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VALLEY CAMP OF UTAH, INC. February, 1993

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APPENDIX 523

Ground Control Study
Kenneth C. Ko & Assoc.
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Technical Report

SUBSIDENCE POTENTIAL OVER TWO-SEAM DEVELOPMENTS

BOARDINGHOUSE CREEK AREA
BELINA MINES

March 1991

Valley Camp of Utah, Inc.
Helper, Utah

PROJECT NO. 2118
KENNETH C. KO & ASSOCIATES, INC.

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March 31, 1991

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President
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Scofield Route
Helper, Utah 84526

SUBSIDENCE POTENTIAL OF BOARDINGHOUSE CREEK AREA
OVER TWO-SEAM DEVELOPMENTS - BELINA MINES

Dear Mr. Wright:

This Report presents the results of our preliminary rock mechanics study regarding the subsidence potential of the Boardinghouse creek area due to the development of entries and room-and-pillar panels in the Belina Mines.

Empirical theories of subsidence do not provide the basis for estimating surface subsidence due to the development of a two seam mine system beneath a relatively shallow overburden of 200 to 300 feet, such as in the case of the Boardinghouse Creek area for the proposed design layout. Past experience with room-and-pillar mining in the Western U.S. indicates that a "plug" type subsidence may occur under certain geologic conditions, particularly for overburden depths of less than 150 feet. Such a condition is triggered by local roof instability, and its upward extent appears to be governed by the height of the opening into which debris can fall. With bulking of the loosened debris, it seems conservative to assume that the height of the plug should not exceed 10 times the height of the opening. Since full seam recovery in the Belina Mines would result in openings on the order of 20 feet in height, maximum chimney height would not exceed 200 feet. It is recommended, therefore, that until a rock mechanics investigation that more directly addresses the issue of plug-type subsidence can be undertaken, full seam recovery should not be employed in the creek areas where the depth of overburden is less than 200 feet.

A more global form of subsidence occurs when failure zones in the overburden are developed connecting the mine opening to the ground surface. These are usually triggered at rib or pillar abutments adjacent to extensive mined-out panels, and extend to the surface along planes sloping at approximately 20 to 35 degrees from the vertical. The investigation of this type of subsidence requires a relatively detailed structural analysis of the rockmass between the mine and the ground surface. Two dimensional finite element calculations were performed to analyze this type of subsidence potential for the given geologic and geometric parameters. Lower limits of the overburden rock quality were assigned to the finite element models to investigate the "worst case scenario" with respect to the subsidence potential of the creek crossing area.

Based on the results of these analyses, we conclude that there is no subsidence potential due to global overburden failure resulting from the full-seam recovery of the two-seam mine system as proposed. We recommend, however, that unless further study can show adequate protection against plug-type subsidence, bottom coal recovery should not be planned in either seam within the Boardinghouse Creek crossing area where the overburden is less than 200 feet.

Respectfully submitted,

KENNETH C. KO & ASSOCIATES, INC.

Kenneth C. Ko, President	David Van Dillen, Associate
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INTRODUCTION AND SUMMARY

The coal reserve located to the southwest of the Second Right and Third Right panels in the First East Mains is planned to be developed by Valley Camp of Utah. This reserve area, in a triangular form, is bounded by a dike to the north, a regional fault known as the O'Connor Fault to the east and a set of local faults to the west (shaded area in Figure 1). The area will be accessed through tunnels to be driven through the dike from the Third Right entries. Figure 2 is an enlarged map of the area to be developed. Within this triangular block, the overburden depth varies from less than 200 feet to about 600 feet above the top of the upper coal seam. Both the mineable seams, Upper O'Connor and Lower O'Connor, will be mined. According to the drillhole log of DH-73-31-2, the two seams are separated by about 38 feet of interburden. The interburden consists of sandstone and sandy siltstone units.

The mid-section of the development will be beneath a perennial stream, Boardinghouse Creek. Figure 3 shows a layout of the underground workings beneath this creek. The purpose of the present study is to resolve the issue of subsidence potential in this area due to the recovery of coal by a two-seam mining system.

Conventional theories of subsidence based on empirical formulas are not applicable to an underground configuration where the depth of overburden is greater than 1.4 times the room width, for a non-yielding pillar system. For a long-term, progressive deterioration of roof rocks, using a bulking factor of 1.2, about five times the room height may be assumed to eventually cave in. Additionally, an equal height of the roof over the caved area may eventually be disturbed during this long-term process. Thus it would appear conservative to estimate that long term deterioration

will not progress all the way to the ground surface if there is at least 100 feet of cover in the case of top coal mining only, or at least 200 feet in the case of full seam mining. These criteria are based on empirical formulas, and could be relaxed if a rock mechanics investigation specifically addressing the issue of long term subsidence were to prove favorable.

The immediate subsidence potential of the Boardinghouse Creek area, due to overstressing of the overburden, was analyzed using two-dimensional finite element models of the vertical section transverse to the creek (Section A-A in Figure 3). The basic finite element model for these analyses is shown in Figure 4. The section was taken at a location in which there is a depth of 200 feet of overburden from the creek bed to the top of the upper seam. The model extends 600 feet to either side of the creek, and 300 feet below the bottom of the lower seam. Subsidence is taken to be indicated by a zone of yielded rock extending all the way from the mine to the ground surface.

A two-dimensional cross section of the main entry configuration provides a good approximation to the loading in the roof, floor, and barrier pillars, since these structures have very little variation in the out-of-plane direction. The pillars in the room and pillar panels are three-dimensional structures, but the load/deflection properties of these pillars for both top coal and full seam mining has been determined through auxiliary three-dimensional analyses in an earlier report (KCKA, 1989). These load/deflection properties have been incorporated into equivalent homogeneous materials suitable for use in a two-dimensional model. These equivalent properties are represented in three layers of elements, corresponding to Materials 1, 2, and 3, occupying the same position. Material 1 represents the pillars left in place after full seam mining. Material 2 represents the supplementary

stiffness between Material 1 and a pillar resulting from top coal mining alone. Materials 1 and 2 add up to the stiffness of a pillar in a single level room and pillar system. Material 3 is the supplement to intact coal, so that Materials 1, 2, and 3 together represent the layer before any mining takes place. The deactivation of selected elements enables the observation of stress changes resulting from the progressive development of the entire mining system.

The results of these analyses of the proposed development plan indicate no possibility of immediate surface subsidence due to overstressing of the overburden, even when the full height of both seams are recovered. There were no zones of yielded rock indicated in any of the models, even when the rockmass quality of the overburden was assumed to be lower than is actually believed. Based on these results, we conclude that there is no theoretical possibility of subsidence resulting from the two seam mining within the reserve block as planned.

ANALYSES OF SUBSIDENCE POTENTIAL

Four two-dimensional cases have been run to investigate the possibility of subsidence during the development of both seams. The formulation of these two-dimensional models is described in Appendix A. In that maximum disturbance to the overburden occurs at the active face of excavation, due to the maximum discontinuity of support, each case observes conditions when the face of each level of each seam is located directly below Boardinghouse Creek.

Case 1 models top coal mining only in both the upper and lower seams, and consists of 5 load steps. Step 1 consists of intact coal prior to any excavation. Step 2 consists of top coal mining in the upper seam to a point below Boardinghouse Creek, with intact coal occupying the

remainder of the seam. Step 3 corresponds to the completion of top coal mining in the upper seam. Step 4 models top coal mining of the lower seam to a position below Boardinghouse Creek with top coal mining of the upper seam completely developed, and Step 5 models full top coal development in both seams.

Case 2 models full seam development of both the upper and lower seams, and takes place in 9 load steps. One step models intact coal, the next two model top coal development of the upper seam, Steps 4 and 5 model full seam development of the upper seam, and Steps 6 through 9 model the same configurations for the lower seam that Steps 2 through 5 model for the upper seam. Cases 3 and 4 are a repeat of Cases 1 and 2 with the overburden material given a rockmass quality index of "FAIR" (Hoek and Brown, 1980). This constitutes a worst case assessment of the actual conditions to be expected.

The loading of the panel cross section is provided by the weight of the overlying rock, which increases in thickness from the creek bed to either side. The idealized overburden profile employed in the 2-D models is shown in Figure 4. The horizontal component of in-situ stress is thought to be approximately equal to the Poisson's component due to gravity alone. This allows the side boundaries be rollered to provide confinement under all circumstances.

As mentioned in the previous section, no significant yielding was observed in any of the cases for any of the load steps, even the very conservative cases. These findings are illustrated in the remaining figures, all of which are taken from Case 4, corresponding to double lift mining of both seams with overburden of FAIR quality. This is the most severe of all the cases considered. A more complete presentation of results from all of the cases is provided in Appendicies B through E.

Figure 5 shows the distribution in effective stress in the upper seam as a result of top coal mining in the left half of the upper seam. The term "effective stress" is used to denote the pillar load divided by the effective area supported by that pillar (room centerline to room centerline). In the case of the unmined coal in the right half of the seam, effective stress corresponds to the actual stress, since the rooms have not yet been mined. There is a discontinuity in effective stress at the location of the active face. This reflects the fact that the development on the left side of the creek has lowered the stiffness of the support on this side. There is some deflection of the overlying strata in response to this reduction in stiffness of the coal seam, but the stiffness of the overburden prevents it from bearing its full weight on those pillars closest to the active face. The coal on the unmined side of the active face is burdened with the weight of the overburden not carried by the adjacent pillars, resulting in a stress abutment at the face. Away from the face, the stress in both the developed portion and the unmined portion of the seam quickly approach in-situ conditions. It is this discontinuity in support that provides the most likely environment for yielding in the overburden; however, none was observed.

Figure 6 shows a similar plot of effective stress in the upper seam at a time when both top and bottom coal have been mined in the left half of the seam while only top coal has been mined in the right half. Again a discontinuity is induced at the active face, but this discontinuity is smaller than in the case of Figure 5. Again no yielding was observed in the overburden.

Figure 7 shows the profile of effective stress after complete full seam development of the upper seam. With no discontinuity in support stiffness, this plot shows that

there is no discontinuity in effective stress. There is again no yielding in the overburden.

Figure 8 shows a profile of yield factor in the overburden immediately above the upper seam during the load step corresponding to the stress profile of Figure 6. Yield factor is defined as the ratio of maximum shear stress in the material to maximum allowable shear stress at the existing level of mean stress. When the yield factor attains a value of 1, the rock is yielding at that location, and a path of yielded rock connecting the mine with the ground surface is taken to be the criterion for subsidence.

