stresses tend to follow a consistent pattern within a coalfield and with respect to certain geologic conditions. Therefore, the knowledge gained from this research will provide mine operators with information that could lead to more effectively planned mine layouts, reduced ground control problems, and improved mine safety.

The Yampa Coalfield (fig. 1) in northwest Colorado was selected for this study because its state of stress is unknown.

At present, there are three operating underground coal mines located in the coalfield. These mines were used to

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

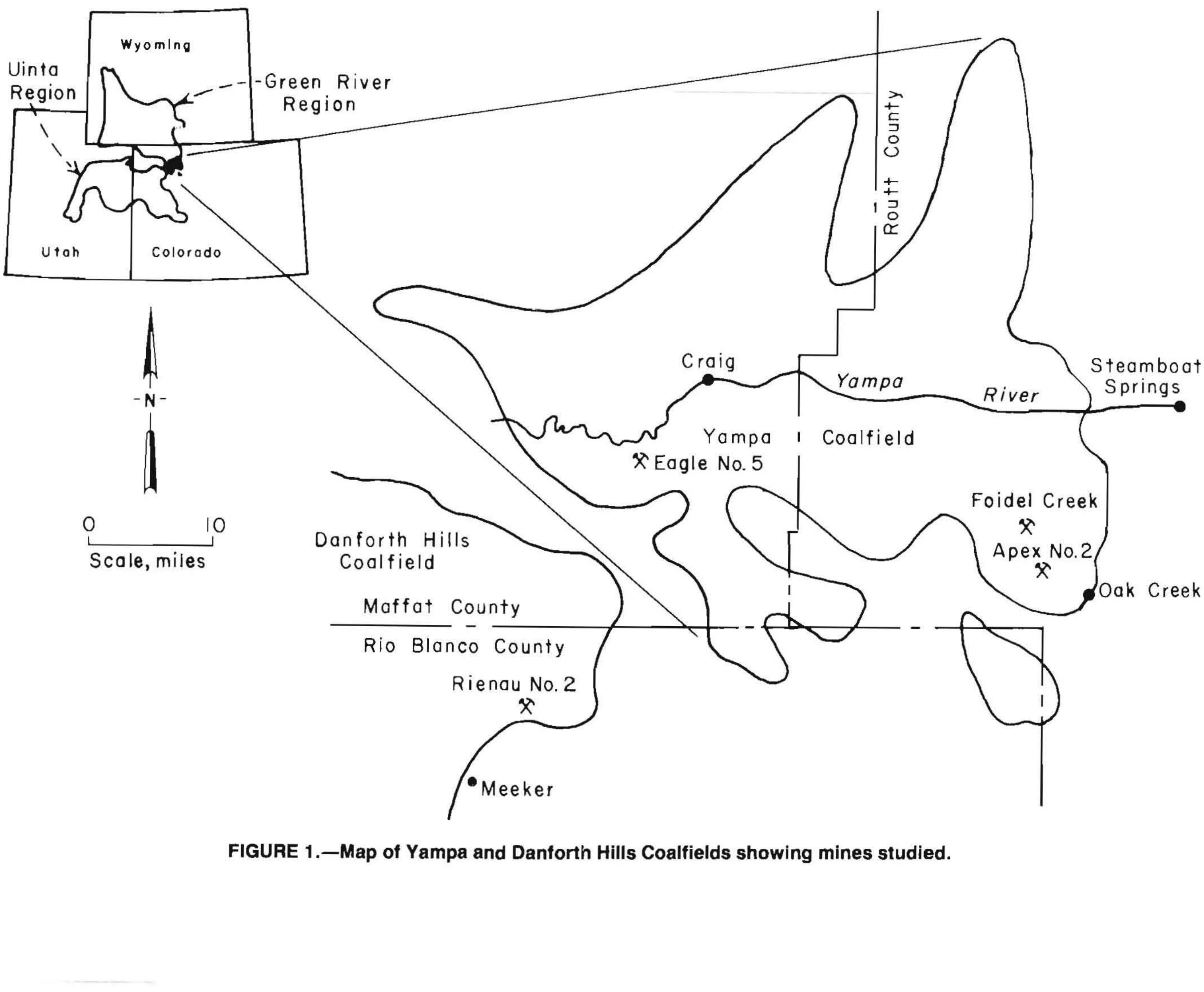

FIGURE 1.—Map of Yampa and Danforth Hills Coalfields showing mines studied.

evaluate possible trends in the in situ horizontal stresses in this coalfield. Because of the complex geology and the closeness of two of the mines, it would have been desirable to investigate additional mines; however, only three underground mines were available for this study.

The three presently operating underground mines in the Yampa Coalfield that were studied are (1) the Eagle No. 5 Mine (Empire Energy Corp., located about 8 miles southwest of Craig, CO), (2) the Apex No. 2 Mine (Sunland Mining Corp., located about 6 miles west-northwest of Oak Creek, CO), and (3) the Foidel Creek Mine (Twentymile Coal Co., located about 15 miles northeast of Oak Creek, CO). The Rienau No. 2 Mine (Northern Coal Co., located about 7 miles north-northeast of Meeker, CO) is not within the boundary of the Yampa Coalfield, but was also investigated because of its proximity to the Yampa Coalfield.

A previous study to determine a regional horizontal state of stress was performed in the Beckley Coal Seam, Beckley District of the Southern Coalfield, in south-central West Virginia (1-2). Five mines with a total of 14 sites were investigated to determine how far measured stresses could be projected for the purpose of mine design. The uniformity of the coal seam and overburden thickness was advantageous to this study. For the four most northern mines, which extended over a distance of approximately 12.8 miles, the stress direction ranged from N 57° E to N 75° E, and the maximum horizontal compressive stress ranged from 3,172 to 3,815 psi. For the southernmost mine, the maximum horizontal compressive stress was 2,305 psi bearing N 52° W. No major structural features were encountered in the other four mines, and any stress variations occurring from site to site were related to changes in lithology. Research results indicated that stresses may be projected for the purpose of mine design. Caution must be taken in using these findings for other coalfields, particularly when major structural features are present, as in the Yampa Coalfield.

All the mines studied under this project were located in a different coal seam and stratigraphic column. Although stress magnitudes and directions varied, stresses were relatively low and no ground control problems were experienced by any of the three mines in the Yampa Coalfield under the present overburden heights and mine design. Since deformation measurements were performed in the Foidel Creek Mine, mining has progressed under deeper cover (1,060 ft) and indications of possible related stress events have been experienced, as evidenced by occurrences of minor cutter roof along the rib lines. The Rienau No. 2 Mine is separated from the Yampa Coalfield by a major geological structure, is under more overburden than mines in the Yampa Coalfield, and is experiencing some minor roof falls in intersections.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Empire Energy Corp., Craig, CO, Northern Coal Co., Meeker, CO, Sunland Mining Corp., Oak Creek, CO, and Twentymile Coal Co., Oak Creek, CO, for providing the mine test sites.

GEOLOGY

The Green River region is predominantly located in southwestern Wyoming, but extends into northwestern Colorado (fig. 1). Within Colorado, the region consists of the Sand Wash structural basin and the north side of the Axial Basin uplift that includes the Williams Fork Mountains. The perimeter of the Green River coal region is defined by the base of the Upper Cretaceous Mesaverde Group. The Yampa Coalfield is the only coalfield currently named in the Green River region and is located on the southeast edge of the region (16). Three of the four mines investigated (Eagle No. 5, Apex No. 2, and Foidel Creek) are located within the Yampa Coalfield (fig. 1).

The Uinta region is located south of the Green River region, with approximately one-half in eastern Utah and the remainder in west-central Colorado (fig. 1). The Danforth Hills Coalfield is in the northeast corner of the Uinta region and is within a few miles of the Yampa Coalfield. The Axial Basin uplift separates the two fields. Coal seams in the Danforth Hills field, like coal seams in the Yampa field, are part of the Iles and Williams Fork Formations, Mesaverde Group, and were formed during the late Cretaceous Age (16). The Rienau No. 2 Mine is in the Danforth Hills Coalfield (fig. 1) approximately 25 miles south of the Eagle No. 5 Mine.

The Eagle No. 5 Mine and the Foidel Creek Mine are approximately 30 miles apart, but have similar geologic structures. The Apex No. 2 Mine and the Foidel Creek Mine are approximately 3.8 miles apart and separated by 400 ft in elevation, but the stratigraphic separation is 1,800 ft. Both the Apex No. 2 and the Foidel Creek Mines are located on an anticline. The mine locations are shown on a geologic structure map (20) of the Yampa and Danforth Hills Coalfields (fig. 2). Specific geologic data for the four mines studied are presented in table 1. Rock types listed in this table are representative of the mine's immediate floor and roof.

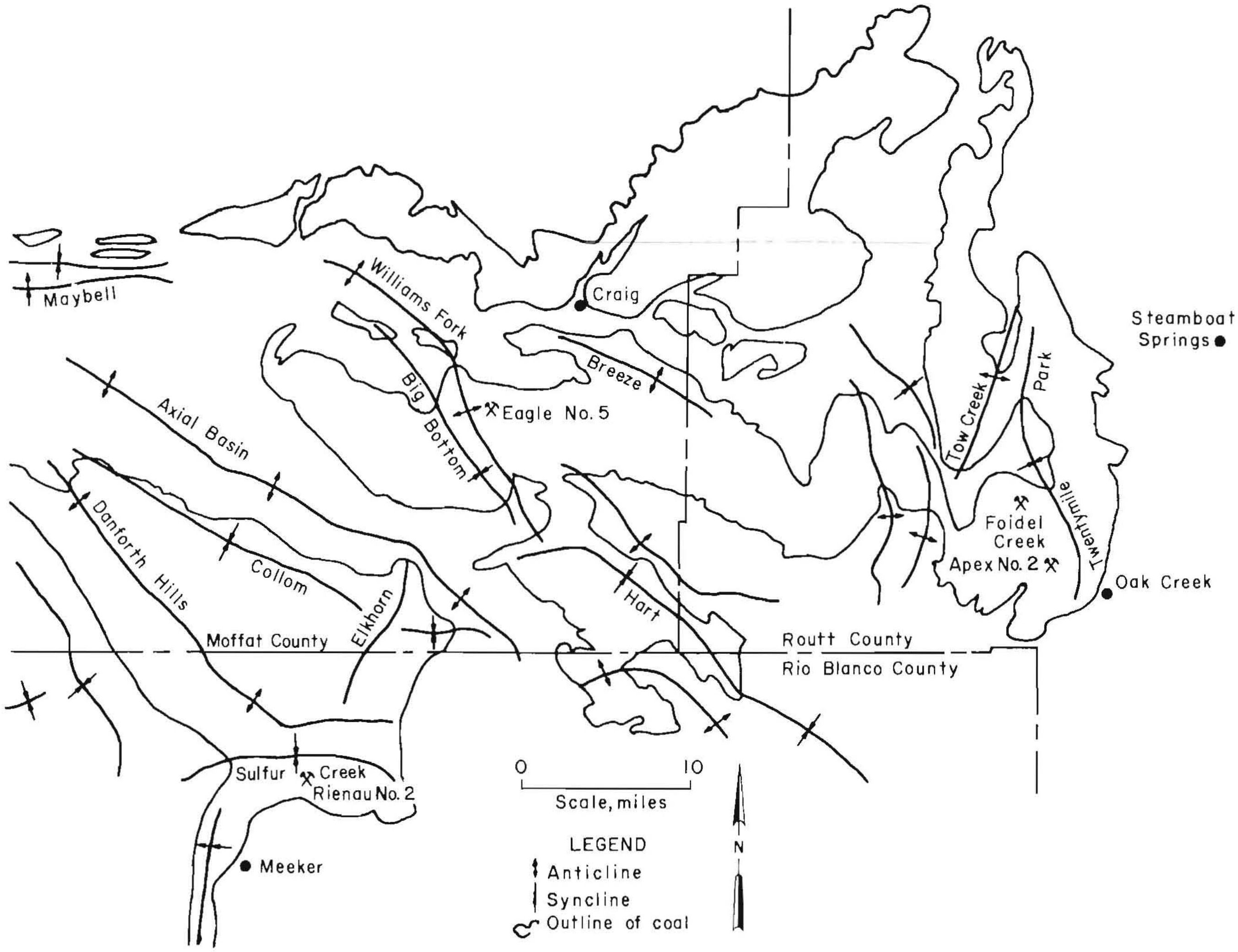

FIGURE 2.—Geologic structure map for Yampa and Danforth Hills Coalfields.

TABLE 1. - Geologic data for mines studied

	Eagle No. 5	Apex No. 2	Foidel Creek	Rienau No. 2
Geologic age..	Upper Cretaceous	Upper Cretaceous	Upper Cretaceous	Upper Cretaceous
Geologic unit.	Williams Fork Formation (Mesaverde Group).	Iles Formation (Lower Mesaverde Group).	Williams Fork Formation (Mesaverde Group).	Williams Fork Formation (Mesaverde Group).
Coal bed or seam.	F...............	Lower Pinnacle..	Wadge...........	G.
Coal thickness, ft.....	11, average......	5, average......	7-11............	18-20.
Dip of bedding	9° N............	6° N...........	7° NW...........	20° N.
Strike of bedding.	S 80° E.........	N 69° E........	N 55° E.........	E.
Site 1:				
Floor rock..	Claystone........	Sandstone.......	Sandstone-shale-mudstone.	Mostly sandstone mudstone.
Roof rock...	Sandstone, sandstone with clay.	Sandstone, shale	Mudstone-sandstone.	Do.
Site 2:				
Floor rock..	Claystone........	No second site..	...do............	Mudstone.
Roof rock...	Fine-grained slatestone.	...do..........	...do............	Not tested.

INSTRUMENTATION

Horizontal stresses were calculated from borehole deformation (stress relief) measurements made with the Bureau's three-component borehole deformation gauge (12, 18), which is shown in figure 3. The borehole deformation gauge is used with the overcoring techniques (9, 12-13) and testing procedures (9, 11, 17) developed by the Bureau to determine in situ rock stresses. The theoretical relationships that relate borehole-deformation data to stress levels are based on the theory of elasticity (15, 19) and include the effects of rock anisotropy (7-8, 14).

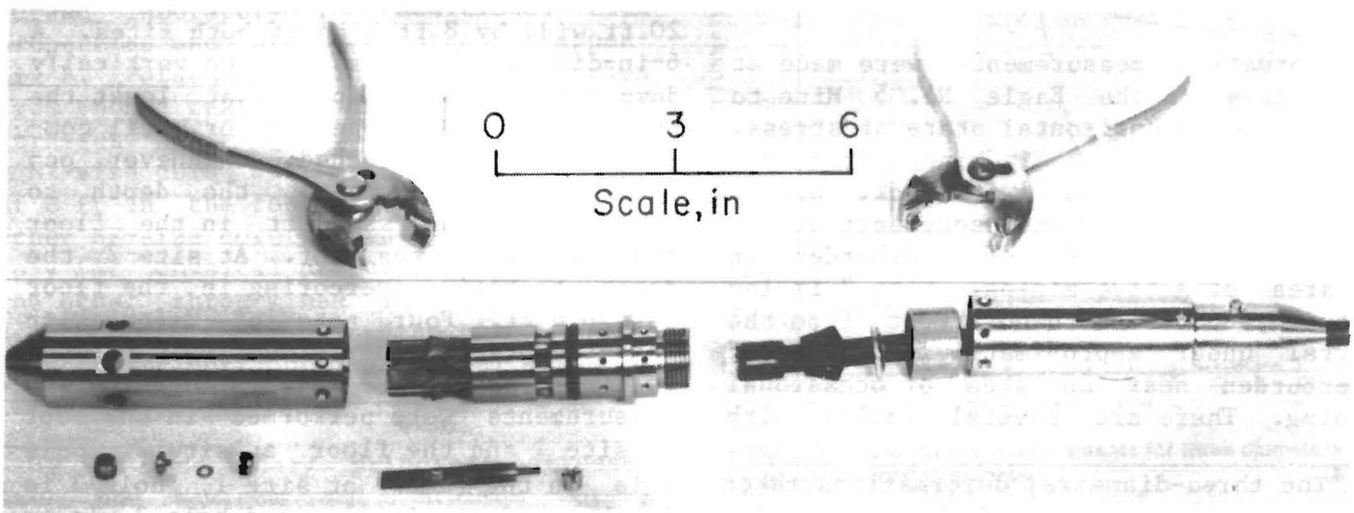

FIGURE 3.—Three-component borehole deformation gauge.

The borehole deformation gauge measures three-diametral deformations, 60° apart, of a 1-1/2-in-diam gauge hole (pilot hole) as the borehole gauge is overcored with a 6-in-diam, thin-walled, diamond drill bit. Overcoring relieves the stress on a thick-walled cylinder of rock containing the gauge. A separate strain indicator is used to continuously monitor the overcoring for each diametral deformation,[4] so that any irregularities will not go unnoticed and the altered deformation readings will be recorded and corrected. The readout sensitivity for the diametral deformation is 1 μin.