The shape of the profile of yield factor shown in this figure is a result of the variation in depth of overburden and method of loading of the rockmass. Loaded by self weight with rollered boundaries, the rockmass develops a greater vertical stress than horizontal stress, and this difference increases as the depth of cover increases. The actual maximum shear stress is proportional to this difference in vertical and horizontal stress, while the shear capacity for this very low quality rockmass does not increase very much with increasing pressure. This explains why the yield factor in Figure 8 is greater toward the edges of the model, where the depth of overburden is greater. It should also be observed in this figure that the discontinuity in support shown in Figure 6 contributes a nearly imperceptible discontinuity in yield factor.

It is also noteworthy that the yield factor is approaching a value of 1 near the right edge of the model. At this location the depth of overburden is less than 500 feet, and yet the rock is almost yielding. Depths of overburden greater than this exist in other portions of the mine, and this would imply that in these locations, if the rock is really as weak as has been assumed, that the rock would be yielding in-situ. If this were to be the case,

uncontrollable, time-dependent roof sag and floor heave would be taking place in the mine openings at these locations. Since such behavior has not been observed, it is safe to conclude that the overburden is not as weak as has been assumed in this model.

CONCLUSIONS AND RECOMMENDATIONS

There are two main conclusions to be drawn from this set of finite element calculations, all supporting the "Bottom Line" conclusion that there will be no subsidence resulting from the proposed development of the two seam mining system beneath Boardinghouse Creek.

1. The first conclusion is that in all of the analyses performed, no evidence of subsidence, in the form of a continuous path of yielded rock connecting the mine to the ground surface, was observed as a result of developing a two seam mining system beneath Boardinghouse Creek.

3. The second conclusion is that even when the strength of the overburden material was reduced to an unreasonably low level, there was still no evidence of subsidence.

Based on these findings, we conclude that there is no danger of subsidence resulting from the development of the two-seam mining system as proposed. Even when conditions were exaggerated to favor subsidence, no indication of subsidence was observed.

Past experience with room-and-pillar mining in the Western U.S. indicates that a "plug" type subsidence may occur under certain geologic conditions, particularly for overburden depths of less than 150 feet. This criterion is based on empirical formulas, and could be relaxed if a rock mechanics investigation specifically addressing the issue of long term subsidence were to prove favorable. It is recommended, therefore, that until a rock mechanics investigation that

more directly addresses the issue of plug-type subsidence can be undertaken, full seam recovery should not be employed in the creek areas where the depth of overburden is less than 200 feet.

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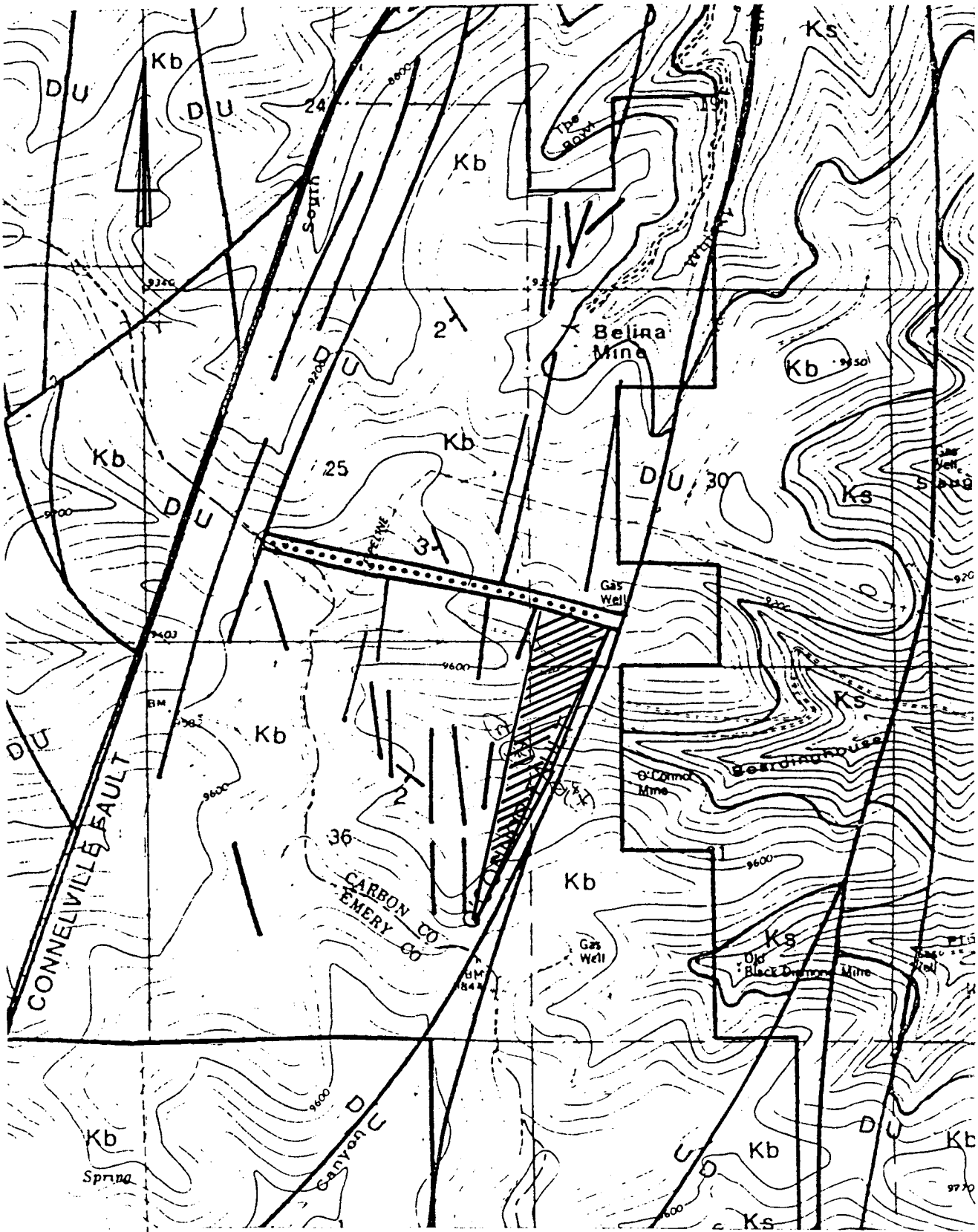

Figure 1. Location of reserves in relation to major geologic structures

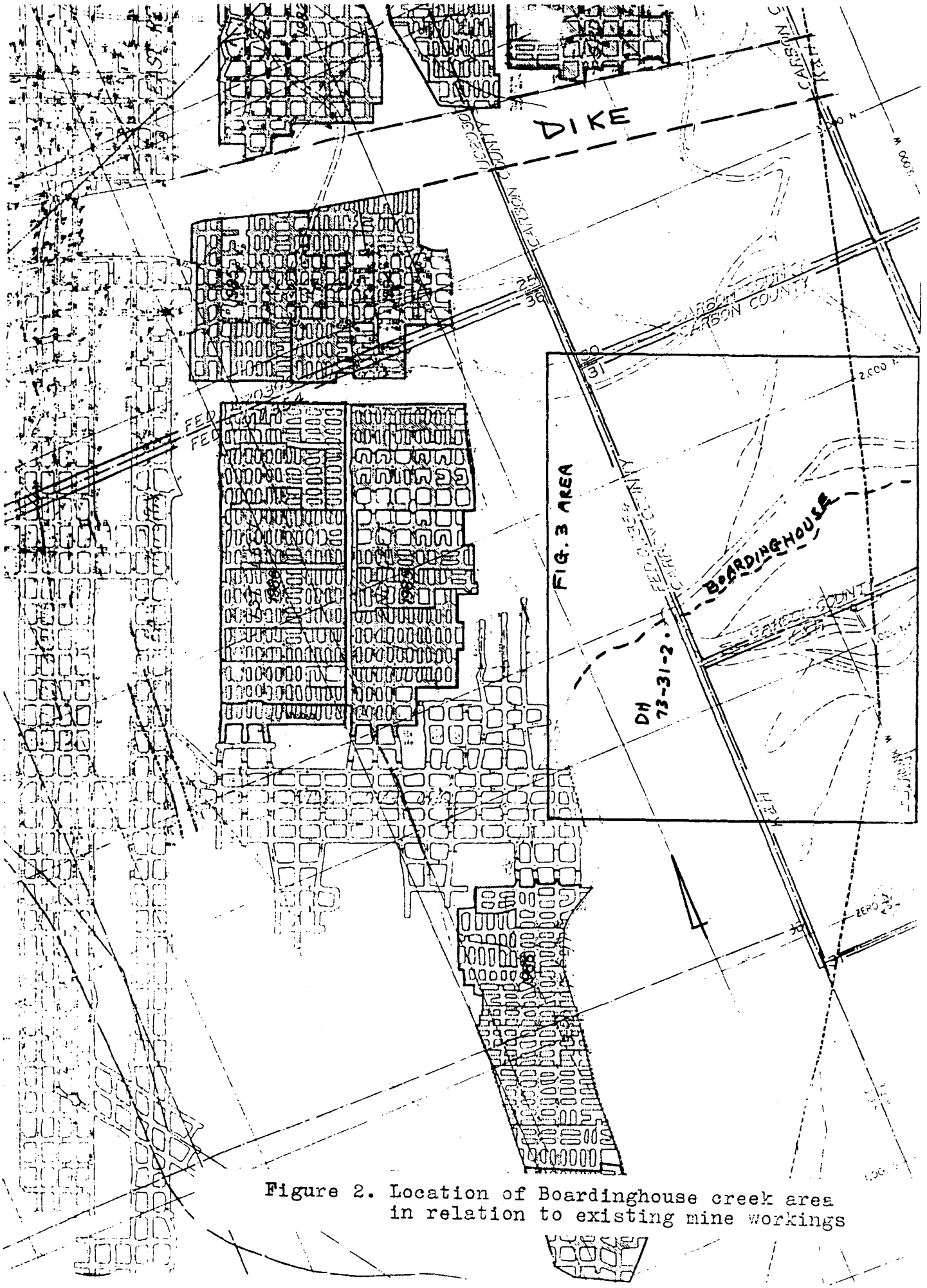

Figure 2. Location of Boardinghouse creek area in relation to existing mine workings

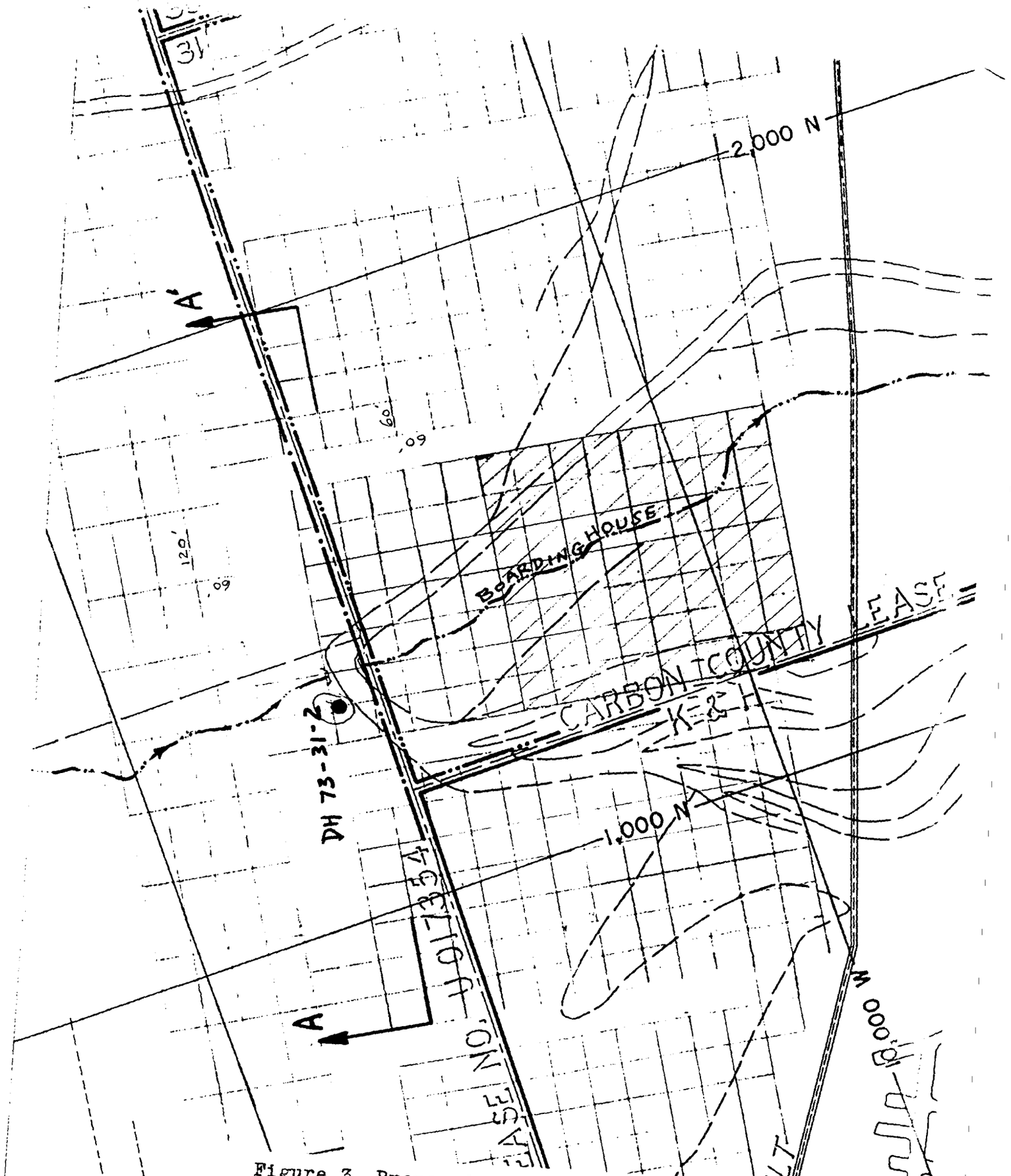

Figure 3. Proposed mine layout in vicinity of Boardinghouse creek crossing with study section

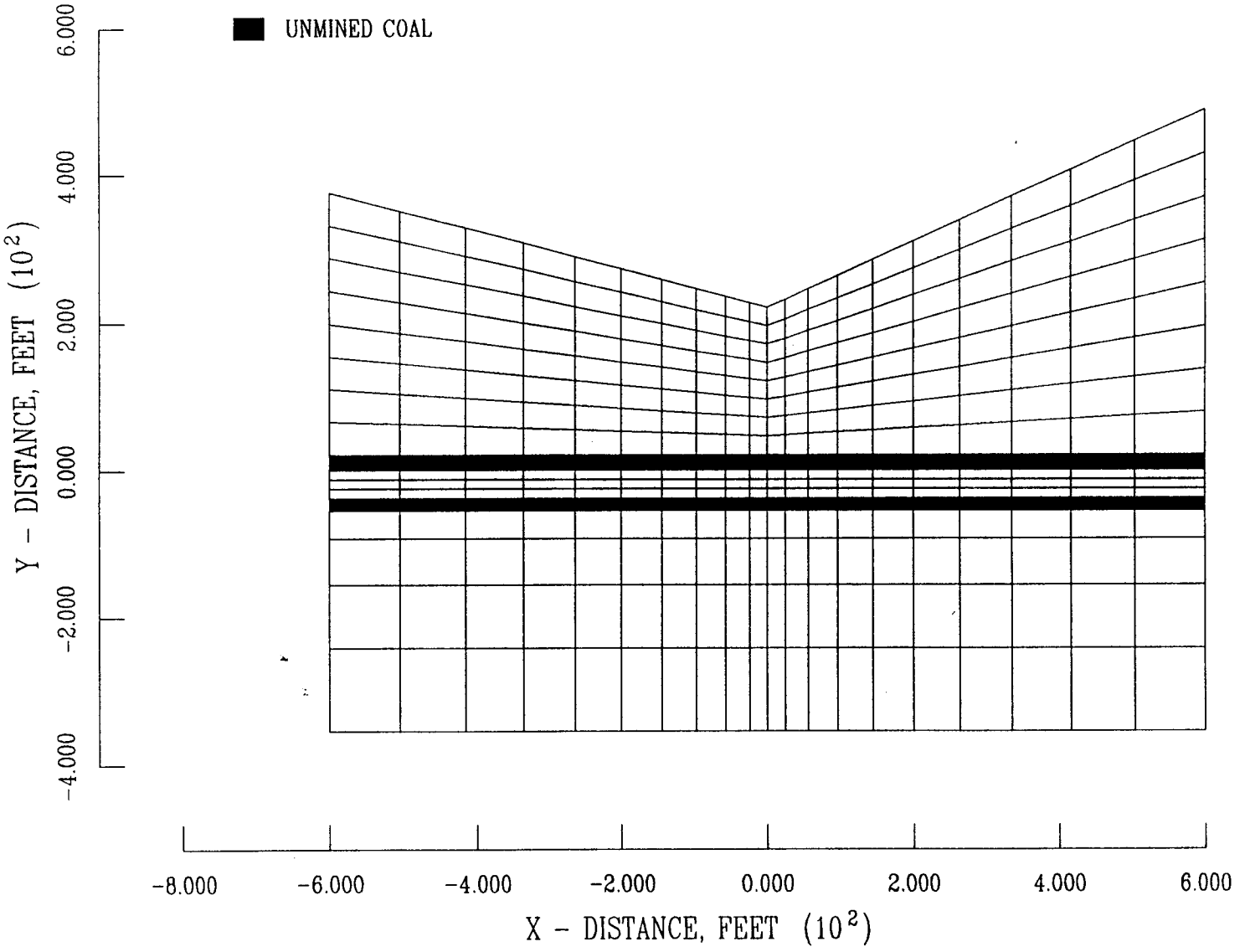

Figure 4. Two-dimensional finite element model of a longitudinal section of the Belina mine showing the element zoning, the two coal seams of interest, and a representative surface contour through Boardinghouse Creek

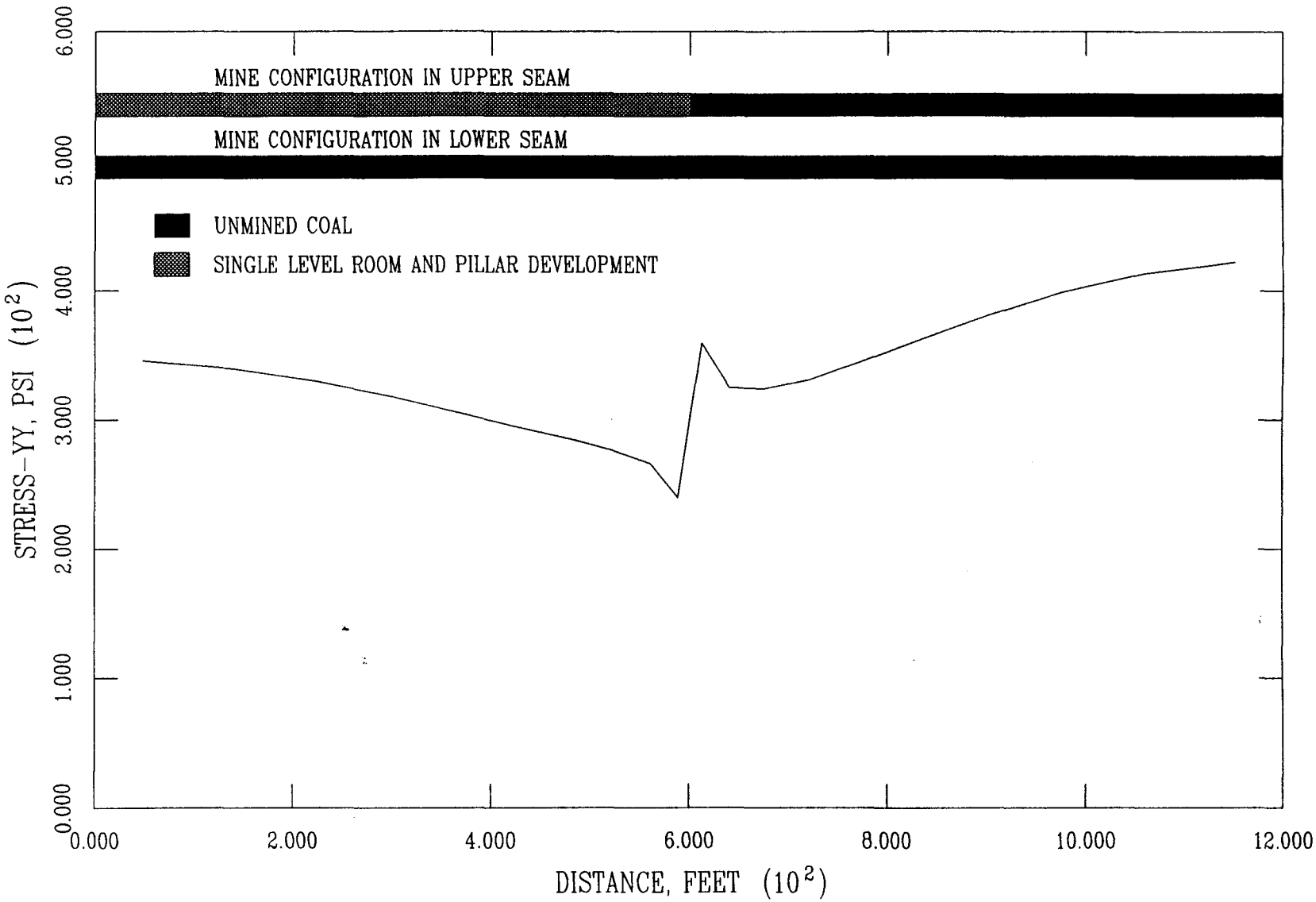

Figure 5. Profile of vertical equivalent stress in the upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