After overcoring, the core is retrieved, marked for orientation and plane of measurement, and tested biaxially on site to determine the rock's Young's modulus and anisotropy (8-9, 11). Biaxial testing is accomplished by placing the core in the biaxial chamber and positioning the three-component borehole gauge in the 1-1/2-in-diam hole of the core at the same place, if possible, as it was during in situ overcoring. A known pressure is applied to the core in the chamber, and three diametral deformations are recorded. The borehole gauge is rotated 15° and the same load is reapplied, yielding three more diametral measurements. The same procedure is repeated two more times, and the twelve resulting deformation measurements are used in a least-squares analysis to determine the rock anisotropy.

Elastic properties determined in the field and laboratory and the three deformation measurements from each overcore stress relief are used to calculate stresses in the plane normal to the borehole (14). All determined stresses presented herein are in the horizontal plane. A negative stress denotes compression.

EXPERIMENTAL RESULTS

Horizontal stress components were calculated from overcoring deformation measurements for plane-stress and plane-strain conditions (14). Plots of the horizontal stress components (P and Q) and corresponding angles show the stress variations at each plane of measurement in the borehole. Results for plane strain are presented in this report.

EAGLE NO. 5 MINE

Deformation measurements were made at two sites in the Eagle No. 5 Mine to determine the horizontal state of stress. Eight feet of coal is mined from the F Seam that averages 11 ft thick. Site 1 is located 6,900 ft east-southeast of the portal under 600 ft of overburden in an area of active mining. Site 2 is located 3,300 ft north-northwest from the portal under approximately 325 ft of overburden near an area of occasional mining. There are several faults with unknown displacements in this area of the mine. Access to air and water for drilling limited the site selection; however, the site was more than 700 ft from the nearest fault. It is not known what influence, if any, the fault had on the calculated stresses. Figure 4 is a plan view of the mine layout showing the location of the sites and faults.

The drill used for overcoring was set in the center of a crosscut that averaged 20 ft wide by 8 ft high at both sites. A 6-in-diam borehole was drilled vertically down and up to a depth of at least the height of the mine opening or until competent rock was reached, whichever occurred last. At site 1, the depth to begin overcoring was 8 ft in the floor and 10.1 ft in the roof. At site 2, the depth to begin overcoring in the floor was 8.6 ft. Four sets of deformation measurements were performed in the floor at site 1, and five sets of deformation measurements were performed in the roof at site 1 and the floor at site 2. Hole 1 is in the floor at site 1, hole 3 is in the roof at site 1, and hole 2 is in the floor at site 2. A sample set of deformation measurements for a typical

[4] The three-diametral deformations taken throughout the length of the overcoring are referred to in this report as a set of deformation measurements.

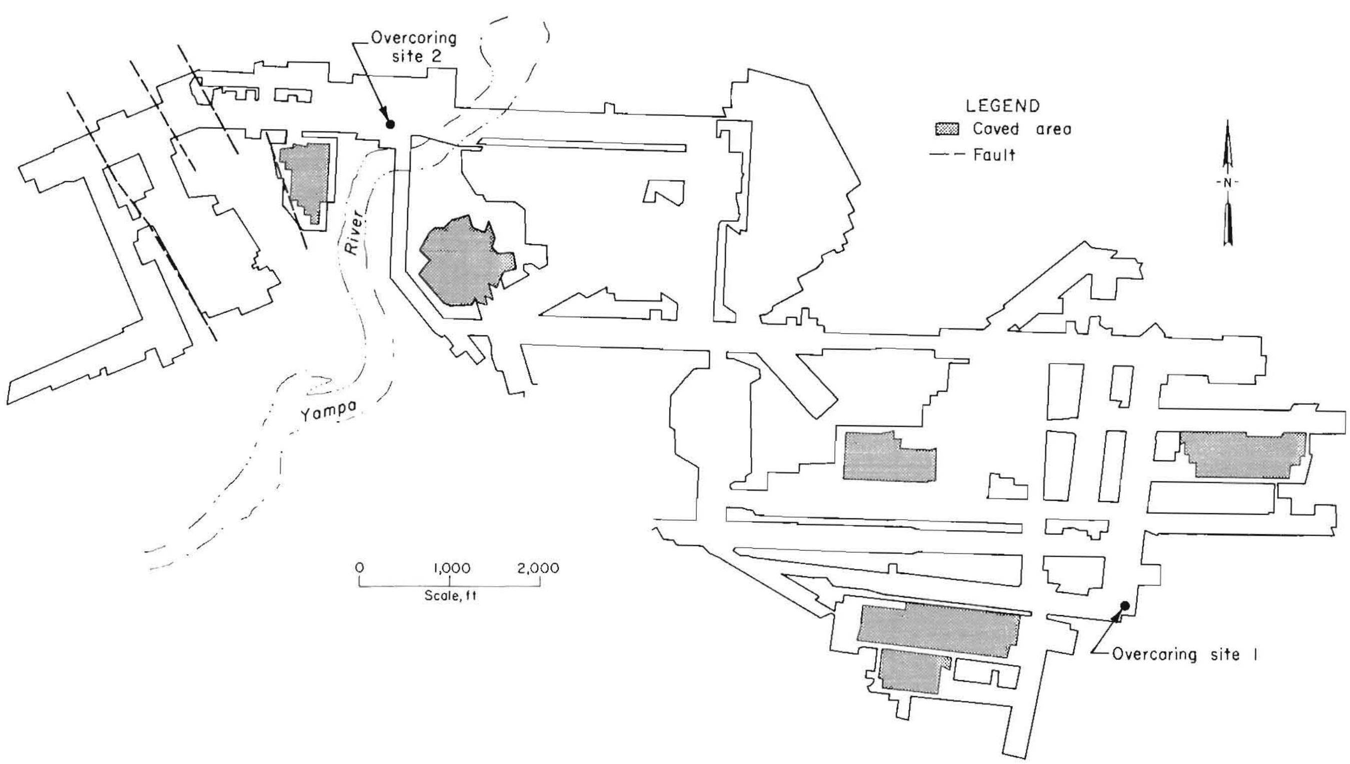

FIGURE 4.—Mine layout and drill sites, Eagle No. 5 Mine.

overcoring is shown in figure 5. These data were obtained from hole 1, 9.6-ft deep. After overcoring, core samples are biaxially tested on site to determine Young's modulus (E). The E values from both sites are presented in table 2. Overcore and NX-size core samples obtained at the sites were tested in a Bureau laboratory for additional rock properties and are presented in appendix B. Poisson's ratio values were taken from these tests for the calculation of stresses.

NX-size core was drilled to a depth of 8 ft in the roof at both sites. All other NX-size core tested in the laboratory for physical properties (including the other three mines investigated) was drilled from solid 6-in-diam core.

Secondary horizontal principal stresses (P and Q)[5] and stress direction for each

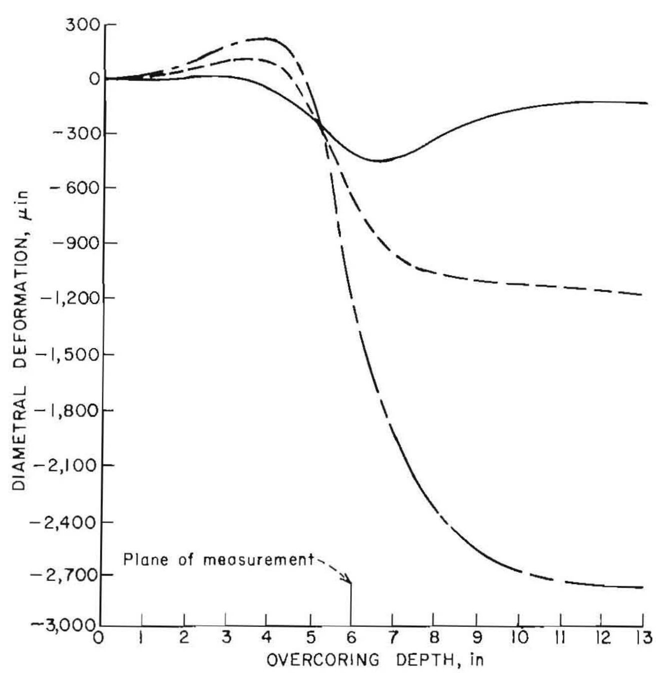

FIGURE 5.—Deformation measurements for three diameters from typical overcoring process.

[5]P and Q secondary principal stresses are the maximum and minimum normal stresses in a given plane.

TABLE 2. - Young's modulus from biaxial tests at Eagle No. 5 Mine

Relief	Depth, ft	$10^6 \times E_{min}$, psi	$10^6 \times E_{max}$, psi	Angle,[1] deg
SITE 1, HOLE 1, IN FLOOR				
1.................	8.6	1.20	1.44	11
2.................	10.7	1.06	1.27	-5
3.................	11.8	1.25	1.37	-30
4.................	12.6	.83	.91	2
SITE 2, HOLE 2, IN FLOOR[2]				
1.................	9.1	0.99	1.57	75
3.................	11.1	2.22	2.47	-19
4.................	12.2	2.48	3.51	80
5.................	13.3	.77	1.58	53
SITE 1, HOLE 3, IN ROOF				
1.................	10.5	1.10	1.48	80
2.................	11.6	.79	.87	-16
3.................	12.6	.81	.89	-20
4.................	13.6	.79	.90	-44
5.................	14.6	.80	.85	-69

E Young's modulus.
[1]Positive angle measured counterclockwise from U_1 (N 85° W) to E_{min}.
[2]Data are missing because the overcore retrieved failed during the biaxial test.

overcoring stress relief are given in table 3. A representation of the calculated stresses are presented in figures 6 to 8. The stress profiles reveal that the greatest stress level occurred at approximately 11 ft deep in all three test holes.

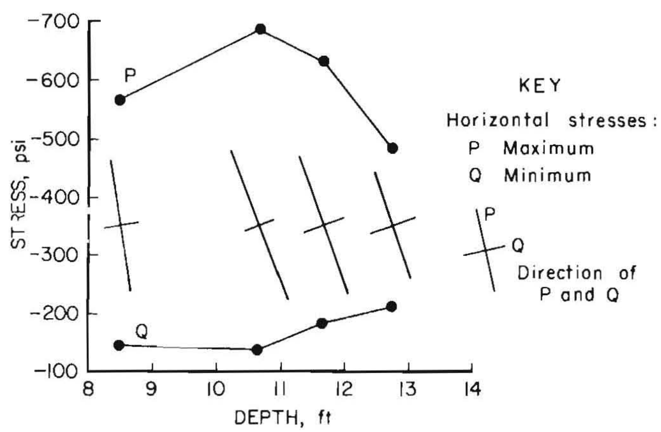

FIGURE 6.—Plot of secondary principal stresses for Eagle No. 5 Mine hole 1.

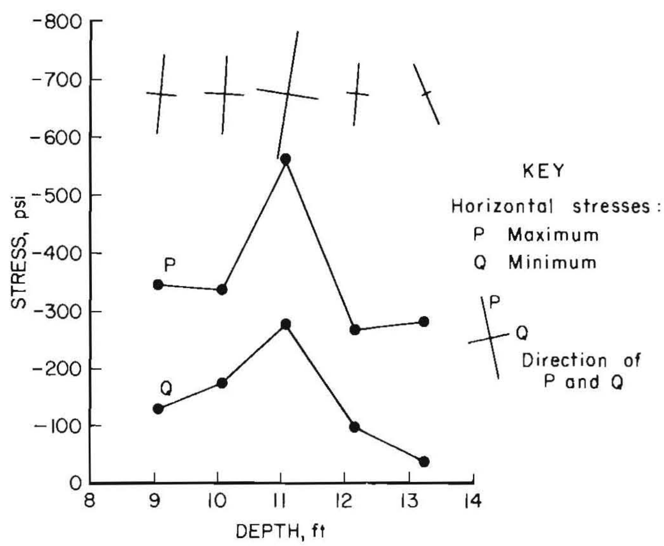

FIGURE 7.—Plot of secondary principal stresses for Eagle No. 5 Mine hole 2.

TABLE 3. - Secondary horizontal principal stresses at Eagle No. 5 Mine

Relief	Depth, ft	P, psi	Q, psi	Bearing of P
SITE 1, HOLE 1, IN FLOOR				
1...........	8.5	-562	-143	N 9° W
2...........	10.7	-686	-134	N 22° W
3...........	11.7	-632	-180	N 20° W
4...........	12.8	-481	-208	N 20° W
SITE 2, HOLE 2, IN FLOOR				
1...........	9.1	-344	-129	N 5° E
2...........	10.1	-336	-174	N 3° E
3...........	11.1	-559	-276	N 9° E
4...........	12.2	-268	-97	N 5° E
5...........	13.3	-281	-37	N 24° W
SITE 1, HOLE 3, IN ROOF				
1...........	10.5	-191	-135	N 1° W
2...........	11.6	-222	-143	N 13° E
3...........	12.6	-179	-111	N 12° E
4...........	13.6	-165	-129	N 15° E
5...........	14.6	-144	-117	N 34° E

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.

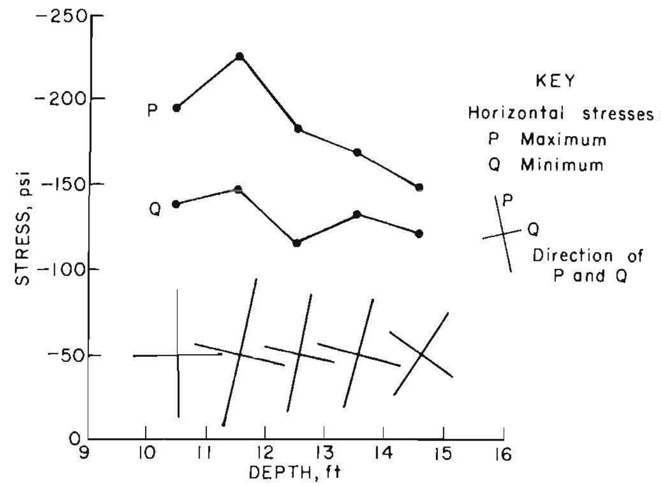

FIGURE 8.—Plot of secondary principal stresses for Eagle No. 5 Mine hole 3.

APEX NO. 2 MINE

Deformation measurements were made at one site in the Apex No. 2 Mine. Coal is mined from the Lower Pinnacle Seam, having an average thickness of 5 ft. The site is in fault block 2, 540 ft from a vertical displacement of 25 ft, and 740 ft from a vertical displacement of 100 ft. The site was selected in an attempt to minimize the influence of these two faults (fig. 9), but the extent that stresses were influenced by the faults, if any, is not known. Other sites were not selected because of extensive faulting and active mining. The site is located in a crosscut adjacent to the intake entry 1,870-ft north by east from the portal under 410 ft of overburden. The crosscut is 20 ft wide and 5 ft high.

Hole 1 was drilled vertically down into the sandstone floor. After 8.5 ft of a 6-in-diam borehole was drilled, four stress reliefs were performed, concluding at 12.5 ft below the floor surface. Hole 2 was drilled vertically up into the sandstone-shale roof. Five stress reliefs were performed from this hole

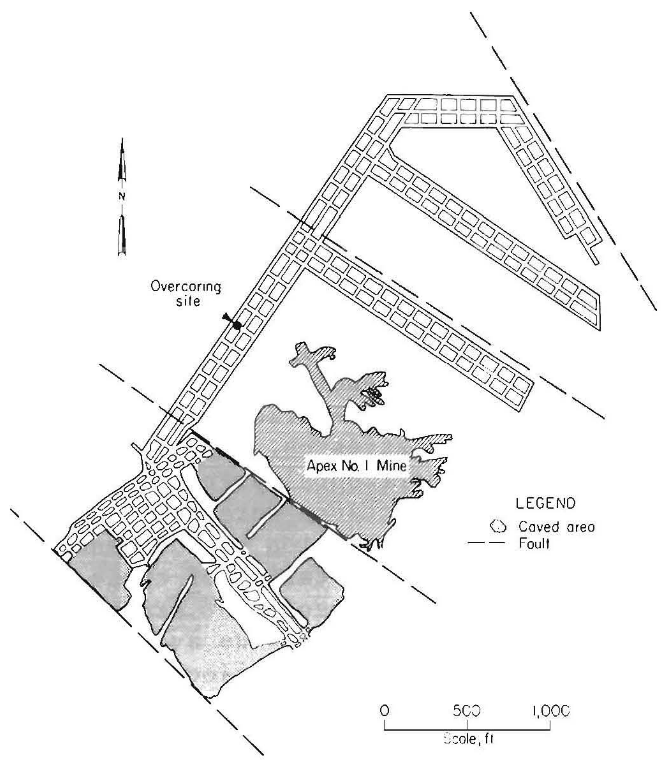

FIGURE 9.—Mine layout and drill site, Apex No. 2 Mine.

TABLE 4. - Young's modulus from biaxial tests at Apex No. 2 Mine

Relief	Depth, ft	$10^6 \times E_{min}$, psi	$10^6 \times E_{max}$, psi	Angle,[1] deg
SITE 1, HOLE 1, IN FLOOR				
1................	9.0	2.40	3.43	58
2................	10.0	2.04	3.58	68
3................	11.0	2.43	3.07	-47
4................	12.0	2.56	2.73	58
SITE 1, HOLE 2, IN ROOF				
1................	6.8	3.28	4.09	5
2................	7.6	3.12	3.15	26
3................	8.6	3.15	3.40	45
4................	9.8	2.17	2.34	12
5................	10.5	2.42	2.66	40

E Young's modulus.