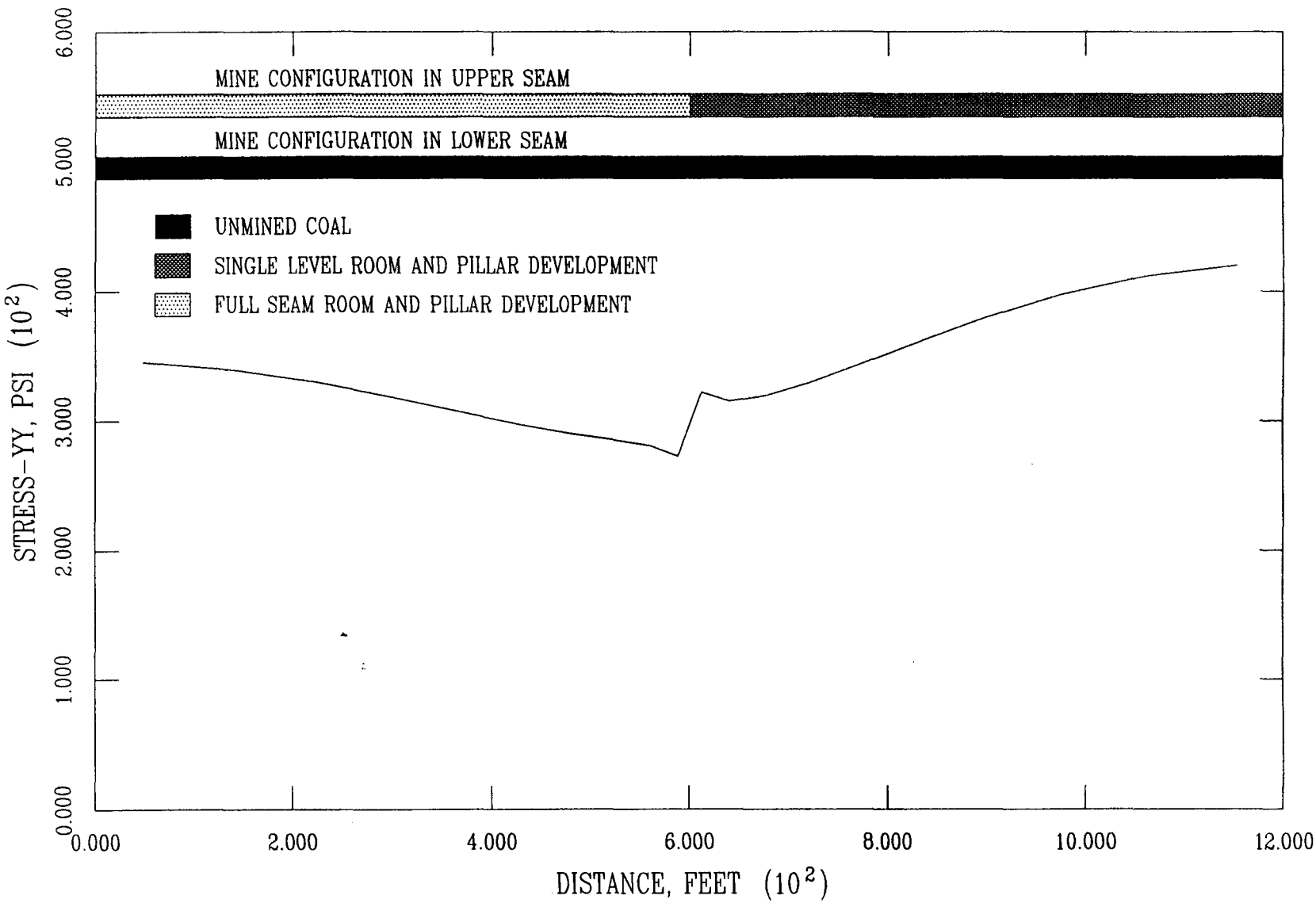

Figure 6. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in the upper seam, and development of the bottom coal in the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

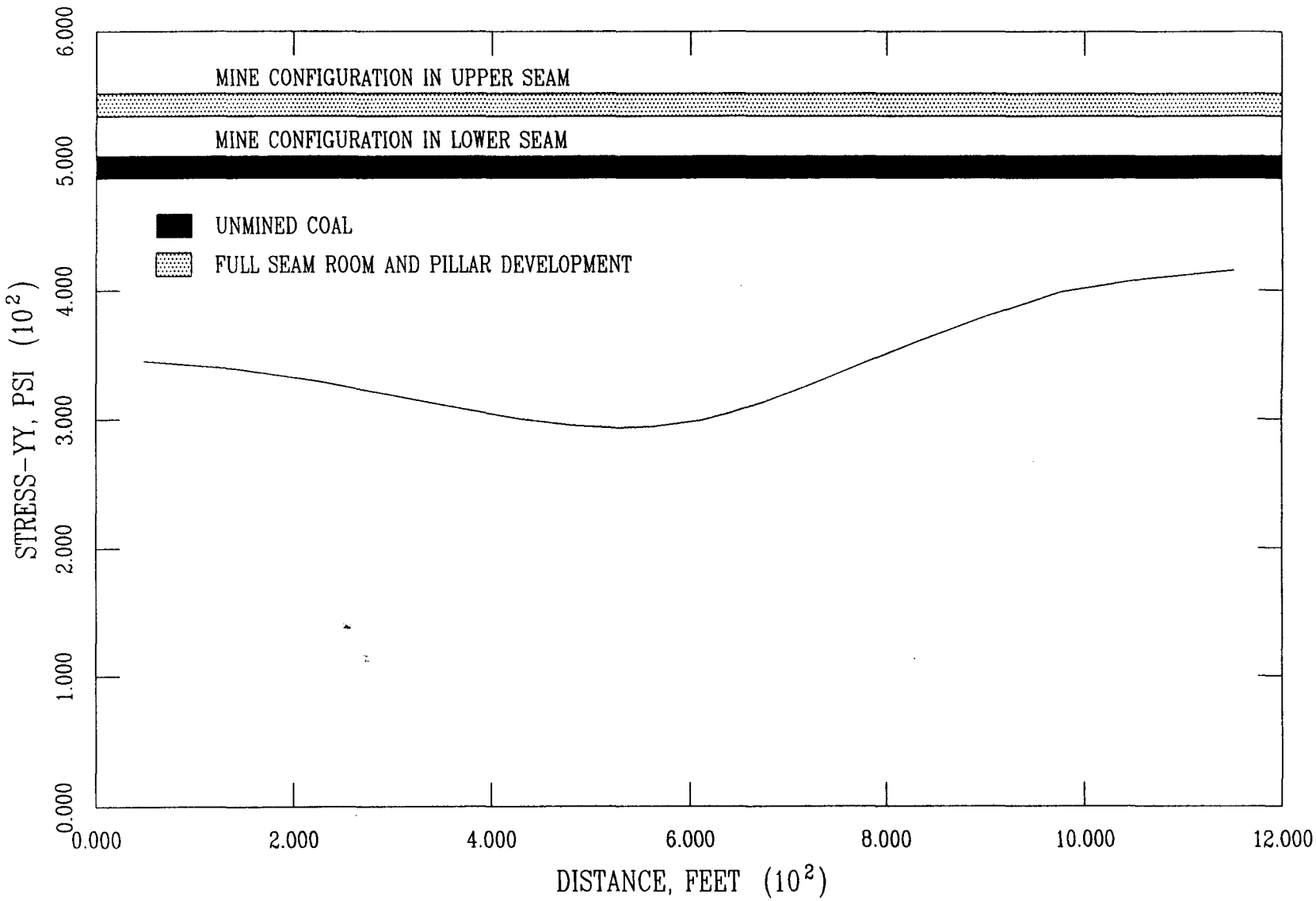

Figure 7. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam. Overburden Quality = "FAIR".

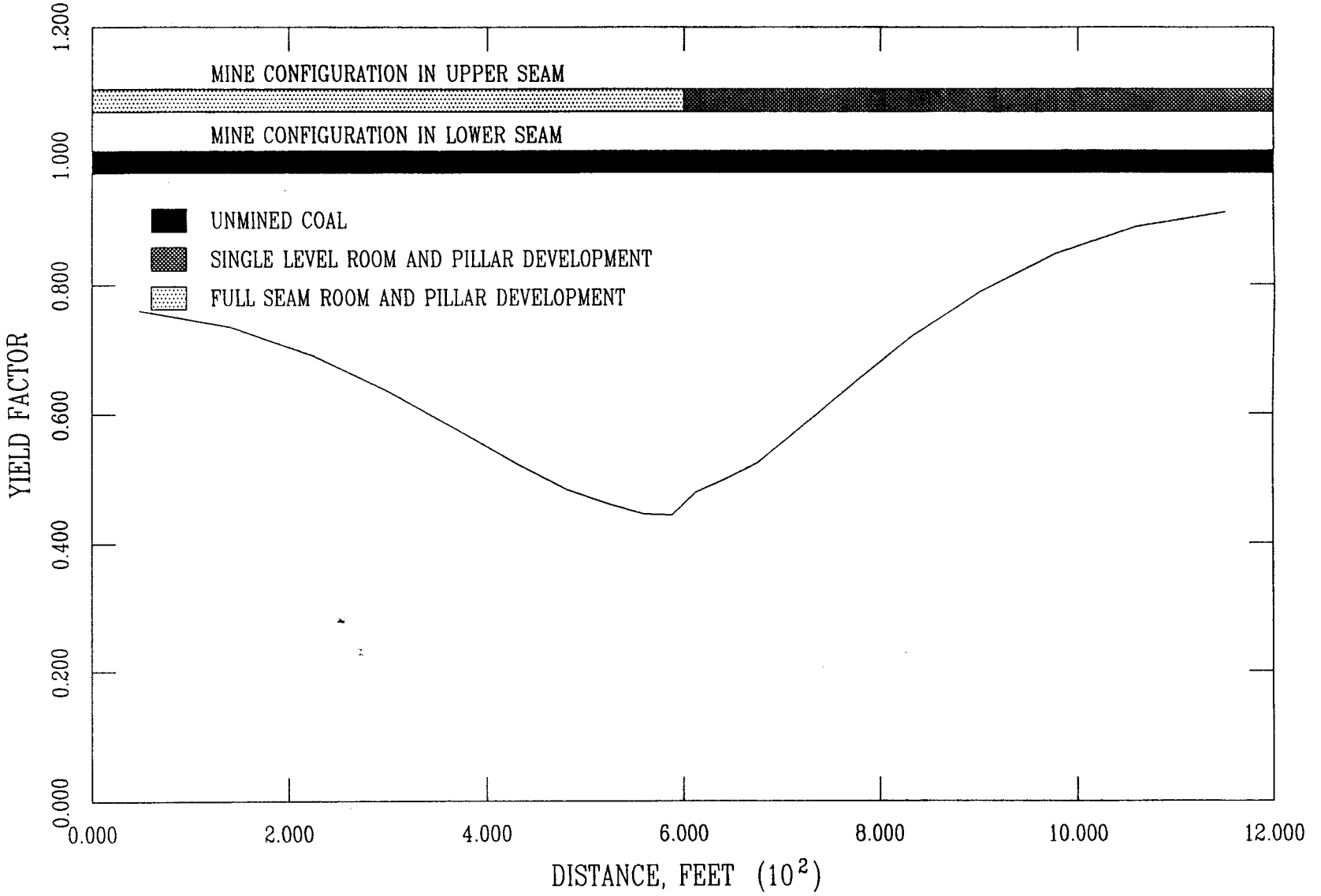

Figure 8. Profile of yield factor in the overburden immediately above the upper seam after complete development of the top coal in the upper seam, and development of the bottom coal in the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

APPENDIX A

FINITE ELEMENT MODELING

The basic finite element model used in all of the analyses is that shown in Figure 4, which models the cross section of Boardinghouse Creek shown as Section A-A in Figure 3. The proposed room and pillar grid is shown in Figure 3, from which it can be seen that Section A-A cuts across the panels normal to their axes. It can also be seen that the proposed separation between panels is about the same as the separation between rooms within a room and pillar panel, making it possible to represent the entire region as if it were one uniform room and pillar system.

There are 3 possible stages of panel development:

1. Unmined
2. Top Coal Recovery, in which the room and pillar panel has been developed in the top 10 feet of the seam only
3. Full Seam Recovery, in which the Double Lift mining technique has been used to claim the bottom coal

Within a given panel, the direction of room and pillar development is normal to Section AA, but the direction of panel development is along the section. To cover all possible configurations of developed and undeveloped regions, a worst case is considered in which all of the coal in a given seam on one side of Boardinghouse Creek is developed to a given stage, while all the coal on the other side is at the next lower stage of development. It is presumed that in the vicinity of Boardinghouse Creek, no panel will be developed to Stage 3 before the adjacent panels have been developed to at least Stage 2, and that no development of the lower seam will take place before

development of the upper seam in that area has been completed. Under these assumptions, the analyses performed herein set up the most severe conditions of discontinuity in support of the overburden at the point where the overburden is at its thinnest.

DESCRIPTION OF THE BMINES FINITE ELEMENT CODE

The BMINES computer program provides for the static, two- or three-dimensional, linear or nonlinear analysis of structural and geologic systems. The code was specifically designed for application to mining problems involving the simulation of excavation and construction sequences. This program was originally developed for the US Bureau of Mines by Agbabian Associates (Van Dillen et al., 1981) and was recently modified, without government sponsorship, to run on the IBM PC.

The capabilities of the BMINES code that are of particular interest for the investigation considered herein include primarily its ability to handle very large models. This is made possible by a non-core-resident equation solver that utilizes disk storage to accommodate stiffness matrices far too large to be contained in random access memory. The code also has the ability to model the excavation sequence through the activation and de-activation of elements. This allows one to observe the full stress history associated with a particular mine configuration. The mesh generator is invaluable in assembling large models in a reasonable length of time and with a minimum of error. The material library contains both linear and nonlinear material models, with a variety of plasticity laws and an ability to represent anisotropic, viscoelastic, and viscoplastic materials.

The load options include externally applied tractions and gravity self weight. Options available for other applications include joint or fault interface elements in

both two and three dimensions and a rockbolt element capable of modeling bolt rupture, bond failure, and dowel shearing across a joint interface. The program is limited to small deformation analyses.

MATERIAL MODELS

The finite element model of Figure 4 consists of only 2 material units, coal and overburden. The coal layers must be modeled in such a way that intact coal, top coal room and pillar development, and full seam recovery can all be represented. Three sets of material properties were used to represent these various stages of mine development in the coal layers. The remaining rock consists primarily of sandstone and shale in about 50-50 proportions. This host rock was modeled as a uniform equivalent material have properties that represent a compromise between sandstone and shale. The resulting hybrid material is called "overburden" for the purposes of these analyses.

The technique for modeling the coal layers in their varying stages of development has been developed in an earlier study of the Belina Mine (KCKA, 1989). This earlier study was performed in support of the Double Lift mining method, and consisted of a regional stress analysis of pillar loads and strains during Stage 2 and Stage 3 development. To perform this analysis efficiently, homogeneous materials were developed that duplicate the mechanical response of pillars in both Stage 2 and Stage 3 configurations. The mechanical properties of these pillars were determined by two separate three-dimensional analyses of single pillars in a region where the seam thickness is 22 feet. In one analysis the pillar occupies only the region between 10 and 20 feet above the base of the seam, corresponding to top coal recovery. In the other, the pillar extends from the base of the seam to a height of 20 feet, simulating full seam recovery.

These two models were compressed by prescribed deformations, from which stress/strain characteristics for each type of pillar could be developed. The seam thicknesses in the present analysis are 21 feet for the upper seam and 17 feet for the lower seam. However, because of the time requirements necessary to perform these 3-D pillar calculations, and because pillars of lesser height are stronger than pillars of greater height, it was judged to be consistent with the objectives of "worst case analysis" to incorporate the results of these earlier analyses into the material models of the present analyses.

The stress/strain properties of the full seam pillars were incorporated into Material 1, while Material 2 represents the difference in strength between the top coal pillars and the full seam pillars. Material 3 represents the difference in strength between intact coal and the top coal pillars. Three individual elements, with material sets 1, 2, and 3, respectively, all occupying the same coordinates in the model, are used to model the intact coal. Note that the three material strengths identified above add up to the properties of intact coal. When stages of the analysis corresponding to top coal development are encountered, the element corresponding to Material 3 is de-activated. This leaves Materials 1 and 2 active at the location, which add up to the strength of top coal pillars. At a later time, when full seam recovery is to be modeled at the location, the element corresponding to Material 2 is de-activated, leaving only Material 1, which represents the strength of the full seam pillar.

The overburden hybrid material contains stiffness and strength parameters that represent an average between sandstone and shale used in the earlier analyses at the Belina Mines (KCKA, 1989). The rockmass reduction factors of Hoek and Brown (1980) corresponding to "GOOD" rockmass quality were incorporated into two of the analyses

(Appendices B and C), representing our judgment of the actual condition of the overburden. Two additional analyses (Appendicies D and E) were performed in which the rockmass reduction factors corresponding to "FAIR" quality were utilized in the overburden.

APPENDIX B

ANALYSIS OF SINGLE LEVEL MINING IN BOTH SEAMS WITH OVERBURDEN QUALITY = "GOOD"

The figures contained in this appendix show profiles of stress in both the upper and lower seam at various stages of development for top coal development only. Overburden quality is assumed to be "GOOD" for these results. Diagrams at the top of each figure schematically indicate the configuration of mine development to which the results apply. Also shown are profiles of yield factor in the overburden immediately above the upper coal seam. Yield factor is defined as the ratio of maximum shear stress at a location to the existing shear strength at that location. Consequently, a yield factor of 1 would indicate that the rock is yielding, and a yield factor of less than 1 indicates that the rock has not yet been loaded to its full capacity. A yield factor in excess of 1 is not possible in an ideally plastic model in that plastic flow would modify the stress state back to a yield factor of 1.

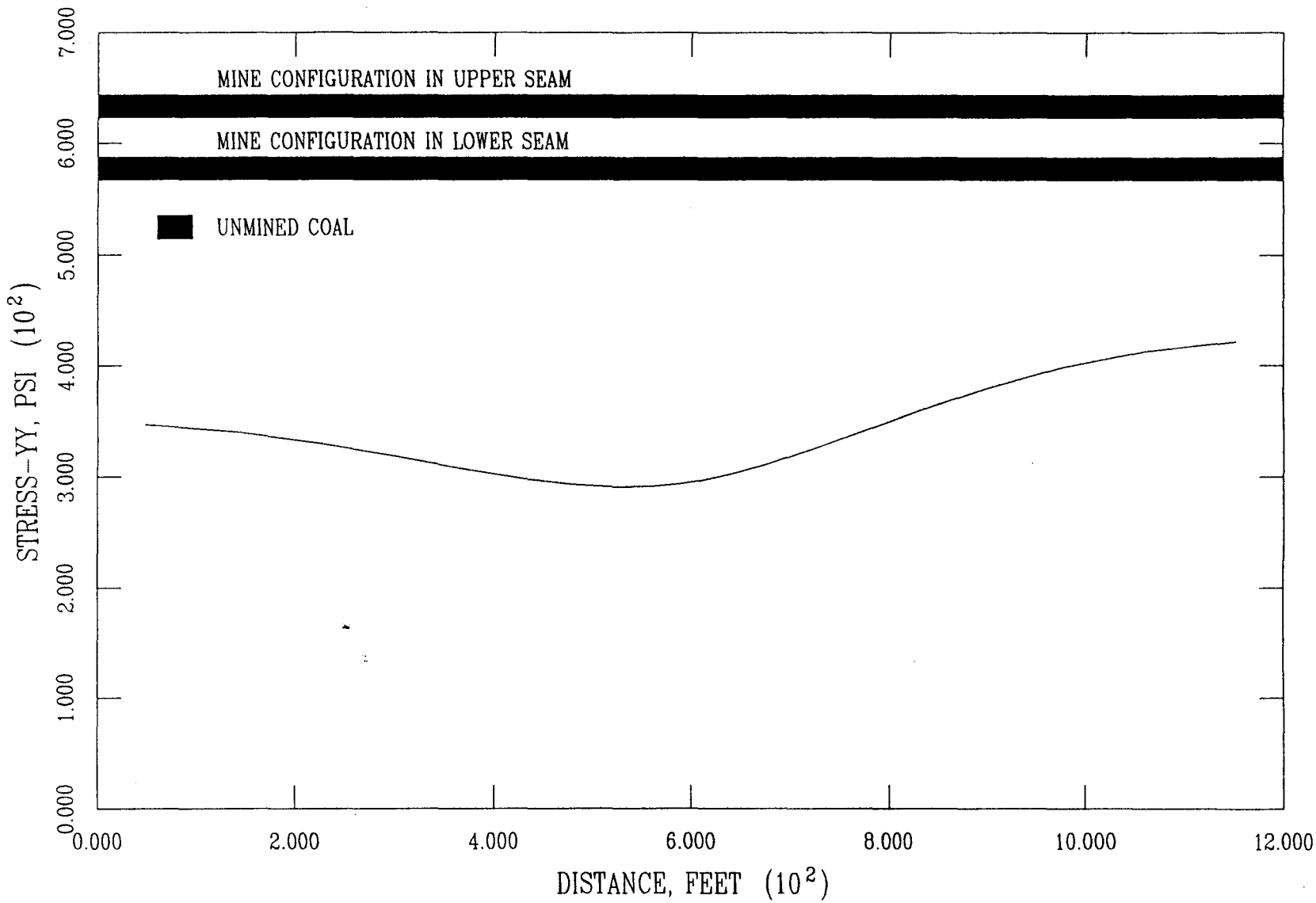

Figure B-1. Profile of vertical equivalent stress in the upper seam prior to any mining activity. Overburden Quality = "GOOD".