[1]Positive angle measured counterclockwise from U_1 (S 50° E) to E_{min}.

starting at 6.3 ft and concluding at 11.2 ft above the roof surface. The recovered cores from overcoring were tested in a biaxial chamber at the site to determine Young's modulus. These values are presented in table 4. NX-size cores were drilled from the overcoring cores, and solid 6-in-diam cores from the overcoring holes, and tested in a Bureau laboratory for additional physical properties. Results from these laboratory tests are presented in appendix B. Poisson's ratio values were taken from these tests to calculate the stresses.

Secondary horizontal principal stresses and stress directions were calculated for each set of deformation measurements (table 5). A representation of these stress magnitudes and directions are presented in figures 10 and 11. The average E values for the sandstone floor were very uniform, ranging from 2.92×10^6 psi at the 9-ft depth to 2.65×10^6 psi at the 12-ft depth. Although the maximum horizontal stress (P) decreased at the 10- and 11-ft depths, the minimum horizontal stress (Q) remained the same. The average stress, $\frac{P+Q}{2}$, differed by only 63 psi at the various depths measured. The maximum stress direction in the floor varied from N 30° E to N 39° W. Fractures present in the floor rock mass, observed during overcoring, probably account for this irregularity. Using data from reliefs 1 to 3, the average stress magnitude, $\frac{P+Q}{2}$, in the sandstone-shale roof is uniform up to 9 ft and averages 425 psi. Beyond 9 ft, the average stress magnitude increases to an average of 632 psi (reliefs 4 and 5). The mine roof is stable without the use of roof bolts; however, roof bolts are used in the vicinity of the faults.

TABLE 5. - Secondary horizontal principal stresses at Apex No. 2 Mine

Relief	Depth, ft	P, psi	Q, psi	Bearing of P
SITE 1, HOLE 1, IN FLOOR				
1...........	9.0	-320	-230	N 9° W
2...........	10.0	-245	-197	N 1° E
3...........	11.0	-220	-204	N 30° E
4...........	12.0	-327	-190	N 39° W
SITE 1, HOLE 2, IN ROOF				
1...........	6.8	-415	-396	N 57° W
2...........	7.6	-521	-392	N 74° E
3...........	8.6	-453	-374	N 83° E
4...........	9.6	-623	-528	N 76° W
5...........	10.6	-710	-668	N 17° E

P Maximum secondary principal compressive stress.

Q Minimum secondary principal compressive stress.

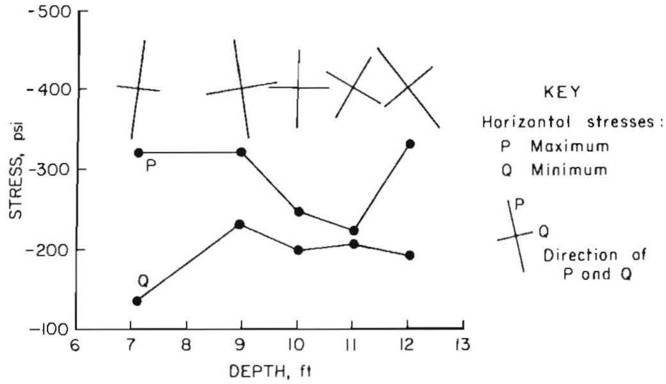

FIGURE 10.—Plot of secondary principal stresses for Apex No. 2 Mine hole 1.

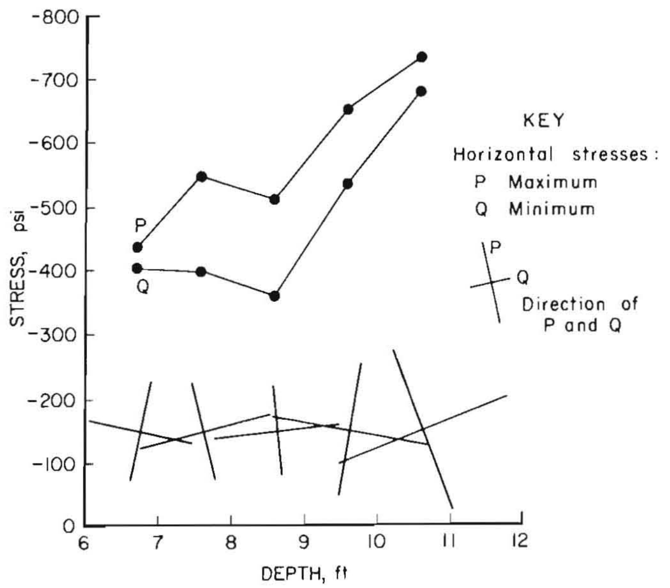

FIGURE 11.—Plot of secondary principal stresses for Apex No. 2 Mine hole 2.

FOIDEL CREEK MINE

Deformation measurements were made at two sites in the Foidel Creek Mine. Approximately 10 ft of coal is being mined from the Wadge Seam, which ranges from 7 to 11 ft thick. Site 1 is located approximately 2,150-ft north of the portal under 283 ft of overburden. Site 2 is located 1,300-ft north of site 1 under 527 ft of overburden (fig. 12). Crosscut dimensions at site 1 are approximately 19 ft wide by 9.5 ft high; at site 2, crosscut dimensions are 19 ft wide by 10 ft high.

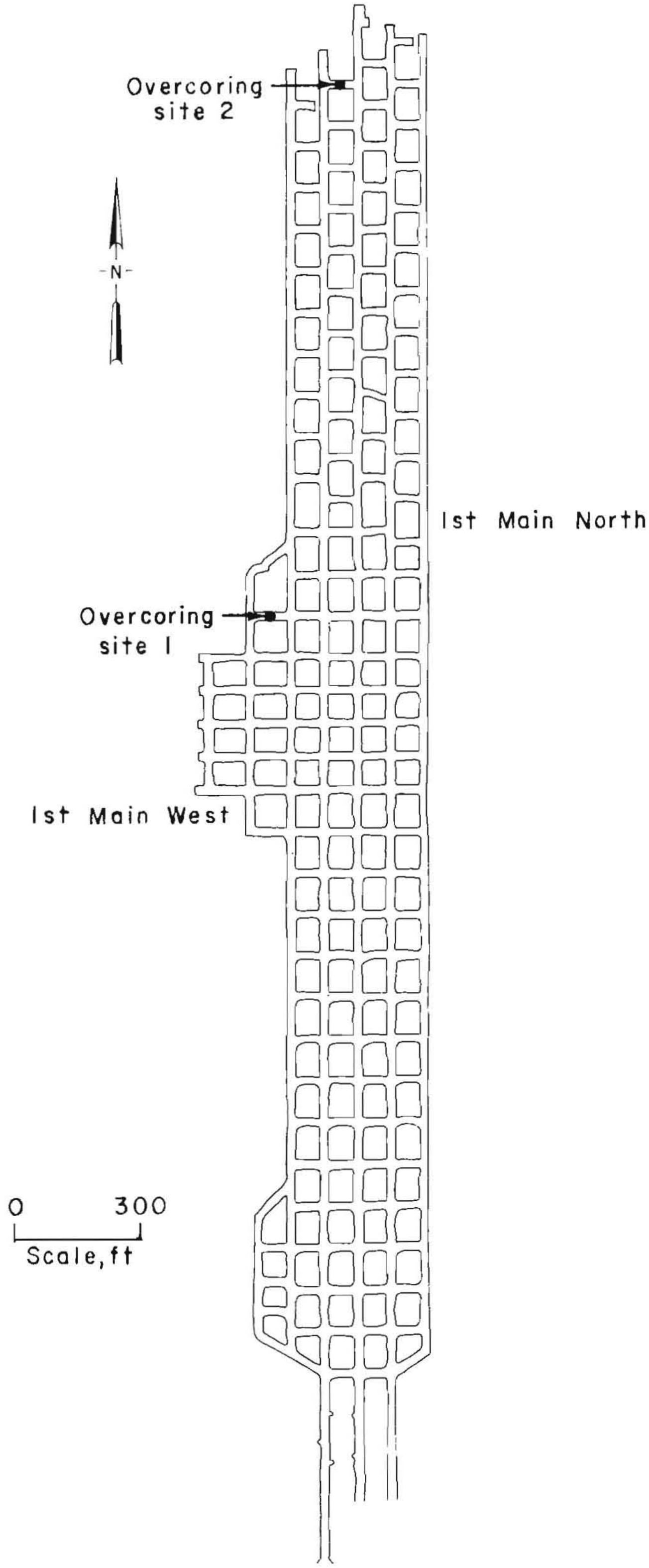

FIGURE 12.—Mine layout and drill sites, Foidel Creek Mine.

Hole 1 was drilled vertically down into the sandstone-shale-mudstone floor at site 1. Five sets of deformation measurements were performed starting at a depth of 10.8 ft and concluding at 16.2 ft below the floor surface. Hole 2 was drilled vertically up into the mudstone-sandstone roof at site 1. Five sets of deformation measurements were performed starting at a depth of 10.1 ft and concluding at 15.7 ft above the roof surface. Hole 3 was drilled vertically down into the sandstone-mudstone floor at site 2. Five sets of deformation measurements were performed starting at a depth of 10.5 ft and concluding at 15.8 ft below the floor surface. Hole 4 was drilled vertically up into the mudstone-sandstone roof at site 2. Six sets of deformation measurements were performed starting at a depth of 10.6 ft and concluding at 16.6 ft above the roof surface. Cores were recovered from all boreholes and biaxially tested at the sites for Young's modulus (table 6). Additional physical property testing of these and other cores was performed in a Bureau laboratory and is presented in appendix B. Poisson's ratio values were taken from these tests to calculate the stresses.

Secondary horizontal principal stresses and stress directions were calculated for each overcoring stress relief (table 7). A representation of the stress magnitudes and directions are presented in figures 13 to 16. In the floor and roof at

TABLE 6. - Young's modulus from biaxial tests at Foidel Creek Mine

Relief	Depth, ft	$10^6 \times E_{min}$, psi	$10^6 \times E_{max}$, psi	Angle,[1] deg
SITE 1, HOLE 1, IN FLOOR[2]				
2.................	12.3	2.90	3.03	27
3.................	13.4	4.77	5.61	60
4.................	14.4	3.40	3.84	33
5.................	15.6	2.63	2.87	-23
SITE 1, HOLE 2, IN ROOF				
1.................	10.6	1.76	1.92	50
2.................	11.7	1.40	1.57	26
3.................	12.8	1.15	1.28	43
4.................	13.8	.83	.92	-40
5.................	15.2	1.03	1.18	17
SITE 2, HOLE 3, IN FLOOR				
1.................	11.0	1.95	2.30	27
2.................	12.1	1.97	2.56	5
3.................	13.2	2.94	3.49	21
4.................	14.3	2.50	2.71	16
5.................	15.3	2.29	2.78	36
SITE 2, HOLE 4, IN ROOF[3]				
1.................	11.1	1.46	1.62	63
2.................	11.9	1.29	1.87	87
3.................	12.9	2.15	2.29	71
5.................	14.9	1.47	1.59	48
6.................	16.0	1.02	1.22	54

E Young's modulus.

[1]Positive angle measured counterclockwise from U_1 (north) to E_{min}.

[2]Data are missing because the overcore retrieved was too short to test.

[3]Data are missing because the overcore retrieved failed during the biaxial test.

TABLE 7. - Secondary horizontal principal stresses at Foidel Creek Mine

Relief	Depth, ft	P, psi	Q, psi	Bearing of P
SITE 1, HOLE 1, IN FLOOR				
1.........	11.3	-1,006	-587	N 15° W
2.........	12.3	-798	-468	N 10° W
3.........	13.4	-652	35	N 4° W
4.........	14.4	-1,011	-457	N 25° W
5.........	15.6	-955	-531	N 14° W
SITE 1, HOLE 2, IN ROOF				
1.........	10.6	-734	-487	N 60° W
2.........	11.7	-802	-386	N 59° W
3.........	12.8	-586	-335	N 62° W
4.........	13.8	-902	-387	N 57° W
5.........	15.1	-788	-331	N 55° W
SITE 2, HOLE 3, IN FLOOR				
1.........	11.0	-1,209	-286	N 81° W
2.........	12.1	-3,817	-833	N 71° W
3.........	13.2	-3,109	-610	N 70° W
4.........	14.3	-1,181	-636	N 86° W
5.........	15.3	-988	-411	N 76° W
SITE 2, HOLE 4, IN ROOF				
1.........	11.1	-1,036	-968	N 57° W
2.........	11.9	-924	-826	S 76° W
3.........	12.9	-981	-736	N 86° W
4.........	13.9	-930	-616	S 84° W
5.........	14.9	-777	-503	West
6.........	16.0	-728	-505	S 87° W

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.

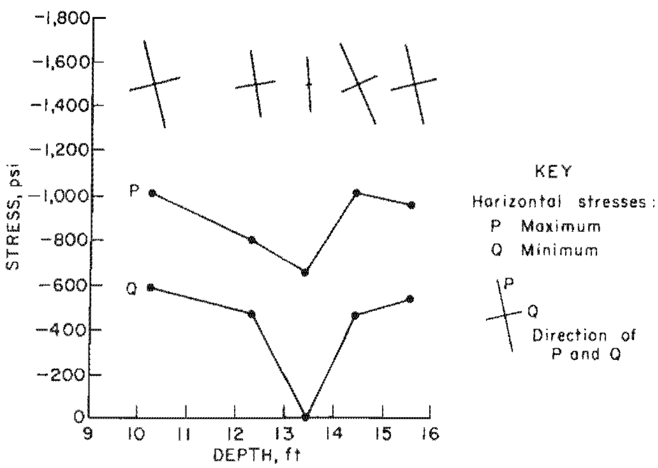

FIGURE 13.—Plot of secondary principal stresses for Foidel Creek Mine hole 1.

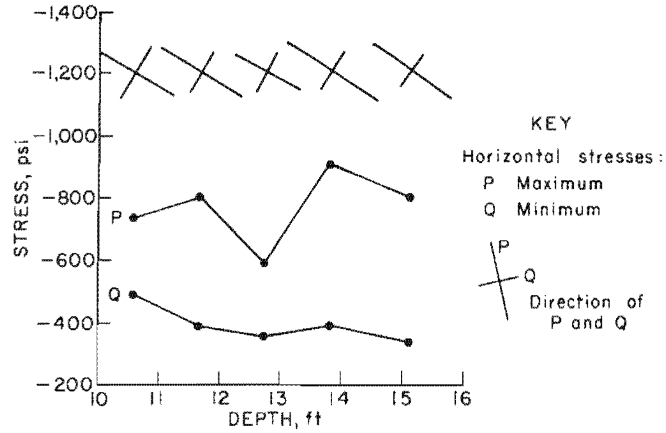

FIGURE 14.—Plot of secondary principal stresses for Foidel Creek Mine hole 2.

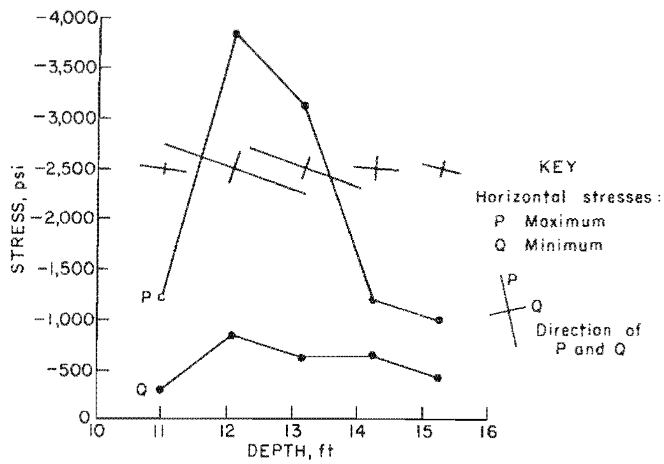

FIGURE 15.—Plot of secondary principal stresses for Foidel Creek Mine hole 3.

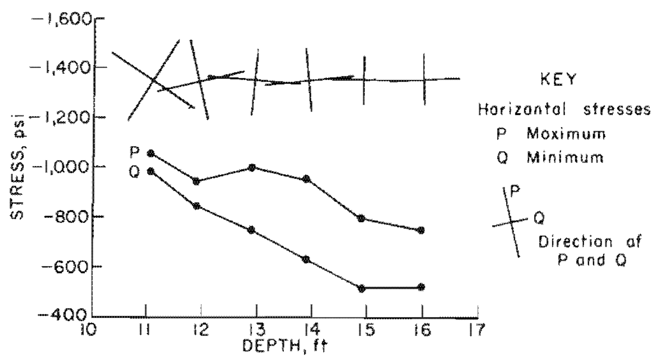

FIGURE 16.—Plot of secondary principal stresses for Foidel Creek Mine hole 4.

site 1 (holes 1 and 2), a decrease of stress occurred near the 13-ft depth. The stress direction, however, remained constant at the various depths measured. In the floor at site 2, hole 3, a sandstone body was present at a depth of 11.6- to 13.3-ft deep. The average stress determined from reliefs 2 and 3 was about 2.7 times (2,092 psi versus 785 psi) higher than the average stress in adjacent strata determined from reliefs 1, 4, and 5. However, the stress direction in the sandstone body was the same as the adjacent strata. The E value for the sandstone body was only 13% higher than the E value of the adjacent strata. The reason for this stress magnitude anomaly has not been determined. In the roof at site 2, the stress magnitude decreased with depth.