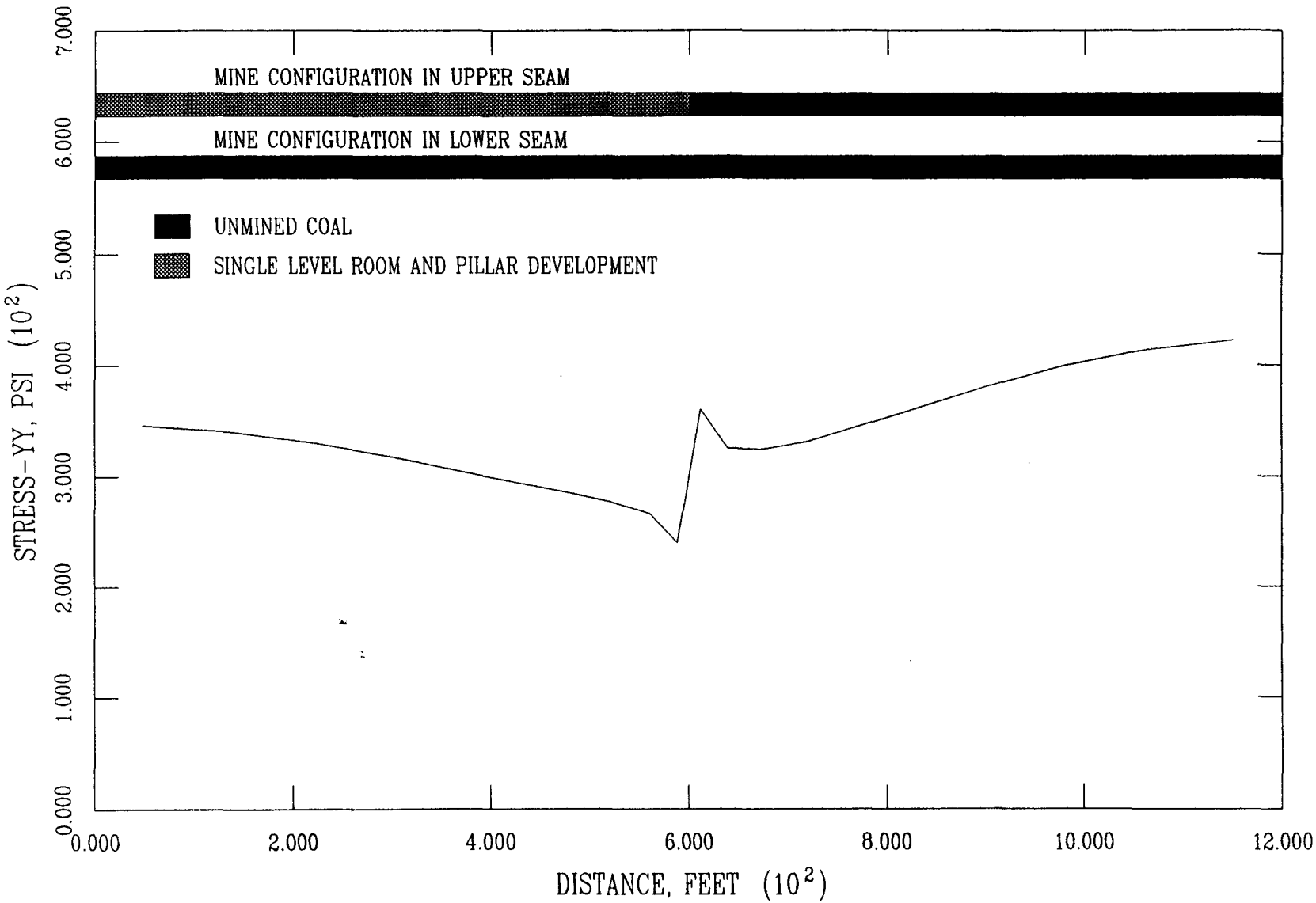

Figure B-2. Profile of vertical equivalent stress in the upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

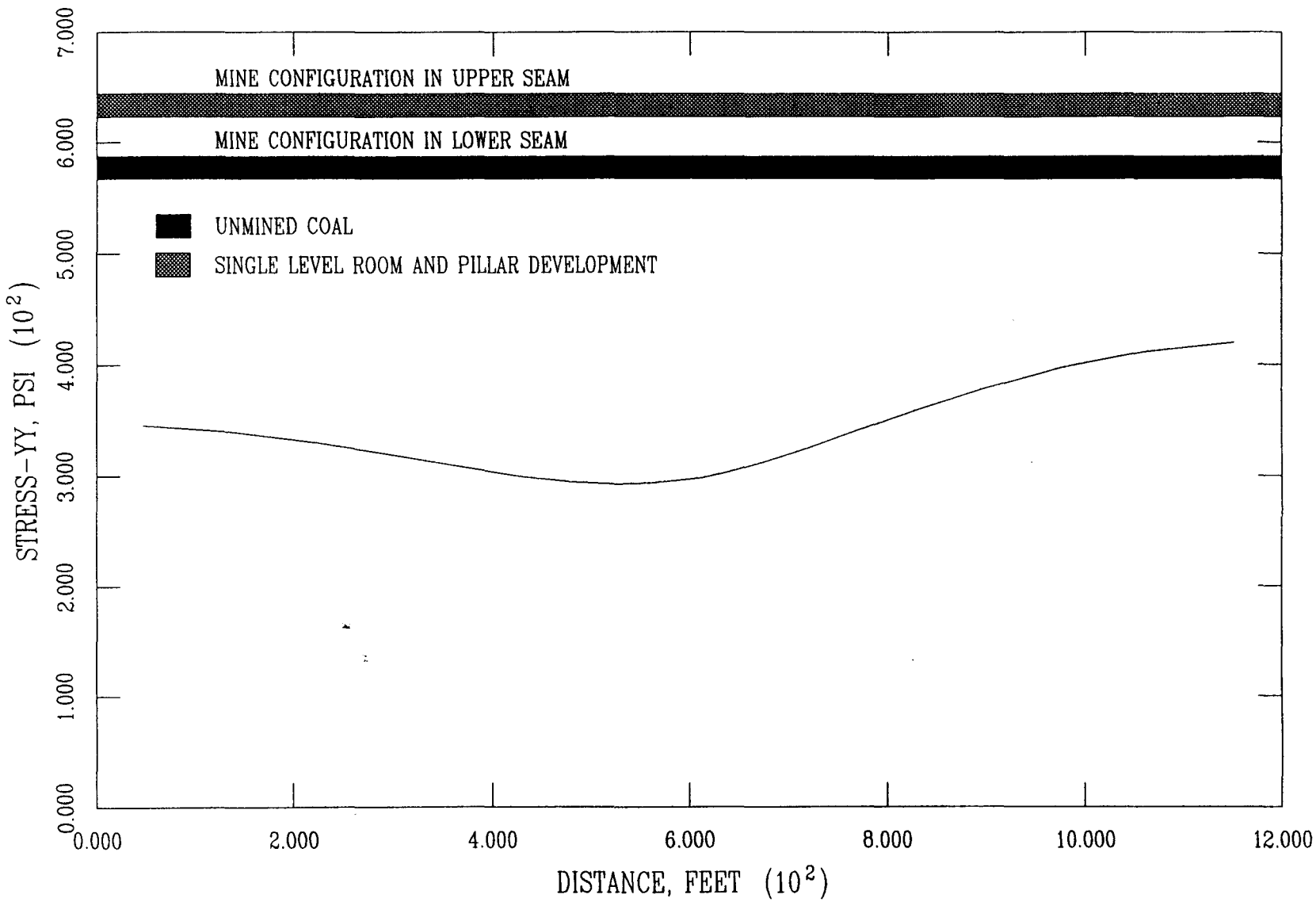

Figure B-3. Profile of vertical equivalent stress in the upper seam after complete development of the top coal of the upper seam. Overburden Quality = "GOOD".