RIENAU NO. 2 MINE

Deformation measurements were made at two sites in the Rienau No. 2 Mine. Approximately 8 ft of coal was mined at site 1 and about 10 ft of coal was mined at site 2 from the G Seam, having an average thickness of 18 to 20 ft. Site 1 is located approximately 1,560-ft north of the portal under about 775 ft of overburden. Site 2 is located approximately 1,860-ft west of the portal under about 735 ft of overburden (fig. 17). The mine opening dimensions at site 1 are 18.5 ft wide by 10 ft high on one side and 6.5 ft high on the opposite side. The unusual mine opening shape resulted from a 20° dip in the coal seam. The mine opening dimensions at site 2 are approximately 18 ft wide by 10 ft high.

Hole 1 was drilled vertically down at site 1 into the predominantly sandstone floor. Four sets of deformation measurements were performed starting at a depth of 14.2 ft and concluding at 18.7 ft below the floor surface. Hole 2 was drilled vertically up at site 1 into the predominantly sandstone roof. Five sets of deformation measurements were performed starting at a depth of 12 ft and concluding at a depth of 17.1 ft above

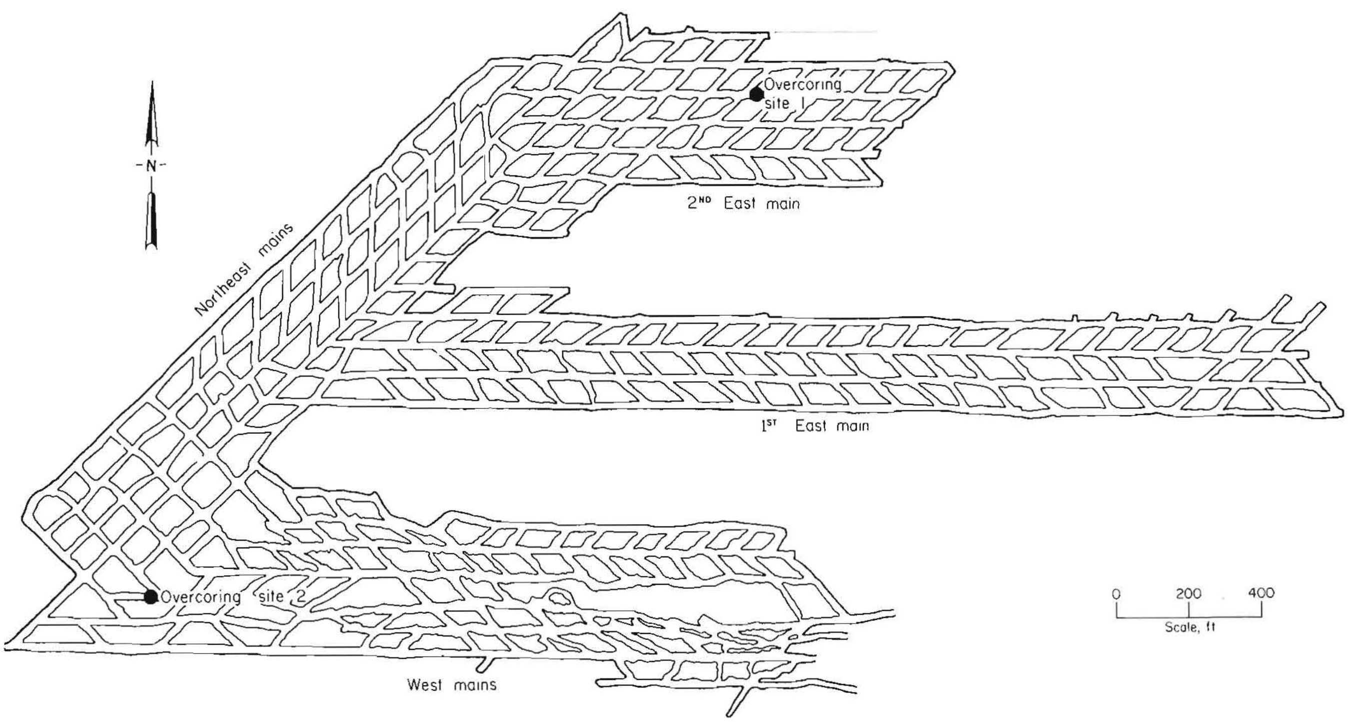

FIGURE 17.—Mine layout and drill sites, Rienau No. 2 Mine.

TABLE 8. - Young's modulus from biaxial tests at Rienau No. 2 Mine

Relief	Depth, ft	$10^6 \times E_{min}$, psi	$10^6 \times E_{max}$, psi	Angle,[1] deg
SITE 1, HOLE 1, IN FLOOR				
1.................	15.2	3.21	3.46	19
2.................	15.9	6.57	7.06	-1
3.................	17.1	5.33	5.89	-43
4.................	18.1	1.85	4.?8	16
SITE 1, HOLE 2, IN ROOF				
1.................	12.5	4.56	5.00	-66
2.................	13.5	4.72	5.09	6
3.................	14.5	4.52	5.57	-61
4.................	15.5	3.73	4.40	-35
5.................	16.6	4.67	4.97	-38
SITE 2, HOLE 3, IN FLOOR[2]				
1.................	20.8	2.14	2.19	-18

E Young's modulus.

[1]Positive angle measured counterclockwise from U_1 (N 88° E) to E_{min}.

[2]Data are missing for relief 2 because the overcore retrieved was too short to test.

the roof surface. Hole 3 was drilled vertically down at site 2 into the mudstone floor. After drilling through approximately 3 ft of coal and 5.5 ft of rock, a 9-ft-thick seam of coal was encountered. Beneath this coal was about 4 ft of mudstone where two sets of deformation measurements were made, starting at 20.6-ft and concluding at 22.8-ft below the floor surface. Overcoring cores were biaxially tested on site for Young's modulus (table 8). Physical property testing of overcores and additional cores was performed in a Bureau laboratory, and results are presented in appendix B. Poisson's ratio values were taken from these tests to calculate the stresses. The average Young's modulus (E) values for the floor range 3.06×10^6 to 6.82×10^6 psi, and the average E values for the roof range from 4.06×10^6 to 5.04×10^6 psi (table 8). Individual sets of deformation measurements in the floor varied extensively; whereas, deformation measurements performed in the roof were more consistent.

Secondary horizontal principal stresses and stress directions were calculated from each set of deformation measurements (table 9). A representation of these stress magnitudes and directions are presented in figures 18 to 20. The maximum horizontal stress (P) at site 1 decreased abruptly in the floor and roof at a depth of approximately 15 ft (figures 18 and

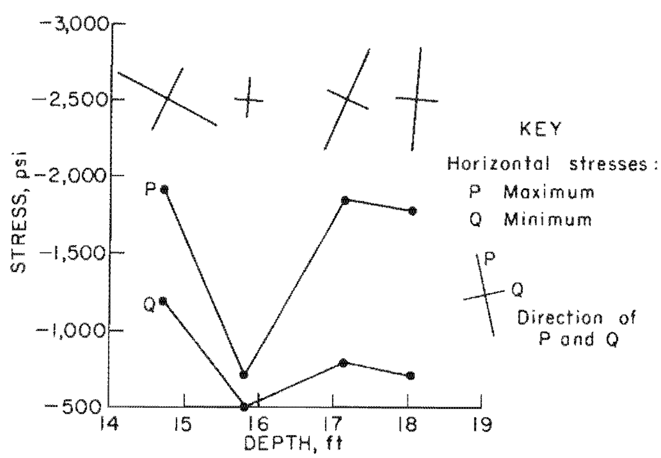

FIGURE 18.—Plot of secondary principal stresses for Rienau No. 2 Mine hole 1.

TABLE 9. - Secondary horizontal principal stresses at Rienau No. 2 Mine

Relief	Depth, ft	P, psi	Q, psi	Bearing of P
SITE 1, HOLE 1, IN FLOOR				
1.......	14.8	-1,893	-1,174	N 63° W
2.......	15.8	-698	-474	N 4° E
3.......	17.2	-1,836	-787	N 25° E
4.......	18.1	-1,758	-689	N 4° E
SITE 1, HOLE 2, IN ROOF				
1.......	12.5	-1,211	-371	N 59° W
2.......	13.5	-986	-356	N 58° W
3.......	14.5	-488	-331	N 87° W
4.......	15.5	-1,114	-834	N 75° W
5.......	16.6	-1,288	-952	S 86° W
SITE 2, HOLE 3, IN FLOOR				
1.......	21.0	-452	-89	N 81° W
2.......	22.2	-284	25	N 86° W

P Maximum secondary principal compressive stress.

Q Minimum secondary principal compressive stress.

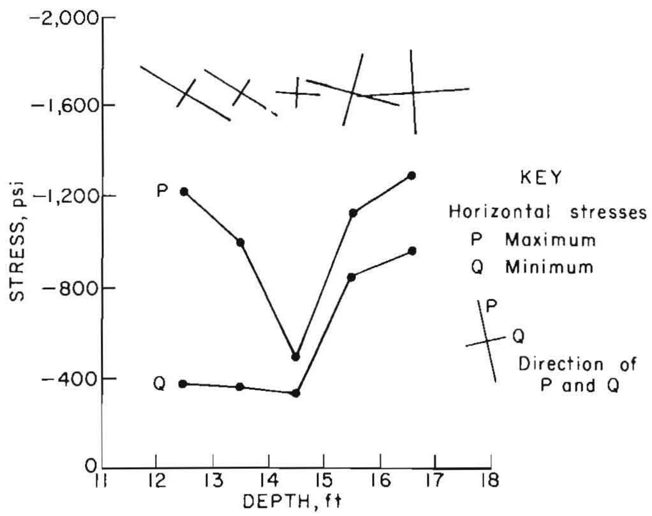

FIGURE 19.—Plot of secondary principal stresses for Rienau No. 2 Mine hole 2.

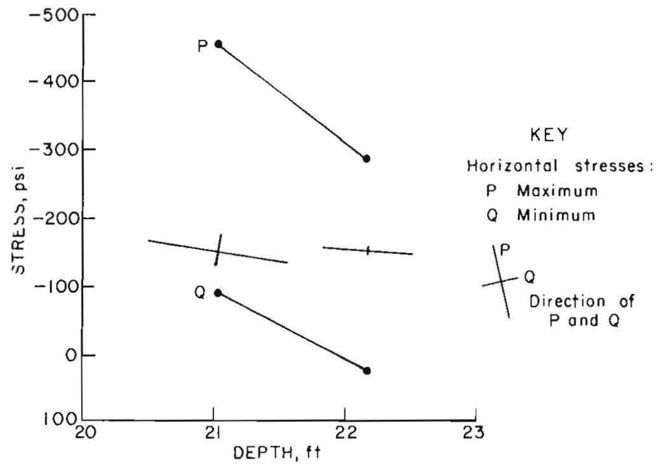

FIGURE 20.—Plot of secondary principal stresses for Rienau No. 2 Mine hole 3.

19) and then returned to the maximum horizontal stress measured closer to the mine opening. However, the highest E value was measured at the 15-ft depth. Geology, geometry, and interaction between strata layers could account for the decrease in horizontal stress. In the floor at site 2, the horizontal stresses were determined at a depth of approximately 22 ft (fig. 20). The minimum horizontal stress (Q) for the last deformation measurement before another coal seam was encountered in the floor was tensile; however, the average ground stress at this location was compressive.

INTERPRETATION OF RESULTS

A least-squares method of calculating the average rock stress components in the horizontal plane was performed (10). This least-squares analysis provided a means to determine multiple correlation coefficient, variance, and scatter for the deformation measurements. Confidence limits can also be calculated for the secondary horizontal principal stresses and stress directions. The multiple correlation coefficient, variance, scatter for deformation measurements, and confidence limits for each mine appear in appendix A.

EAGLE NO. 5 MINE

The average maximum (P) and minimum (Q) horizontal compressive stresses from the least-squares analysis are shown below.

Site 1, floor: P = -577 psi, N 20° W,
Q = -199 psi, N 70° E.

Site 1, roof: P = -235 psi, N 12° E,
Q = -185 psi, N 78° W.

Site 2, floor: P = -363 psi, N 4° W,
Q = -133 psi, N 86° E.

It is of value to determine, statistically, if P and Q were significantly different at a particular site (10). A 95% confidence level was used. In the floor and roof, P and Q were determined statistically to be significantly different, hence a biaxial stress field existed. The biaxial stress field in the roof at site 1 had a P:Q ratio less than 1.5:1. The biaxial stress field in the floor at both sites had a P:Q ratio of about 3:1.

The maximum stress (P) in the floor at site 1 and site 2 was statistically determined to be significantly different; however, the minimum stress (Q) at both sites was determined not to be significantly different (fig. 21).

The horizontal component of stress, S_h, due to overburden (Poisson's effect) can be approximated from

$$S_h = \frac{\nu}{1-\nu}\sigma_z \qquad (1)$$

where ν = Poisson's ratio,

and σ_z = vertical stress, psi.

Using the laboratory-determined Poisson's ratio (secant value) and assuming 1 psi per foot of overburden, the horizontal stress components become the following:

Site 1, floor: $S_h = \frac{.19}{1-.19}$ (-660 psi)

= -155 psi.

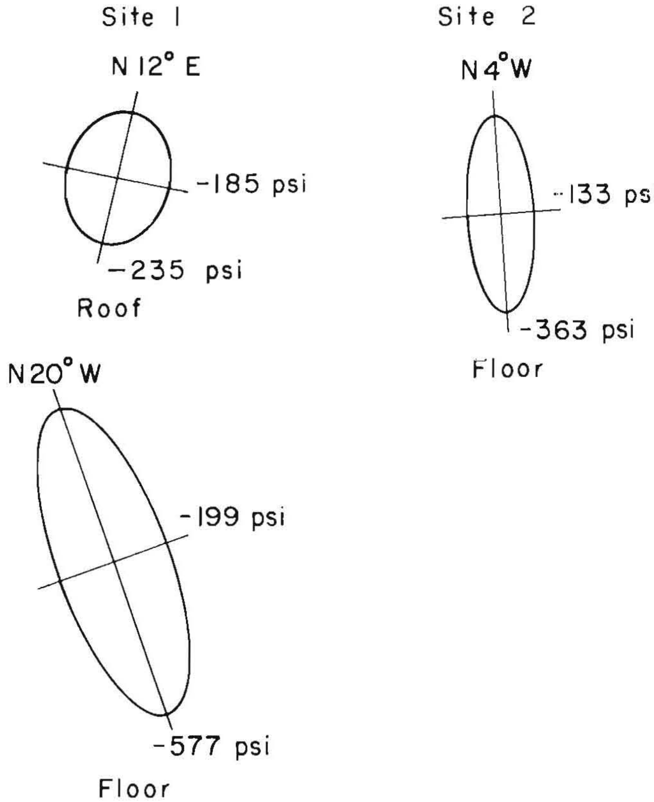

FIGURE 21.—Average horizontal stresses at each hole in Eagle No. 5 Mine.

Site 1, roof: $S_h = \frac{.21}{1-.21}$ (-630 psi)

= -167 psi.

Site 2, floor: $S_h = \frac{.17}{1-.17}$ (-325 psi)

= -67 psi.

Subtracting these values from the calculated average maximum and minimum horizontal compressive stresses, the remaining values are the average excess horizontal compressive stresses (P', Q').[6]

[6]The excess horizontal stress is calculated to eliminate the overburden effects for comparison of horizontal stresses measured at various depths. However, the measured stress would still be used for mine design.

Site 1, floor: P' = -422 psi, N 20° W,

Q' = -44 psi, N 70° E.

Site 1, roof: P' = -68 psi, N 12° E,

Q' = -18 psi, N 78° W.

Site 2, floor: P' = -296 psi, N 4° W,

Q' = -66 psi, N 86° E.

The magnitude of the stresses indicated excess horizontal stress was present in the floor. At site 1, the average excess horizontal stress (43 psi) in the roof was approximately 18% of the average excess horizontal stress (233 psi) in the floor. The average excess floor stress (233 psi) was about 35% of the estimated vertical stress (660 psi), and the average excess roof stress (43 psi) was only about 7% of the estimated vertical stress (630 psi). At site 2, the average excess floor stress (181 psi) was approximately 56% of the estimated vertical stress (325 psi).

APEX NO. 2 MINE

The average maximum (P) and minimum (Q) horizontal compressive stresses from the least-squares analysis are shown below.

Site 1, floor: P = -257 psi, N 19° W,

Q = -213 psi, N 71° E.

Site 1, roof: P = -567 psi, N 86° W,

Q = -493 psi, N 4° E.

In both the floor and roof, P and Q were determined statistically (using a 95% confidence level) not to be significantly different, hence, a biaxial stress field did not exist at the test site (fig. 22).

The average horizontal stress components calculated in the roof were approximately 2.2 times greater (P = 567 psi versus 257 psi and Q = 493 psi versus 213 psi) than in the floor (figures 10 and 11). Examining the roof (fig. 11) at 9.5 ft (approximately 2 times the mining height), the stress magnitude increased about 26% over the previous three average stress magnitudes (463 psi), and the stress magnitude at 10.6 ft was 35% higher, even though the average Young's modulus (E) was lower by 29% at these two depths than the previous three average E values. The reason(s) for these differences have not been determined.