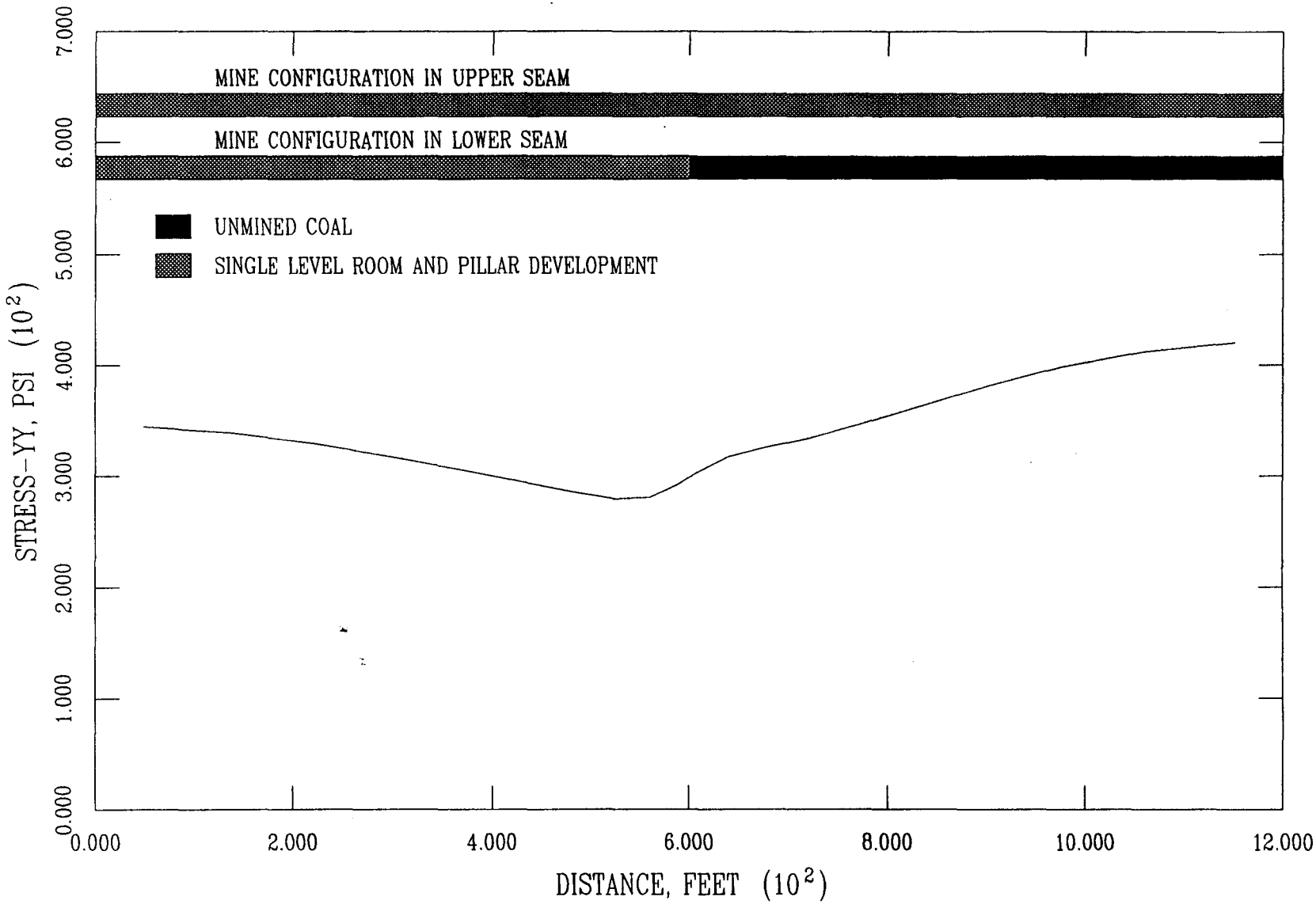

Figure B-4. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

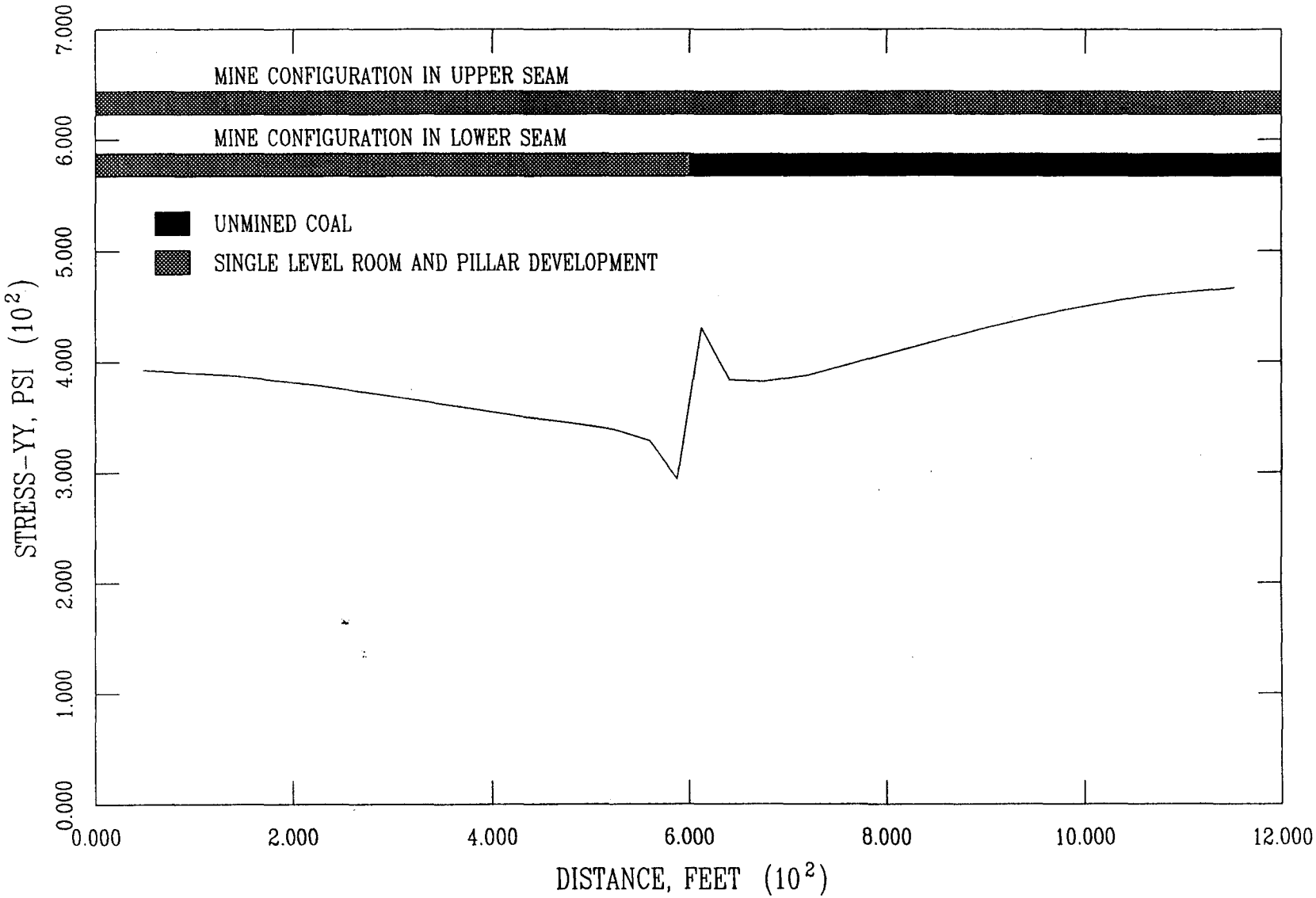

Figure B-5. Profile of vertical equivalent stress in the lower seam after complete development of the top coal in the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

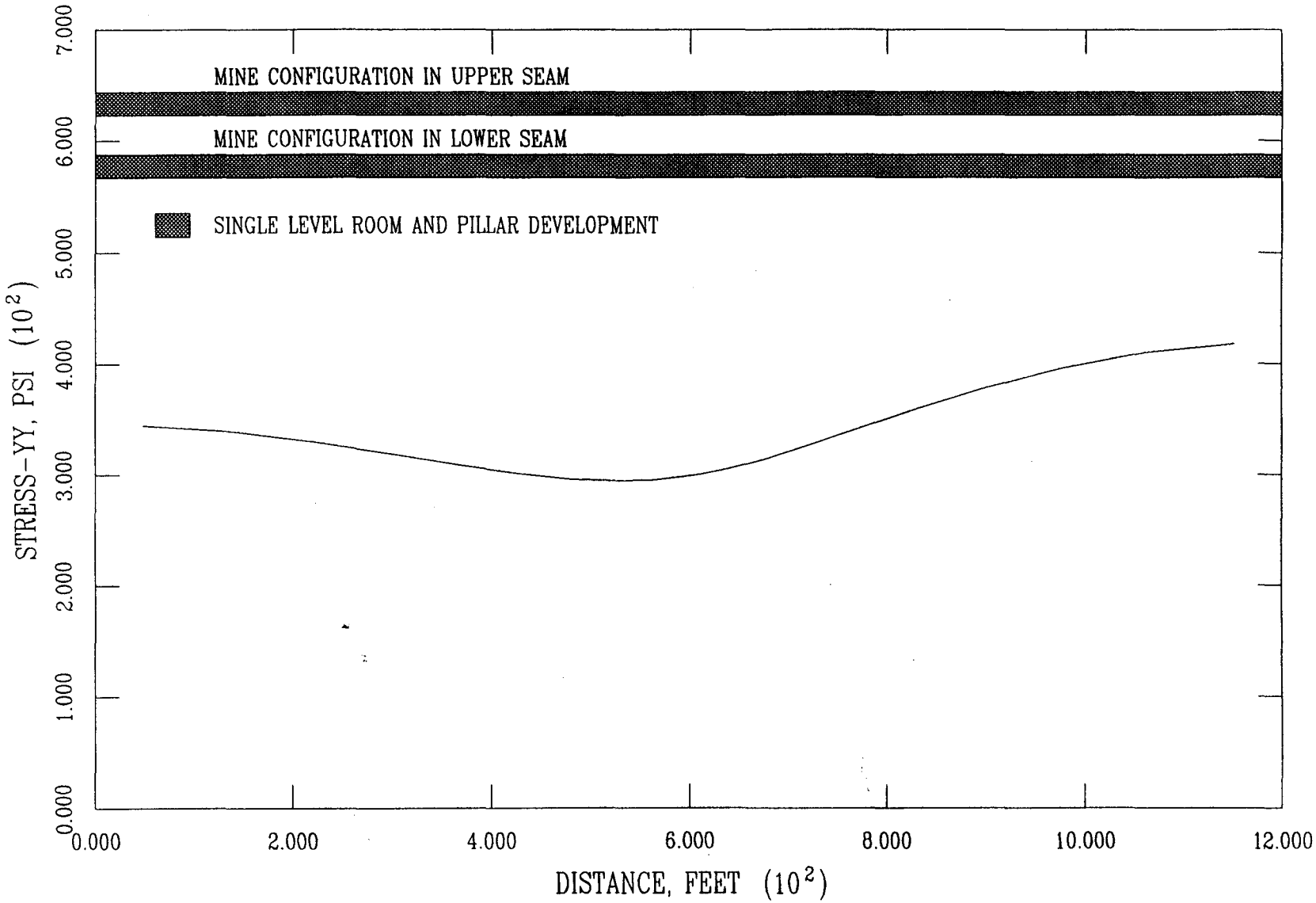

Figure B-6. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in both the upper and lower seams. Overburden Quality = "GOOD".