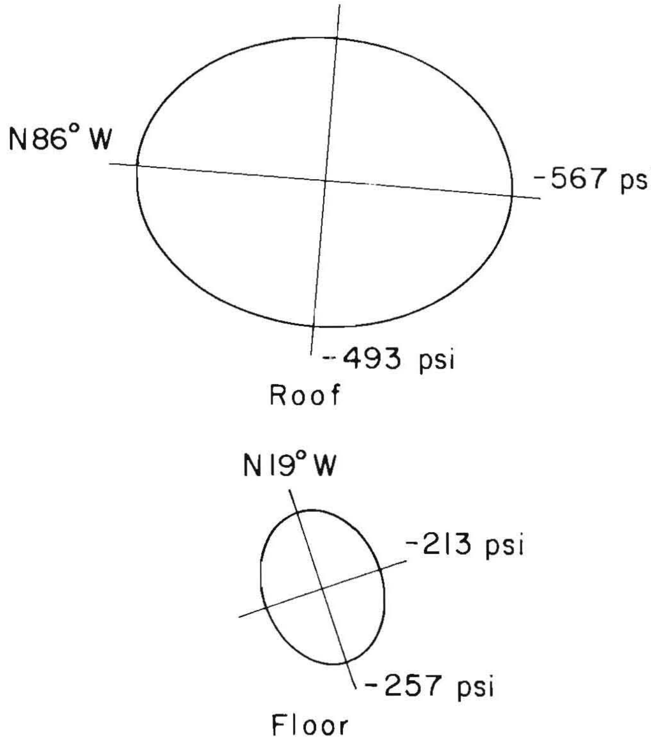

FIGURE 22.—Average horizontal stresses at each hole in Apex No. 2 Mine.

The horizontal component of stress, S_h, due to overburden is approximated from equation 1--

$$\text{Floor:}\quad S_h = \frac{.26}{1-.26}(-420 \text{ psi})$$

$$= -148 \text{ psi.}$$

$$\text{Roof:}\quad S_h = \frac{.19}{1-.19}(-400 \text{ psi})$$

$$= -94 \text{ psi.}$$

Subtracting these values from the calculated average maximum and minimum horizontal compressive stresses, the remaining values are the average excess horizontal compressive stresses.

Site 1, floor: P' = -109 psi, N 19° W,

Q' = -65 psi, N 71° E.

Site 1, roof: P' = -473 psi, N 86° W,

Q' = -399 psi, N 4° E.

The average excess horizontal stress (436 psi) present in the roof is 5 times the average excess horizontal stress (87 psi) in the floor. The average excess floor stress (87 psi) is about 21% of the estimated vertical stress (420 psi); whereas, the average excess roof stress (436 psi) is 109% of the estimated vertical stress (400 psi).

FOIDEL CREEK MINE

The average maximum (P) and minimum (Q) horizontal compressive stresses from the least-squares analysis are shown below.

Site 1, floor: P = -923 psi, N 14° W,

Q = -476 psi, N 76° E.

Site 1, roof: P = -786 psi, N 57° W,

Q = -376 psi, N 33° E.

Site 2, floor: P = -1,956 psi, N 72° W,

Q = -555 psi, N 18° E.

Site 2, roof: P = -875 psi, N 84° W,

Q = -673 psi, N 6° E.

In the floor and roof at both sites, P and Q were determined statistically (using a 95% confidence level) to be significantly different, hence, a biaxial stress field existed (fig. 23).

A sandstone body was present at a depth of 11.6 to 13.3 ft in the floor at site 2, resulting in a high maximum horizontal stress of -1,956 psi (fig. 15). If stresses in the sandstone body are not used to calculate the average horizontal field stresses in the floor, the results are

P = -1,132 psi, N 79° W,

and Q = -433 psi, N 11° E.

These stress values are representative at 11 ft and 14 to 15 ft deep in the floor. Stress direction in the sandstone body was only 7° from the stress direction in the adjacent strata. The sandstone body appeared to act as a stiff beam supporting higher stress components.

In the floor at both sites (with and without the sandstone body at site 2), the maximum stress components (P) were statistically determined to be significantly different (10); however, the minimum stress components (Q) were not significantly different. In the roof at both sites, the maximum components were determined not to be significantly different, while the minimum stress components were determined to be significantly different. Site 1 was approximately 1,200-ft north of an oblique strike-slip fault with a 0.9- to 3.0-ft vertical displacement, and approximately 600-ft northwest of a low-angle shear fault of less than 1-ft vertical displacement. It is not known how much, if any, the stresses are influenced by the faults at this site. The stress direction between the floor and roof at site 2 statistically shows no difference. The stress direction in the floor is N 72° W ±8°, and the stress direction in the roof is N 84° W ±9°.

The horizontal component of stress, S_h, due to overburden is approximated from equation 1--

Site 1, floor: $S_h = \frac{.10}{1-.10}$ (-301 psi)

$= -33$ psi.

Site 1, roof: $S_h = \frac{.24}{1-.24}$ (-265 psi)

$= -84$ psi.

Site 2, floor: $S_h = \frac{.20}{1-.20}$ (-545 psi)

$= -136$ psi.

Site 2, roof: $S_h = \frac{.29}{1-.29}$ (-508 psi)

$= -207$ psi.

Subtracting these values from the calculated average maximum and minimum horizontal compressive stresses, the remaining values are the average excess horizontal compressive stresses.

Site 1, floor: P' = -890 psi, N 14° W,

Q' = -443 psi, N 76° E.

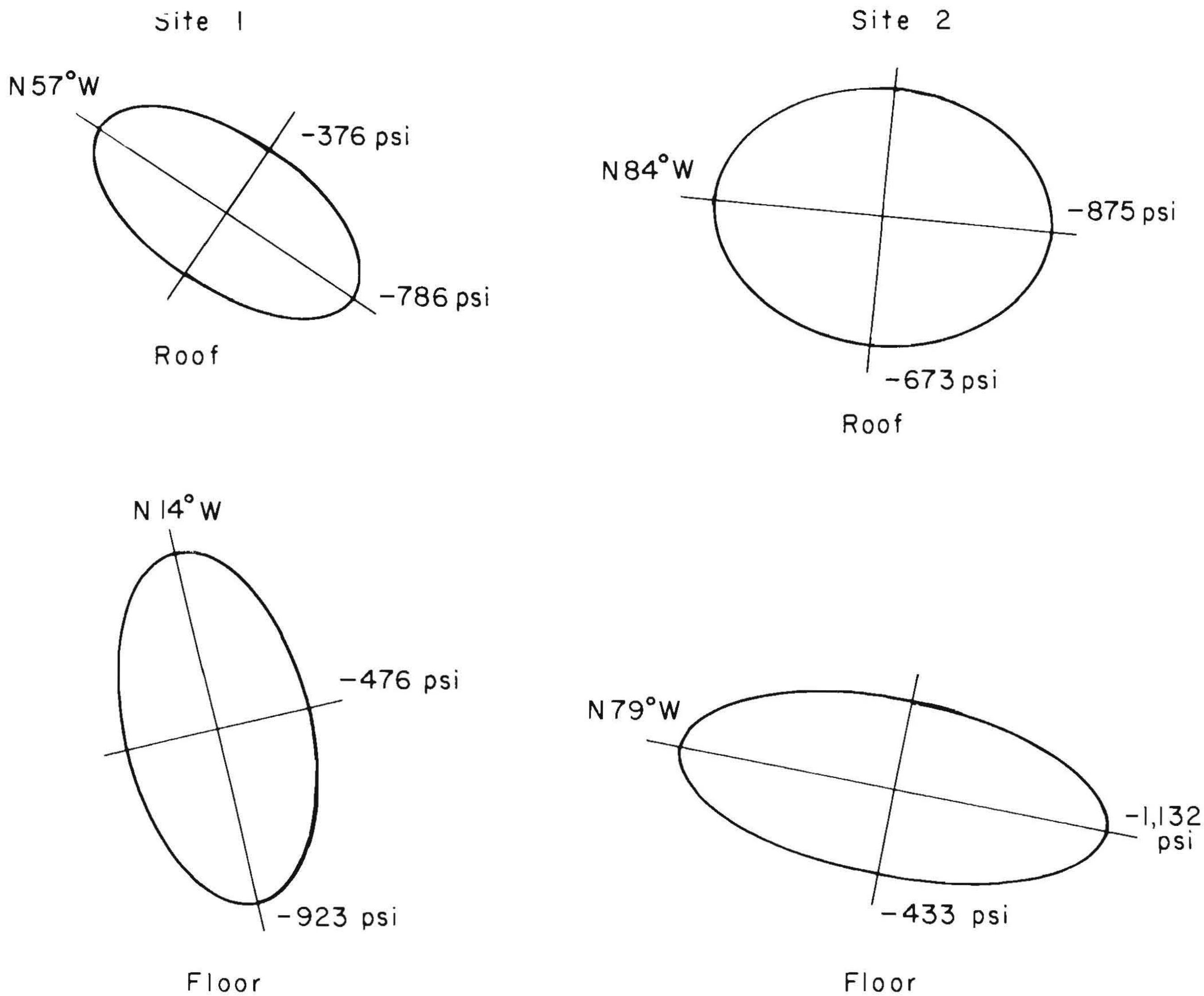

FIGURE 23.—Average horizontal stresses at each hole in Foidel Creek Mine.

Site 1, roof: P' = -702 psi, N 57° W,

Q' = -292 psi, N 33° E.

Site 2, floor: P' = -1,820 psi,

N 72° W,

Q' = -419 psi,

N 18° E.

Site 2, roof: P' = -668 psi,

N 84° W,

Q' = -466 psi,

N 6° E.

At site 1, the average excess horizontal stress (497 psi) in the roof was approximately 75% of the average excess horizontal stress (667 psi) in the floor. At site 2, the average excess horizontal stress (567 psi) in the roof was approximately 51% of the average excess horizontal stress (1,120 psi) in the floor. At site 1, the average excess floor stress (667 psi) was 2.2 times the estimated vertical stress (301 psi), and the average excess roof stress (497 psi) was about 1.9 times the estimated vertical stress (265 psi). At site 2, the average excess floor stress (1,120 psi) was about 2.1 times the estimated vertical stress (545 psi) and the average excess roof stress (567 psi) was 1.1 times the estimated vertical stress (508 psi).

RIENAU NO. 2 MINE

The average maximum (P) and minimum (Q) horizontal compressive stresses from the least-squares analysis are shown below.

Site 1, floor: P = -1,481 psi, N 9° E,

Q = -1,200 psi, N 81° W.

Site 1, roof: P = -1,024 psi, N 67° W,

Q = -599 psi, N 23° E.

Site 2, floor: P = -360 psi, N 83° W,

Q = -14 psi, N 7° E.

At site 2, only two overcore stress reliefs were performed in the floor, because the poorly cemented floor rock separated.

In the floor at site 1, P and Q were determined statistically (using a 95% confidence level) not to be significantly different, hence, a biaxial stress field did not exist. However, in the roof, P and Q were significantly different, hence, a biaxial stress field existed. In the floor at site 2, P and Q were determined to be significantly different, thus a biaxial stress field existed (fig. 24).

At site 1, the average maximum stress magnitude in the floor was approximately 31% higher than in the roof.

Approximately 800 ft south of site 2, the coal outcropped into a gulch and appeared to relieve most of the stress (fig. 25). With loss of confinement south of the site, the principal horizontal stress direction rotated to an east-west direction.

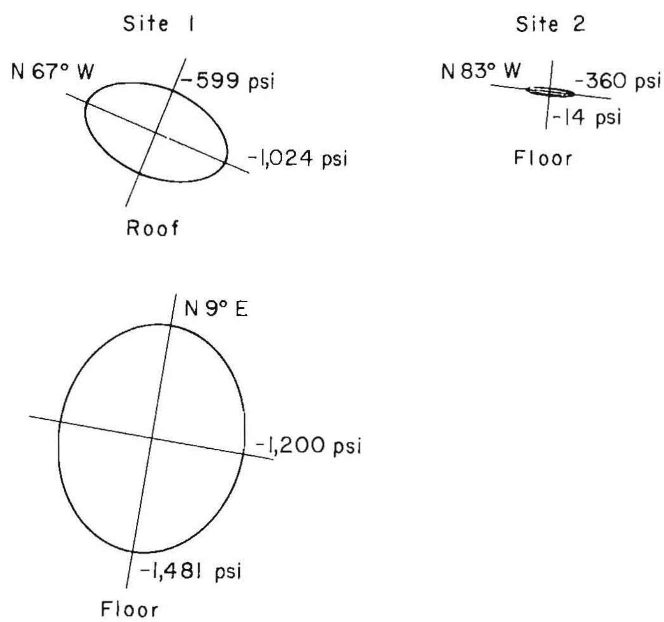

FIGURE 24.—Average horizontal stresses at each hole in Rienau No. 2 Mine.

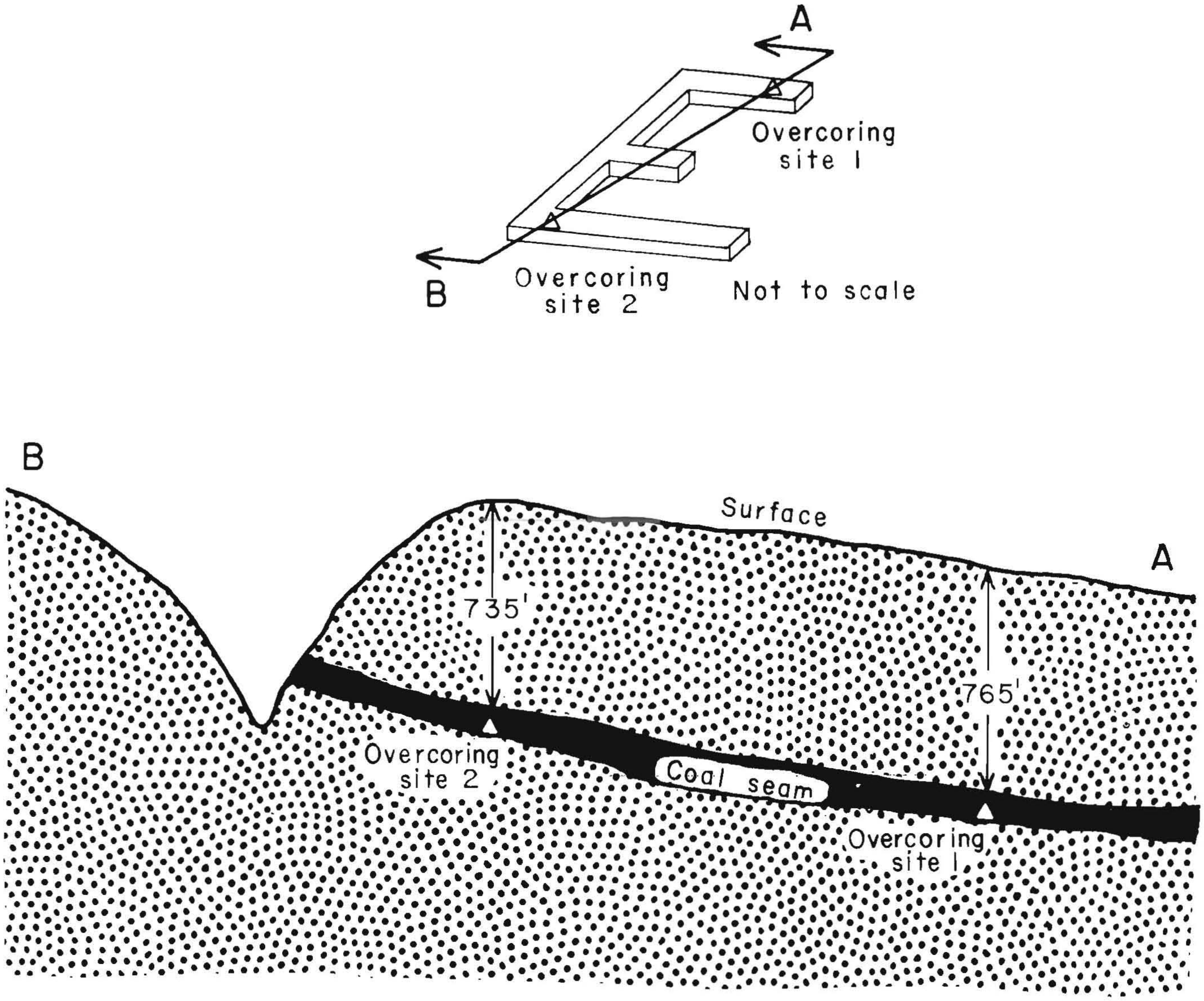

FIGURE 25.—Cross section of the Rienau No. 2 Mine showing site location to topography.

At site 1, the maximum stress components (P) between the floor and roof were determined statistically not to be significantly different.

The horizontal component of stress, S_h, due to overburden is approximated from equation 1--

Site 1, floor: $S_h = \frac{.16}{1-.16}(-775)$

$= -148$ psi.

Site 1, roof: $S_h = \frac{.18}{1-.18}(-735)$

$= -161$ psi.

Site 2, floor: $S_h = \frac{.13}{1-.13}(-765)$

$= -114$ psi.

Subtracting these values from the calculated average maximum and minimum compressive stresses, the remaining values are the average excess horizontal compressive stresses.

Site 1, floor: P' = -1,333 psi, N 9° E,

Q' = -1,052 psi, N 81° W.

Site 1, roof: P' = -863 psi, N 67° W,

Q' = -438 psi, N 23° E.

Site 2, floor: P' = -246 psi, N 83° W,

Q' = 100 psi, N 7° E.

The tensile value of Q' (100 psi) in the floor at site 2 was a result of subtracting out the expected effects of overburden and may or may not represent an in situ tensile stress. The stress value indicated a loss of confinement in the north-south direction, possibly because of the gulch and/or coal outcrop. At site 1, the average excess horizontal stress (651 psi) in the roof was approximately 55% of the average excess horizontal stress (1,193 psi) in the floor. The average excess floor stress (1,193 psi) was about 1.6 times the estimated vertical stress (775 psi), and the average excess roof stress (651 psi) was about 0.9 of the estimated vertical stress (735 psi). At site 2, the average excess floor stress (73 psi) was only about 0.1 of the estimated vertical stress (765 psi).

STRESS TRENDS IN THE YAMPA COALFIELD

The primary objective of measuring the horizontal stresses in the Yampa Coalfield was to determine if a trend existed in the horizontal stresses, and if that trend could be used to project the stresses for improved mine design. Figure 26 shows the excess horizontal stresses in the floor, and figure 27 shows the excess horizontal stresses in the roof for each mine in the Yampa Coalfield. Excess horizontal stresses determined at site 1 in the Rienau No. 2 Mine are also shown in these figures.[7] The average excess horizontal stresses (P' and Q') for each mine are from the least-squares analysis. These stresses are used for comparison between mines, since the effects of the different overburden depths (280-600 ft) have been eliminated from each site. Stress magnitudes and directions are represented by the ellipses in these figures.

The maximum excess horizontal compressive stress in the floor of the three mines in the Yampa Coalfield ranged from 109 to 1,372 psi, and the minimum excess horizontal compressive stress ranged from 65 to 560 psi. The direction of the average maximum excess stress (P') ranged from N 15° W to N 66° W (fig. 26). Variability of stresses in the floor indicated no consistent trend in the stress magnitudes or stress directions (fig. 26). The maximum excess horizontal compressive stress in the roof ranged from 68 to 664 psi, and the minimum excess horizontal compressive stress ranged from 18 to 399 psi. The direction of the average maximum excess stress (P') ranged from N 12° E to N 63° W (fig. 27). Variability of stresses in the roof also indicated no consistent trend in the stress magnitudes or stress directions. In the Eagle No. 5 Mine, the average excess roof stress magnitude was 18.5% of the excess floor stress; in the Foidel Creek Mine, the average excess roof stress magnitude was 59.5% of the excess floor stress; in the Apex No. 2 Mine, the average excess roof stress magnitude was five times the excess floor stress. Stress direction varied between the floor and roof by 32° in the Eagle Mine and an average of 28° in the Foidel Creek Mine. The horizontal stress field was nonbiaxial in the Apex No. 2 Mine. The larger stress magnitude varied between the floor and roof, as did the stress direction. Since variation of stress direction between floor and roof existed, it is difficult to know which direction to use for the mine design.

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[7]Stresses determined from site 2 in the Rienau No. 2 Mine were not included because of the topographic relief at the site.

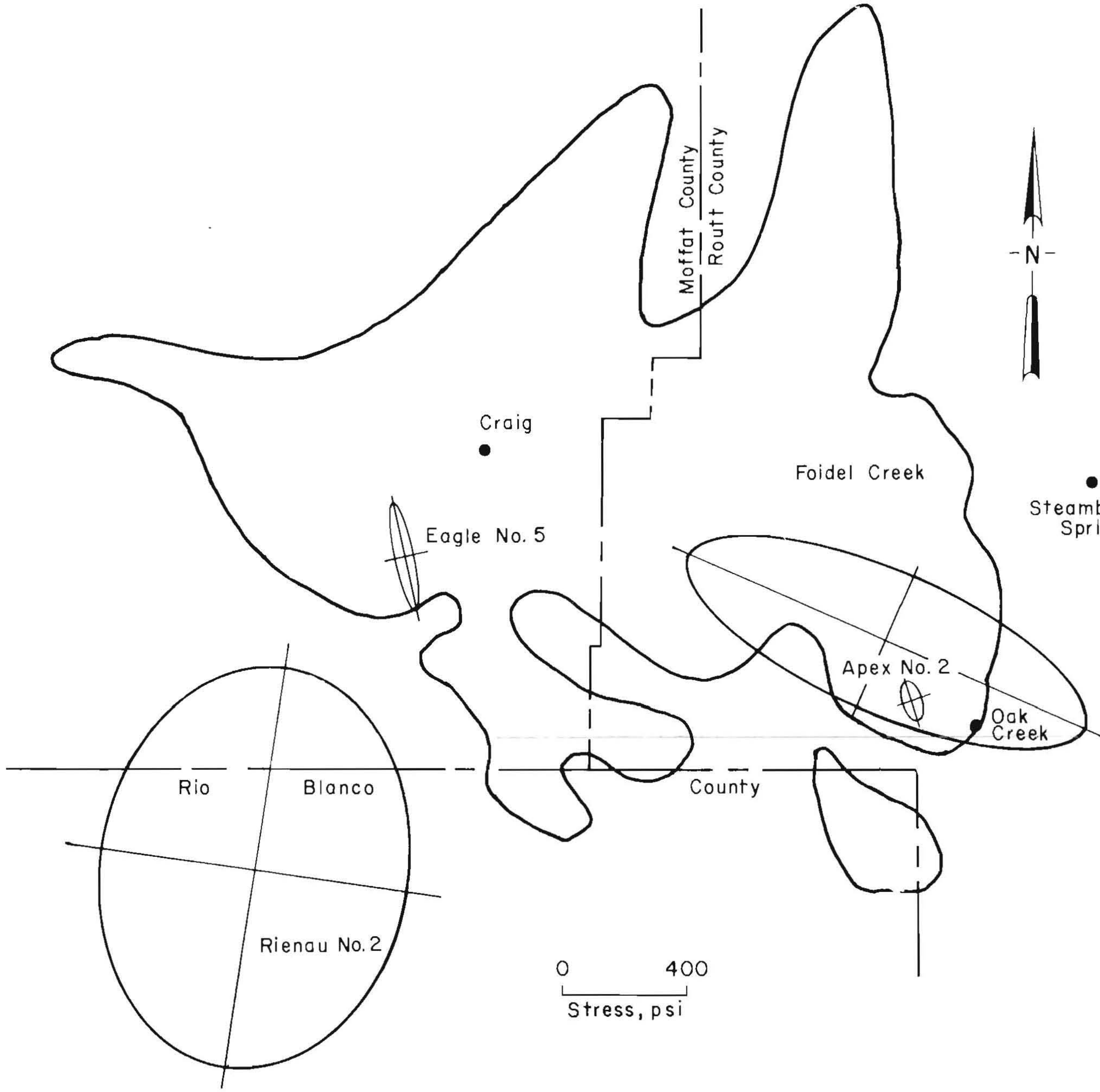

FIGURE 26.—In situ horizontal stress determination in the floor from the Yampa and Danforth Hills Coalfields (outlined area indicates Yampa Coalfield).

From these results, it does not appear that a consistent horizontal stress magnitude or direction was acting over the Yampa Coalfield. Therefore, it would be difficult to accurately predict the magnitude or direction of the horizontal stresses at other sites in the coalfield. However, from the standpoint of mine design, a stress trend does exist in the Yampa Coalfield. The magnitude of the maximum measured horizontal stresses ranged from 235 to 1,481 psi (in the Beckley District in West Virginia these stresses ranged from 3,172 to 3,815 psi), while ground control problems were not prevalent in the existing mines where the overburden was less than 1,000 ft. Therefore, a trend of relatively low stress magnitudes existed in the Yampa Coalfield. Because of this trend, the

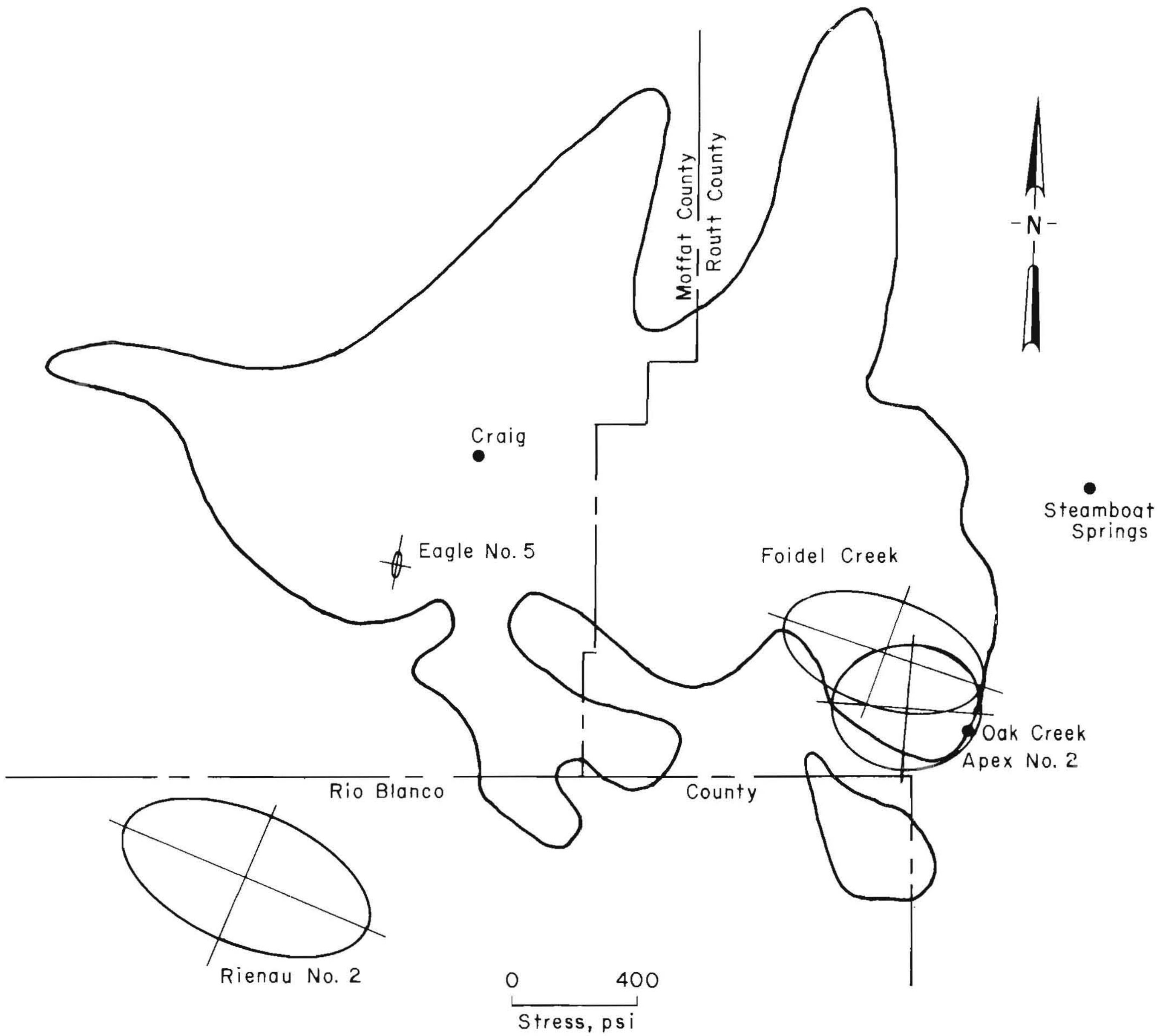

FIGURE 27.—In situ horizontal stress determination in the roof from the Yampa and Danforth Hills Coalfields (outlined area indicates Yampa Coalfield).

magnitude and direction of the horizontal stresses will not be critical to the initial mine design in the Yampa Coalfield when the overburden is less than 1,000 ft.

SUMMARY AND CONCLUSIONS

This report presented the horizontal principal stresses and rock properties in the floor and roof of three mines in the Yampa and one mine in the Danforth Hills Coalfields. A general overview of mine geology was also presented. In the Yampa Coalfield, the maximum horizontal principal compressive stress (P) in the floor ranged from 257 to 1,956 psi, and the direction of the maximum horizontal principal stress ranged from N 4° W to N 72° W. The maximum horizontal principal compressive stress (P) in the roof ranged from 235 to 875 psi, and the direction of the maximum horizontal principal stress ranged from N 12° E to N 84° W.

Research results showed that a trend of relatively low horizontal stresses was present in the Yampa Coalfield. The lack of ground control problems in the operating underground mines suggest that at depths less than 1,000 ft, existing mine design may be adequate for the horizontal stresses present. The differences in the direction and magnitude of the horizontal stresses between the floor and roof strata are currently unexplained, as is the effect of faults and sand bodies on the stress field. As mining proceeds under greater overburden, the potential for ground control problems increases; if this condition occurs, a study of stress differences between floor and roof and the effect of faults and sand bodies on the stress field should be considered.

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APPENDIX A.--INPUT DATA AND STRESS CALCULATIONS FOR MINES STUDIED

Deformation measurements from each overcoring stress relief, Young's modulus (E) determined from biaxial tests, and Poisson's ratio determined from laboratory tests are provided in the tables that follow. Results from the least-squares plane-strain solution are also included for the mines studied. The significance of the P and Q solution for each hole in the four mines is presented in table A-9. The following equation (10)[1] is used to determine if P and Q are significantly different at a particular site. If

$$\frac{|P - Q|}{S_E(C_{11} - 2C_{12} + C_{22})^{1/2}} > t\alpha \qquad \text{(A-1)}$$

where $t\alpha$ is the table value of student's t statistic for the desired probability, α, with n-3 degrees of freedom,

S_E is the standard error of the data,

and C_{11}, C_{12}, C_{22} are constants from least-squares calculation, then it can be said, with less than a probability of being incorrect, that P differs significantly from Q.

It is also possible to compare any stress component determined at one site to the corresponding stress component determined at another site (10) using the following equation. If

$$\frac{|P - P'|}{[C_{11} + C'_{11}]^{-1/2}\left[\dfrac{(n-3)S_E^2 + (n'-3)S'^2_E}{n + n'-6}\right]^{-1/2}} > t\alpha(n+n'-6) \qquad \text{(A-2)}$$

where P and P' are the corresponding stress components, then P and P' are significantly different. Least-squares plane strain solution for multiple holes within a mine are presented in table A-11. There were two holes in the floor of the Eagle No. 5 Mine, and there were two holes in the floor and roof of the Foidel Creek Mine.

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[1]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

TABLE A-1. - Input data for least-squares analysis, Eagle No. 5 Mine

(U_1 is N 85° W, U_2 is S 35° W, U_3 is N 25° W)

Relief	Deformation,[1] μin			10^6 × Eav, psi	Poisson's ratio
	U_1	U_2	U_3		
SITE 1, HOLE 1,[2] IN FLOOR					
1.	90	-673	-1,389	1.32	0.19
2.	-193	-316	-2,264	1.17	
3.	-198	-459	-1,826	1.31	
4.	-521	-724	-1,918	.87	
SITE 2, HOLE 2,[3] IN FLOOR					
1.	39	-840	-947	1.28	0.17
2.	-115	-780	-956	[4]1.28	
3.	-159	-676	-616	2.35	
4.	43	-269	-246	3.00	
5.	74	-179	-886	1.18	
SITE 1, HOLE 3,[5] IN ROOF					
1.	-45	-301	-312	1.29	0.21
2.	-201	-560	-463	.83	.40
3.	-98	-399	-335	.85	.41
4.	-190	-344	-333	.85	.41
5.	-194	-329	-219	.82	.43

Eav Average Young's modulus.
[1]Negative values indicate compression.
[2]Overburden depth, 660 ft. [3]Overburden depth, 325 ft.
[4]E value from relief 1 was also used for relief 2 (hole 2).
[5]Overburden depth, 630 ft.

TABLE A-2. - Results from least-squares plane-strain solution for Eagle No. 5 Mine

	Hole 1	Hole 2	Hole 3		Hole 1	Hole 2	Hole 3
P.............psi..	-577	-363	-235	SE(xy)........psi..	23	20	6
Q.............psi..	-199	-133	-185	n..................	12	15	15
θ.............deg..	25	9	-7	$\Sigma u^2 \times 10^{-6}$.....in..	19.5870	5.7381	7.7722
SE(θ).........deg..	3	5	7	$\Sigma e^2 \times 10^{-7}$.....in..	7.6890	5.2632	1.0842
σ_x............psi..	-243	-134	-187	R^2.................	.9607	.9083	.9861
σ_y............psi..	-533	-361	-232	$S_E \times 10^{-4}$......in..	2.9229	2.0943	.9505
T_{xy} ....psi..	121	16	-10	$C_{11} \times 10^{10}$.........	1.7756	2.5402	1.0010
SE(x).........psi..	39	33	10	$C_{22} \times 10^{10}$.........	1.7756	2.5402	1.0010
SE(y).........psi..	39	33	10	$C_{12} \times 10^{9}$..........	6.2125	8.8016	4.1368

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.
θ Positive angle measured counterclockwise from U_1 (location of first deformation measurement) to Q.
SE Standard error.
σ_x Stress component, east, with respect to x-y coordinate system.
σ_y Stress component, north, with respect to x-y coordinate system.
T_{xy} Shear stress component.
n Number of deformation measurements.
Σu^2 Deformation sum of squares.
Σe^2 Residual sum of squares.
R^2 Multiple correlation coefficient squared.
S_E Standard error at 95% confidence level.
C_{11}, C_{22}, C_{12} Constants from least-squares calculations.

TABLE A-3. - Input data for least-squares analysis, Apex No. 2 Mine

(U_1 is S 50° E, U_2 is N 70° E, U_3 is S 10° W)

Relief	Deformation,[1] µin U_1	U_2	U_3	$10^6 \times$ Eav, psi	Poisson's ratio
		SITE 1, HOLE 1,[2] IN FLOOR			
1	-217	-161	-268	2.92	0.26
2	-132	-186	-213	2.81	
3	-148	-161	-184	2.75	
4	-361	-99	-209	2.65	
		SITE 1, HOLE 2,[3] IN ROOF			
1	-344	-261	-240	3.69	0.19
2	-344	-501	-294	3.14	
3	-315	-409	-238	3.32	
4	-823	-758	-562	2.26	
5	-737	-783	-766	2.54	

Eav Average Young's modulus.
[1]Negative values indicate compression.
[2]Overburden depth, 420 ft.
[3]Overburden depth, 400 ft.

TABLE A-4. - Results from least-squares plane-strain solution for Apex No. 2 Mine

	Hole 1	Hole 2		Hole 1	Hole 2
P...psi	-257	-567	SE(xy)...psi	14	27
Q...psi	-213	-493	n...	15	15
θ...deg	59	54	$\Sigma u^2 \times 10^{-6}$...in	0.8253	4.9801
SE(θ)...deg	16	18	$\Sigma e^2 \times 10^{-7}$...in	.4043	2.6172
σ_x...psi	-252	-567	R^2...	.9510	.9474
σ_y...psi	-218	-493	$S_E \times 10^{-4}$...in	.6702	1.4768
T_{xy}...psi	14	5	$C_{11} \times 10^{10}$...	11.2501	9.2425
SE(x)...psi	22	45	$C_{22} \times 10^{10}$...	11.2501	9.2425
SE(y)...psi	22	45	$C_{12} \times 10^9$...	41.0775	32.3367

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.
θ Positive angle measured counterclockwise from U_1 to Q.
SE Standard error.
σ_x Stress component, east, with respect to x-y, coordinate system.
σ_y Stress component, north, with respect to x-y, coordinate system.
T_{xy} Shear stress component.
n Number of deformation measurements.
Σu^2 Deformation sum of squares.
Σe^2 Residual sum of squares.
R^2 Multiple correlation coefficient squared.
S_E Standard error at 95% confidence level.
C_{11}, C_{22}, C_{12} Constants from least-squares calculations.

TABLE A-5. - Input data for least-squares analysis, Foidel Creek Mine

(U_1 is N, U_2 is N 60° W, U_3 is N 60° E)

Relief	Deformation,[1] μin			10^6 × Eav, psi	Poisson's ratio
	U_1	U_2	U_3		
SITE 1, HOLE 1,[2] IN FLOOR					
1.....................	-1,169	-804	-415	[3]2.97	0.10
2.....................	-947	-582	-361	2.97	
3.....................	-545	-29	-90	5.19	
4.....................	-925	-781	-127	3.62	
5.....................	-1,231	-746	-423	2.75	
SITE 1, HOLE 2,[4] IN ROOF					
1.....................	-749	-1,370	-735	1.84	0.24
2.....................	-810	-1,965	-665	1.49	
3.....................	-812	-1,688	-809	1.22	
4.....................	-1,412	-3,605	-1,140	.88	
5.....................	-1,115	-2,614	-620	1.11	
SITE 2, HOLE 3,[5] IN FLOOR					
1.....................	161	-1,956	-1,147	2.13	0.20
2.....................	-265	-6,325	-2,043	2.27	
3.....................	-67	-3,830	-1,156	3.22	
4.....................	-415	-1,346	-1,175	2.61	
5.....................	-224	-1,393	-728	2.54	
SITE 2, HOLE 4,[6] IN ROOF					
1.....................	-1,701	-2,020	-1,696	1.54	0.29
2.....................	-1,428	-1,726	-1,529	1.58	
3.....................	-740	-1,287	-1,172	2.22	
4.....................	-548	-1,098	-1,209	[7]2.22	
5.....................	-633	-1,414	-1,343	1.53	
6.....................	-918	-1,855	-1,744	1.12	

Eav Average Young's modulus.
[1]Negative values indicate compression.
[2]Overburden depth, 300 ft.
[3]E value from relief 2 was also used for relief 1 (hole 1).
[4]Overburden depth, 265 ft.
[5]Overburden depth, 545 ft.
[6]Overburden depth, 510 ft.
[7]E value from relief 3 was also used for relief 4 (hole 4).

TABLE A-6. - Results from least-squares plane-strain solution for Foidel Creek Mine

	Hole 1	Hole 2	Hole 3	Hole 4
P..............................psi..	-923	-786	-1,956	-875
Q..............................psi..	-476	-376	-555	-673
θ..............................deg..	-76	-33	-18	-6
SE(θ)..........................deg..	4	3	8	9
σ_x.............................psi..	-503	-661	-1,815	-873
σ_y.............................psi..	-895	-501	-696	-675
T_{xy}............................psi..	108	189	421	21
SE(x)..........................psi..	59	32	338	52
SE(y)..........................psi..	59	32	338	52
SE(xy).........................psi..	34	19	201	32
n..................................	15	15	15	18
$\Sigma u^2 \times 10^{-6}$.......................in..	7.8515	40.2890	74.2590	42.4810
$\Sigma e^2 \times 10^{-7}$.......................in..	3.4945	7.3215	196.1200	16.8050
R^2................................	.9555	.9818	.7359	.9604
$S_E \times 10^{-4}$.......................in..	1.7065	2.4701	12.7840	3.3471
$C_{11} \times 10^{10}$...........................	11.8207	1.6300	7.0005	2.4104
$C_{22} \times 10^{10}$...........................	11.8207	1.6300	7.0005	2.4104
$C_{12} \times 10^{9}$............................	39.9321	5.8714	24.6219	9.0015

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.
Θ Positive angle measured counterclockwise from U_1 to Q.
SE Standard error.
σ_x Stress component, east, with respect to x-y, coordinate system.
σ_y Stress component, north, with respect to x-y, coordinate system.
T_{xy} Shear stress component.
n Number of deformation measurements.
Σu^2 Deformation sum of squares.
Σe^2 Residual sum of squares.
R^2 Multiple correlation coefficient squared.
S_E Standard error at 95% confidence level.
C_{11}, C_{22}, C_{12} Constants from least-squares calculations.

TABLE A-7. - Input data for least-squares analysis, Rienau No. 2 Mine

(U_1 is N 88° E, U_2 is N 28° E, U_3 is S 32° E)

Relief	Deformation,[1] µin			10^6 × Eav, psi	Poisson's ratio
	U_1	U_2	U_3		
SITE 1, HOLE 1,[2] IN FLOOR					
1	-1,744	-709	-1,654	3.34	0.16
2	-111	-257	-232	6.82	
3	-324	-1,173	-476	5.61	
4	-522	-2,015	-1,149	3.06	
SITE 1, HOLE 2,[3] IN ROOF					
1	-649	68	-808	4.78	0.18
2	-527	18	-598	4.90	
3	-269	-120	-190	5.04	
4	-877	-450	-741	4.06	
5	-855	-560	-474	4.82	
SITE 2, HOLE 3,[4] IN FLOOR					
1	-765	116	-230	[5]2.16	0.13
2	-513	205	43	2.16	.13

Eav Average Young's modulus.
[1]Negative sign for deformations indicates compression.
[2]Overburden depth, 775 ft.
[3]Overburden depth, 735 ft.
[4]Overburden depth, 765 ft.
[5]E value from relief 1 was also used for relief 2 (hole 3).

TABLE A-8. - Results from least-squares plane-strain solution for Rienau No. 2 Mine

	Hole 1	Hole 2	Hole 3		Hole 1	Hole 2	Hole 3
P, psi	-1,481	-1,024	-360	SE(xy), psi	147	70	33
Q, psi	-1,200	-599	-14	n	12	15	6
θ, deg	-11	65	81	$\Sigma u^2 \times 10^{-6}$, in	14.8680	5.2625	1.1453
SE(θ), deg	23	9	5	$\Sigma e^2 \times 10^{-7}$, in	24.9510	6.7903	.7298
σ_x, psi	-1,207	-959	-355	R^2	.8322	.8710	.9363
σ_y, psi	-1,474	-664	-19	$S_E \times 10^{-4}$, in	5.2653	2.3788	1.5597
τ_{xy}, psi	-43	153	42	$C_{11} \times 10^{10}$	22.6427	24.8657	13.1098
SE(x), psi	251	119	56	$C_{22} \times 10^{10}$	22.6427	24.8657	13.1098
SE(y), psi	251	119	56	$C_{12} \times 10^{9}$	78.1076	86.5647	44.6980

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.
θ Positive angle measured counterclockwise from U_1 to Q.
SE Standard error.
σ_x Stress component, east, with respect to x-y, coordinate system.
σ_y Stress component, north, with respect to x-y, coordinate system.
τ_{xy} Shear stress component.
n Number of deformation measurements.
Σu^2 Deformation sum of squares.
Σe^2 Residual sum of squares.
R^2 Multiple correlation coefficient squared.
S_E Standard error at 95% confidence level.
C_{11}, C_{22}, C_{12} Constants from least-squares calculations.

TABLE A-9. - Significance of difference between P and Q in each hole

(95% confidence level)

Hole	tα[1]		Significant difference	Hole	tα[1]		Significant difference
	Table value	Calculated			Table value	Calculated	
EAGLE NO. 5 MINE				FOIDEL CREEK MINE			
1..........	2.2620	8.5275	Yes	1..........	2.1790	6.6176	Yes
2..........	2.1790	6.0320	Yes	2..........	2.1790	11.4993	Yes
3..........	2.1790	4.9280	Yes	3..........	2.1790	3.6373	Yes
APEX NO. 2 MINE				4..........	2.1310	3.4686	Yes
1..........	2.2620	1.7261	No	RIENAU NO. 2 MINE			
2..........	2.1790	1.4456	No	1..........	2.2620	0.9792	No
				2..........	2.1790	3.1397	Yes
				3..........	3.1820	5.3285	Yes

[1]Student's t statistic with n-3 degrees of freedom.

TABLE A-10. - Results from least-squares plane-strain solution for multiple holes within a mine

	Eagle Mine	Foidel Creek Mine			Eagle Mine	Foidel Creek Mine	
	Floor	Floor	Roof		Floor	Floor	Roof
P..........psi..	-484	-1,457	-810	SE(xy).....psi..	21	136	26
Q..........psi..	-177	-645	-509	n...............	27	30	33
θ..........deg..	20	-24	-27	$\Sigma u^2 \times 10^{-6}$..in..	25.3250	82.1150	82.7700
SE(θ)......deg..	4	9	5	$\Sigma e^2 \times 10^{-7}$..in..	27.9370	328.1400	57.9120
σ_x.........psi..	-213	-1,323	-748	R^2.............	.8897	.6004	.9300
σ_y.........psi..	-448	-780	-572	$S_E \times 10^{-4}$...in..	3.4110	11.0240	4.3936
T_{xy} ....psi..	99	302	122	$C_{11} \times 10^{10}$.....	1.0451	4.3958	.9723
SE(x)......psi..	35	231	43	$C_{22} \times 10^{10}$.....	1.0451	4.3958	.9723
SE(y)......psi..	35	231	43	$C_{12} \times 10^{9}$.......	3.6419	15.2307	3.5535

P Maximum secondary principal compressive stress.
Q Minimum secondary principal compressive stress.
θ Positive angle measured counterclockwise from U_1 to Q.
SE Standard error.
σ_x Stress component, east, with respect to x-y, coordinate system.
σ_y Stress component, north, with respect to x-y, coordinate system.
T_{xy} Shear stress component.
n Number of deformation measurements.
Σu^2 Deformation sum of squares.
Σe^2 Residual sum of squares.
R^2 Multiple correlation coefficient squared.
S_E Standard error at 95% confidence level.
C_{11}, C_{22}, C_{12} Constants from least-squares calculations.

APPENDIX B.--PHYSICAL PROPERTIES OF THE ROCK FROM MINES STUDIED

Laboratory physical property testing of core from the sites was conducted on a MTS[1] stiff testing machine. This is a closed loop, servocontrolled, hydraulic system with a load capacity of 600,000 lb that can be programmed for either a constant load or constant strain rate. A triaxial chamber was used to add confining pressure to the core for multistage triaxial tests. Because of the limited number of specimens available for testing, multistage triaxial testing was performed on a single test specimen. This procedure consists of selecting a lateral pressure (750 psi was selected) and applying one-third (250 psi) of this pressure to the specimen in the triaxial chamber. An axial load is then applied to the specimen until the first sign of failure is observed by the operator. The axial load is then instantly released. Two-thirds (500 psi) of the lateral pressure is applied, then the axial load is reapplied until the first sign of failure is observed. The axial load is instantly released again. The full lateral pressure (750 psi) is applied and a third loading cycle performed. If the failure of the rock cannot be controlled and a second loading cycle performed, shear strength or angle of internal friction are not obtained. Multistage testing provides data to generate a Mohr's envelope, from which shear strength and angle of internal friction are obtained. These data were obtained from single specimen multistage triaxial testing for the Eagle No. 2 Mine. The type of rock in the Apex No. 2, Foidel Creek, and Rienau No. 2 mines did not permit testing a complete series of loading cycles on a single specimen; therefore, no shear strength or angle of internal friction data were obtained.

Linear variable differential transformers (LVDT's) were used to measure the axial and lateral deformation of the test specimens. These measurements were used to calculate a tangent and secant Young's modulus (E) and Poisson's ratio (ν). Values for E and ν were calculated at 50% of the ultimate compressive strength as specified in the American Society for Testing and Materials (ASTM) standards (6).[2] Calculated ν values greater than 0.5 are not valid. These values of ν indicate that the test specimen was beginning to fail, and are represented by NAp in the tables. Specimens drilled and tested in the horizontal direction provide an E value in the horizontal plane; however, the ν value that would be obtained normal to this plane is considered not valid and is also represented by NAp in the tables. Poisson's ratio values obtained from rock specimens for the Foidel Creek Mine indicated several specimens were beginning to fail under 50% of the ultimate compressive strength load, so 25% of the ultimate compressive strength load was also used to compute E and ν. In addition, indirect tensile strength tests (Brazilian) were performed.

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[1]Reference to specific products does not imply endorsement by the Bureau of Mines.

[2]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

TABLE B-1. - Physical properties of the floor and roof at Eagle No. 5 Mine

Location and depth	Direction	Length, in	Diameter, in	Sp gr	Lateral pressure, psi	Compressive strength, psi	50% of ultimate stress: $10^6 \times E$ Tan	50% of ultimate stress: $10^6 \times E$ Sec	50% of ultimate stress: Poisson's ratio Tan	50% of ultimate stress: Poisson's ratio Sec
				SITE 1, HOLE 1						
Floor:										
7-8'0"............	N 85° W.......	4.243	2.080	2.431	0	12,213	1.76	1.72	NAp	NAp
		4.245	2.080	2.457	0	9,476	1.65	1.79	NAp	NAp
		4.252	2.080	2.736	0	13,243	3.33	2.63	NAp	NAp
8'0"-9'0".........	Vertical......	3.958	1.980	2.306	0	11,205	1.99	1.83	0.44	0.20
		3.958	1.980	2.322	0	9,824	1.86	1.69	.18	.07
		3.947	1.980	2.370	0	7,047	2.02	2.32	.35	.25
		3.955	1.980	2.309	0	11,140	1.85	1.58	.39	.15
				SITE 2, HOLE 2						
Floor: 7'6"-8'7"....	N 5° E........	4.248	2.080	2.492	0	12,154	2.09	2.01	NAp	NAp
		4.270	2.080	2.481	0	10,300	2.63	2.62	NAp	NAp
	N 85° W.......	4.235	2.080	2.499	0	12,861	3.47	3.26	NAp	NAp
		4.241	2.080	2.518	0	8,387	3.82	3.14	NAp	NAp
		4.238	2.080	2.503	0	10,153	3.39	3.48	NAp	NAp
				SITE 1, HOLE 3						
Roof:										
0-18".............	Vertical......	4.246	2.090	1.314	0	2,886	0.42	0.32	0.38	0.24
		2.200	2.090	1.355	0	7,257	.60	.52	ND	ND
		2.200	2.090	1.355	250	7,345	.58	.54	ND	ND
		2.200	2.090	1.355	500	7,461	.55	.51	ND	ND
		2.200	2.090	1.355	750	7,374	.53	.47	ND	ND
4'1"-4'5"[2]........	...do.........	4.197	2.080	2.033	0	2,575	ND	ND	ND	ND
		4.197	2.080	2.033	250	3,487	ND	ND	ND	ND
		4.197	2.080	2.033	500	3,885	ND	ND	ND	ND
		4.197	2.080	2.033	750	4,267	ND	ND	ND	ND
4'7"-5'0".........	...do.........	4.225	2.080	2.482	0	4,620	.91	.83	.39	.25
5'0"-5'6".........	...do.........	4.215	2.080	2.528	0	7,917	1.43	1.47	ND	ND
5'5"-6'0"[3]........	...do.........	2.083	2.080	2.521	0	8,211	ND	ND	ND	ND
		2.083	2.080	2.521	250	9,153	ND	ND	ND	ND
		2.083	2.080	2.521	750	9,947	ND	ND	ND	ND

6'1"-6'5"..........	...do.........	4.206	2.080	2.322	250	4,620	.85	.91	ND	ND
		4.206	2.080	2.322	500	4,665	.83	.89	ND	ND
		4.206	2.080	2.322	750	5,194	.84	.91	ND	ND
7'6"-8'0"..........	...do.........	4.288	2.080	2.478	0	6,092	1.18	.99	NAp	.46
8'6"...............	...do.........	3.953	1.965	2.402	0	5,573	1.82	1.10	NAp	.21
11'7"..............	...do.........	3.950	1.965	2.275	0	7,007	2.95	1.83	NAp	.37
		3.950	1.965	2.325	0	7,255	3.85	1.86	NAp	.37
		3.963	1.965	2.222	0	6,694	2.80	1.85	NAp	.48
		3.965	1.965	2.343	0	7,386	2.99	2.12	NAp	.43
		3.962	1.965	2.277	0	7,601	3.14	2.22	NAp	.36
14'7"..............	...do.........	3.963	1.965	2.179	0	7,209	3.20	2.17	NAp	.40
		3.963	1.965	2.261	0	7,243	3.42	2.52	NAp	.47
		3.965	1.965	2.269	0	6,784	2.88	1.57	NAp	.43
		3.963	1.965	2.155	0	7,056	4.80	2.60	NAp	NAp
		3.965	1.965	2.333	0	9,011	4.10	2.97	NAp	.42
				SITE 2, HOLE 4						
Roof:										
0-8"[1]..............	Vertical......	4.215	2.080	1.794	0	3,031	0.57	0.44	0.39	0.27
1'8"-2'0"..........	...do.........	4.181	2.080	2.197	0	3,844	.64	.45	.27	.19
4'4"-4'9"..........	...do.........	4.197	2.080	2.483	0	5,062	1.01	.93	.34	.21
4'9"-5'2"..........	...do.........	4.207	2.080	2.443	0	5,915	.31	.27	ND	.21
5'5"-5'10".........	...do.........	4.197	2.080	2.349	0	2,295	.49	.29	.26	ND
6'0"-6'6"[4]........	...do.........	4.194	2.080	2.394	250	5,356	ND	ND	ND	.11
		4.194	2.080	2.394	500	6,107	ND	ND	ND	ND
6'6"-7'2"..........	...do.........	4.194	2.080	2.394	750	6,515	.25	.24	ND	ND
7'10"-8'3".........	...do.........	4.195	2.080	2.345	0	2,192	.47	.37	.46	.31
8'3"-8'5"[5]........	...do.........	4.204	2.080	2.407	0	3,885	1.03	.78	ND	ND
		4.190	2.080	2.338	250	4,768	ND	ND	ND	ND
		4.190	2.080	2.338	500	5,489	ND	ND	ND	ND
		4.190	2.080	2.338	750	5,945	ND	ND	ND	ND
8'8"-9'0"..........	...do.........	4.204	2.080	2.294	0	3,458	.38	.31	.52	.36

E Young's modulus.
NAp Not applicable.
ND Not determined.
sp gr Specific gravity.
[1]Coal specimen.
[2]Shear strength, 896 psi; angle of internal friction, 22.88°.
[3]Shear strength, 2,747 psi; angle of internal friction, 23.23°.
[4]Shear strength, 1,329 psi; angle of internal friction, 30.01°.
[5]Shear strength, 1,364 psi; angle of internal friction, 24.12°.

TABLE B-2. - Indirect tensile strength tests (Brazilian) of roof specimens at Eagle No. 5 Mine[1]

Depth	Length, in	Diameter, in	Sp gr	Tensile strength, psi	
				Indirect	Average
HOLE 3					
4'7"	2.097	2.090	2.078	341	341
5'6"-5'9"	2.171	2.090	2.687	446	
6'5"-6'10"	2.116	2.090	2,081	253	
7'0"-7'3"	2.063	2.090	1.581	323	
11'7"	1.882	1.965	2.191	650	374
	1.934	1.965	2.283	356	
	1.958	1.965	2.208	373	
	1.974	1.965	2.127	259	
14'7"	1.783	1.935	2.413	264	
	1.955	1.935	2.301	343	
HOLE 4					
2'0"-2'3"	2.043	2.080	2.326	343	314
3'8"-4'0"	2.100	2.080	2.565	369	
4'0"-4'4"	2.100	2.080	2.386	344	
7'4"-7'6"	2.163	2.080	2.429	201	

Sp gr Specific gravity.
[1]All tests were in the vertical direction.

TABLE B-3. - Physical properties of the floor and roof at Apex No. 2 Mine

Location and depth	Direction	Length, in	Diameter, in	Sp gr	Compressive strength, psi	50% of ultimate stress			
						$10^6 \times E$		Poisson's ratio	
						Tan	Sec	Tan	Sec
SITE 1, HOLE 1									
Floor:									
2'-3'4"..	N 50° W..	4.20	2.10	2.509	7,868	3.26	3.61	NAp	NAp
		4.19	2.10	2.423	3,580	2.33	1.47	NAp	NAp
	N 40° E..	4.19	2.10	2.436	8,575	2.49	2.68	NAp	NAp
		4.20	2.10	2.444	4,735	2.45	1.66	NAp	NAp
11'......	Vertical.	3.57	1.77	2.530	14,060	2.61	2.61	0.33	0.22
		3.52	1.77	2.562	11,546	2.44	2.66	.32	.21
		3.32	1.77	2.563	10,749	2.53	2.37	.32	.22
12'......		3.50	1.77	2.503	15,449	2.92	2.38	.48	.22
		3.52	1.77	2.521	16,246	2.92	2.39	.41	.19
		3.52	1.77	2.544	14,142	2.67	2.45	.34	.16
		3.49	1.77	4.489	14,571	2.81	2.25	.32	.17
SITE 1, HOLE 2									
Roof:									
3'1"-4'6"	N 50° W..	4.20	2.10	2.675	14,797	4.86	3.82	NAp	NAp
		4.18	2.10	2.558	9,932	2.80	2.57	NAp	NAp
	N 40° E..	4.20	2.10	2.530	10.033	3.11	3.00	NAp	NAp
4'6"-5'6"	N 50° W..	4.18	2.10	2.491	5,717	2.24	2.81	NAp	NAp
		4.20	2.10	2.586	8,142	3.03	2.94	NAp	NAp
	N 40° E..	4.19	2.10	2.527	8,777	2.81	2.39	NAp	NAp
8'7".....	Vertical.	3.52	1.77	2.559	14,305	2.28	2.32	0.23	0.14
		3.52	1.77	2.581	13,692	2.50	1.93	.27	.15
10'7"....		3.52	1.77	2.466	9,564	1.30	1.39	.21	.13
		3.52	1.77	2.464	9,441	1.27	1.07	.24	.13

Sp gr Specific gravity. E Young's modulus. NAp Not applicable.

TABLE B-4. - Indirect tensile strength tests (Brazilian) of floor and roof specimens at Apex No. 2 Mine[1]

Location and depth	Length, in	Diameter, in	Sp gr	Tensile strength, psi	
				Indirect	Average
SITE 1, HOLE 1					
Floor:					
11'..........................	1.65	1.77	2.599	746	867
	1.80	1.77	2.538	863	
12'..........................	1.79	1.77	2.525	1,030	
	1.68	1.77	2.487	828	
SITE 1, HOLE 2					
Roof: 8'7"...................	1.74	1.77	2.629	1,004	1,156
	1.64	1.77	2.598	1,308	

Sp gr Specific gravity. [1]All tests were in the vertical direction.

TABLE B-5. - Physical properties of the floor and roof at Foidel Creek Mine

Location and depth	Direction	Length, in	Diameter, in	Sp gr	Compressive strength, psi	50% of ultimate stress				25% of ultimate stress			
						$10^6 \times E$		Poisson's ratio		$10^6 \times E$		Poisson's ratio	
						Tan	Sec	Tan	Sec	Tan	Sec	Tan	Sec
SITE 1, HOLE 1													
Floor:													
1'8"-3'...	N........	4.200	2.100	2.390	7,175	3.10	2.49	NAp	NAp	2.65	2.19	NAp	NAp
		4.200	2.100	2.027	2,685	1.70	1.20	NAp	NAp	1.44	.92	NAp	NAp
	E........	4.205	2.100	2.414	2,959	2.77	2.09	NAp	NAp	2.24	1.71	NAp	NAp
5'10"-7'..	N........	4.204	2.100	2.343	8,488	2.93	2.84	NAp	NAp	3.24	2.63	NAp	NAp
		4.202	2.100	2.365	9,383	3.21	3.06	NAp	NAp	3.24	2.96	NAp	NAp
		4.210	2.100	2.277	4,937	1.61	1.13	NAp	NAp	1.36	.90	NAp	NAp
	E........	4.197	2.100	2.310	10,913	2.89	2.47	NAp	NAp	2.92	2.13	NAp	NAp
		4.202	2.100	2.339	8,589	3.14	3.03	NAp	NAp	3.18	2.97	NAp	NAp
14'5".....	Vertical.	3.960	1.965	2.569	14,971	4.28	3.55	0.18	0.10	4.41	3.20	0.13	0.07
SITE 1, HOLE 2													
Roof:													
8'7"-10'1"	N........	4.203	2.100	2.447	6,381	3.20	3.12	NAp	NAp	3.30	3.05	NAp	NAp
8'4"-10'1"		4.210	2.100	2.453	5,514	3.20	2.66	NAp	NAp	3.32	2.40	NAp	NAp
		4.218	2.100	2.382	9,095	3.34	2.94	NAp	NAp	3.15	2.68	NAp	NAp
	E........	4.193	2.100	2.454	5,197	3.49	2.59	NAp	NAp	3.33	2.14	NAp	NAp
		4.210	2.100	2.459	6,713	3.12	3.17	NAp	NAp	2.94	3.17	NAp	NAp
	Vertical.	3.973	1.965	2.345	8,013	3.68	2.11	NAp	0.48	2.60	1.57	NAp	0.33
		3.975	1.965	2.374	11,722	2.96	2.55	NAp	.17	3.53	2.02	NAp	.35
12'9".....		3.971	1.965	2.343	12,349	3.28	2.03	NAp	.14	2.44	1.56	0.22	.05

					SITE 2, HOLE 3										
Floor:															
2'11"-4'..	E........	4.170	2.100	2.390	11,722	4.63	4.88	NAp	NAp	4.70	5.17	NAp	NAp
9'4"-10'6"	N........	4.187	2.100	2.500	5,024	3.35	2.77	NAp	NAp	3.00	2.44	NAp	NAp
		4.181	2.100	2.484	5,486	3.25	2.84	NAp	NAp	3.28	2.89	NAp	NAp
		4.193	2.100	2.494	5,514	4.01	3.38	NAp	NAp	3.96	2.93	NAp	NAp
	E........	4.200	2.100	2.426	6,698	3.78	3.68	NAp	NAp	4.32	3.38	NAp	NAp
		4.193	2.100	2.440	6,453	3.76	2.24	NAp	NAp	2.78	1.70	NAp	NAp
12'1".....	Vertical.	3.974	1.965	2.520	17,279	5.75	3.97	NAp	0.26	4.53	3.20	0.30	0.18
		3.968	1.965	2.515	17,444	5.91	3.45	NAp	.26	4.61	2.55	.41	.17
		3.972	1.965	2.460	15,037	5.13	3.03	NAp	.24	4.84	2.28	.30	.14
14'3".....		3.972	1.965	2.549	12,629	3.52	3.01	0.47	.30	3.19	2.69	.30	.27
		3.970	1.965	2.493	8,508	2.45	2.33	.46	.35	3.41	2.97	.39	.26
					SITE 2, HOLE 4										
Roof:															
7'10"-9'2"	N........	4.190	2.100	2.459	14,263	5.88	4.24	NAp	NAp	5.11	3.46	NAp	NAp
		4.207	2.100	2.469	14,522	6.00	5.40	NAp	NAp	5.00	5.35	NAp	NAp
		4.205	2.100	2.391	16,746	6.09	4.39	NAp	NAp	5.04	3.55	NAp	NAp
	E........	4.210	2.100	2.404	12,934	5.53	3.30	NAp	NAp	4.45	2.43	NAp	NAp
		4.204	2.100	2.442	15,591	6.50	5.01	NAp	NAp	5.55	4.33	NAp	NAp
9'8"-10'7"	N........	4.235	2.100	2.383	10,336	4.05	2.44	NAp	NAp	3.07	1.85	NAp	NAp
		4.223	2.100	2.422	7,362	2.69	2.09	NAp	NAp	2.58	1.70	NAp	NAp
	E........	4.188	2.100	2.511	4,591	3.06	2.53	NAp	NAp	2.72	2.15	NAp	NAp
14'11"....	Vertical.	3.983	1.965	2.426	11,541	2.92	2.71	NAp	0.38	2.66	2.62	0.39	0.31
		3.970	1.965	2.439	10,123	4.02	2.98	NAp	.50	3.34	2.43	NAp	.43
		3.972	1.965	2.453	9,563	2.80	2.25	NAp	.32	2.54	1.95	.43	.22
16'.......		3.967	1.965	2.385	13,421	4.49	3.36	NAp	.25	3.57	2.81	.44	.17
		3.975	1.965	2.390	11,739	3.14	2.39	NAp	.39	2.67	2.00	NAp	.3C

Sp gr Specific gravity. E Young's modulus. NAp Not applicable.

TABLE B-6. - Indirect tensile strength tests (Brazilian) of floor and roof specimens at Foidel Creek Mine[1]

Location and depth	Length, in	Diameter, in	Sp gr	Tensile strength, psi	
				Indirect	Average
SITE 2, HOLE 2					
Roof: 12'9"....................	1.926	1.965	2.366	488	541
	1.993	1.965	2.353	593	
SITE 2, HOLE 3					
Floor:					
12'1".........................	1.902	1.965	2.425	681	684
	2.006	1.965	2.462	686	
14'3".........................	1.934	1.965	2.479	737	
	1.972	1.965	2.491	633	
SITE 1, HOLE 4					
Roof:					
14'11"........................	1.928	1.965	2.446	471	533
	1.962	1.965	2.424	462	
16'...........................	1.955	1.965	2.391	621	
	1.941	1.965	2.400	576	

Sp gr Specific gravity.
[1]All tests were in the vertical direction.

TABLE B-7. - Physical properties of the floor and roof at Rienau No. 2 Mine

Location and depth	Direction	Length, in	Diameter, in	Sp gr	Compressive strength, psi	50% of ultimate stress			
						$10^6 \times E$		Poisson's ratio	
						Tan	Sec	Tan	Sec
SITE 1, HOLE 1									
Floor:									
5'-6'.....	N 88° E..	4.210	2.110	2.770	11,039	4.23	3.40	NAp	NAp
	N 2° W...	3.980	2.110	3.191	10,210	6.78	5.22	NAp	NAp
		4.184	2.110	2.933	7,865	3.82	1.72	ND	ND
17'2".....	Vertical.	3.907	1.980	2.580	15,557	2.83	2.50	0.35	0.13
		3.895	1.980	2.597	13,705	3.24	2.71	ND	ND
		3.959	1.980	2.560	14,355	4.23	3.78	.49	.25
18'1".....		3.938	1.980	2.299	8,379	1.25	1.01	.20	.10
SITE 1, HOLE 2									
Roof:									
8'-9'.....	N 88° E	4.212	2.110	2.457	12,240	2.74	2.65	NAp	NAp
		4.185	2.110	2.827	4,976	1.98	1.92	NAp	NAp
14'6".....	Vertical.	3.904	1.980	2.702	23,189	5.92	4.87	0.22	0.18
		3.948	1.980	2.606	11,335	1.83	1.52	ND	ND
SITE 2, HOLE 3									
Floor: 21'..	Vertical.	3.955	1.980	2.362	11,042	1.53	1.53	0.19	0.13

E Young's modulus. ND Not determined.
NAp Not applicable. Sp gr Specific gravity.

TABLE B-8. - Indirect tensile strength tests (Brazilian) of floor specimens at Rienau No. 2 Mine

(Site 1, hole 1. Depth: 17'2". Direction: vertical)

Length, in	Diameter, in	Sp gr	Indirect tensile strength,[1] psi
2.002	1.980	2.525	1,626
1.820	1.980	2.585	1,210

Sp gr Specific gravity.
[1]Average tensile strength, 1.418.

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