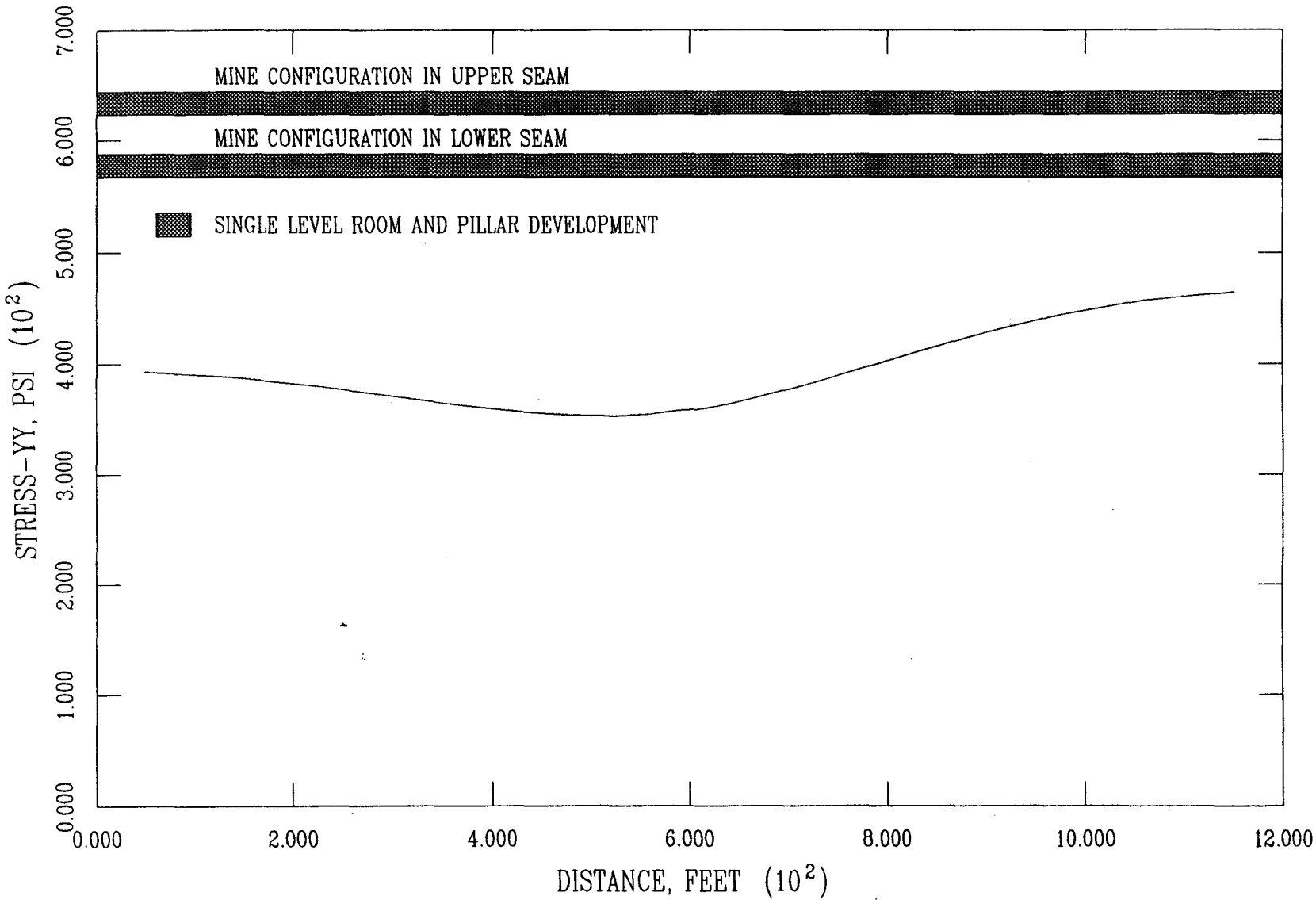

Figure B-7. Profile of vertical equivalent stress in the lower seam after complete development of the top coal in both the upper and lower seams. Overburden Quality = "GOOD".

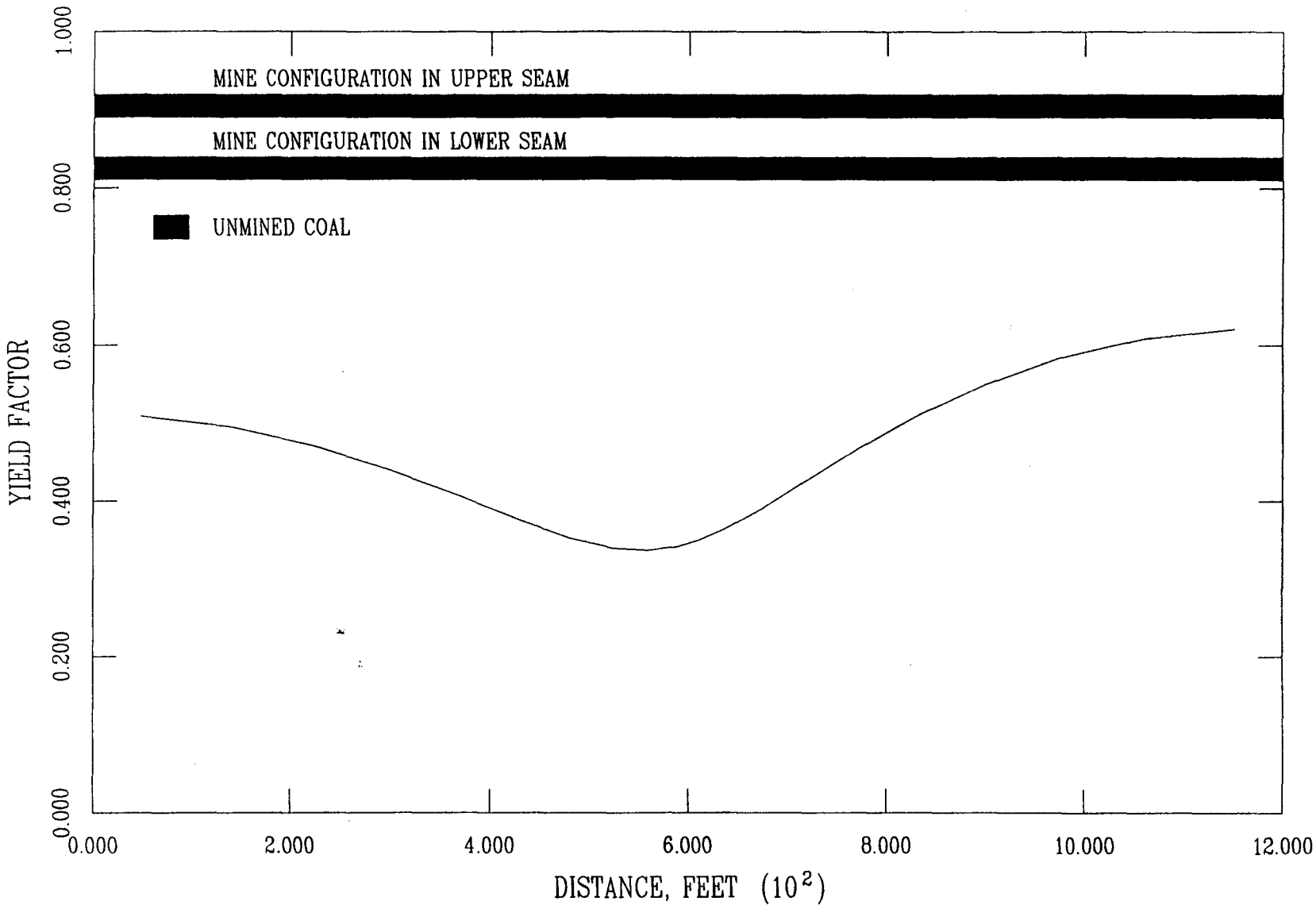

Figure B-8. Profile of yield factor in overburden above upper seam prior to any mining activity. Overburden Quality = "GOOD".

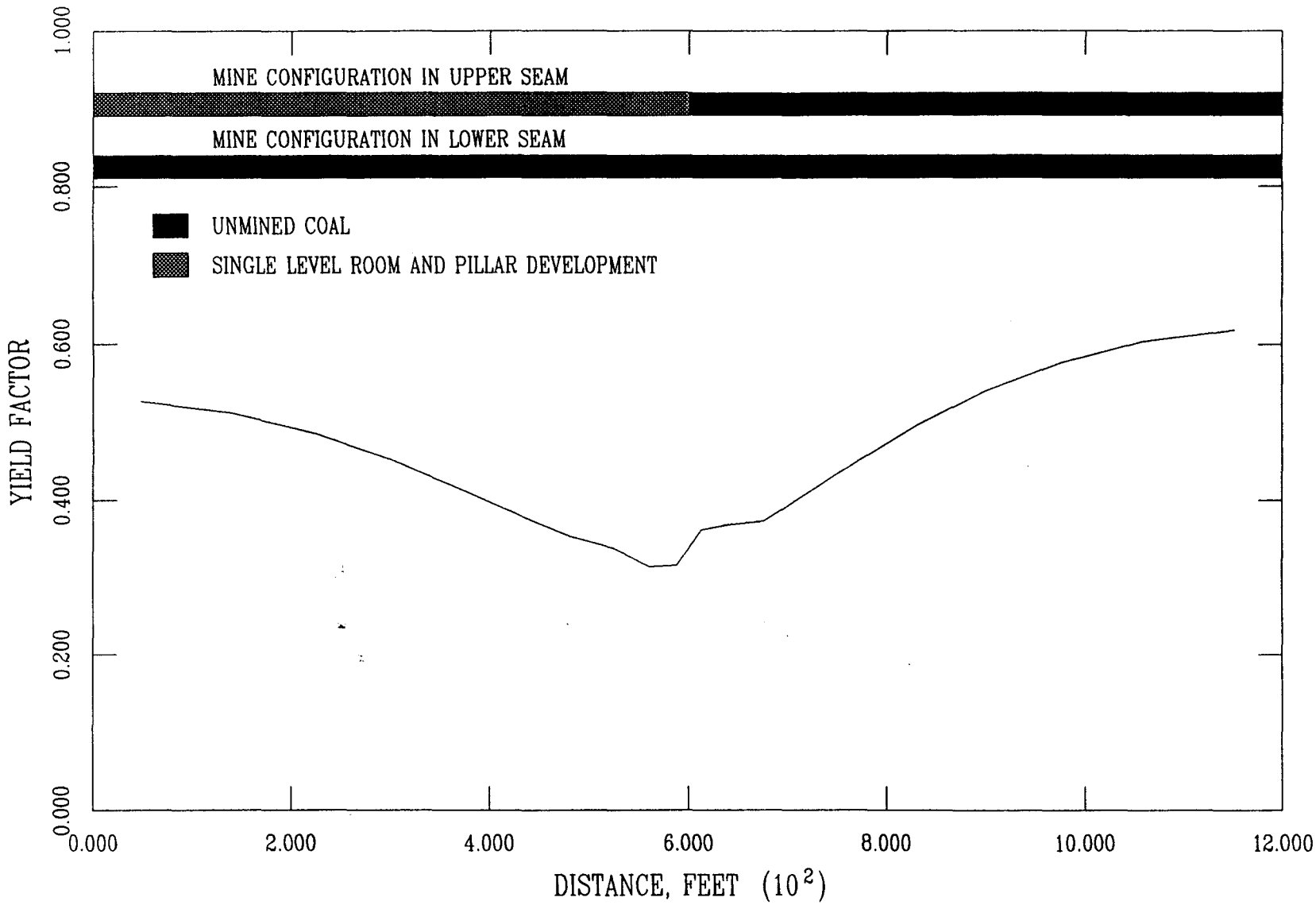

Figure B-9. Profile of yield factor in overburden above upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

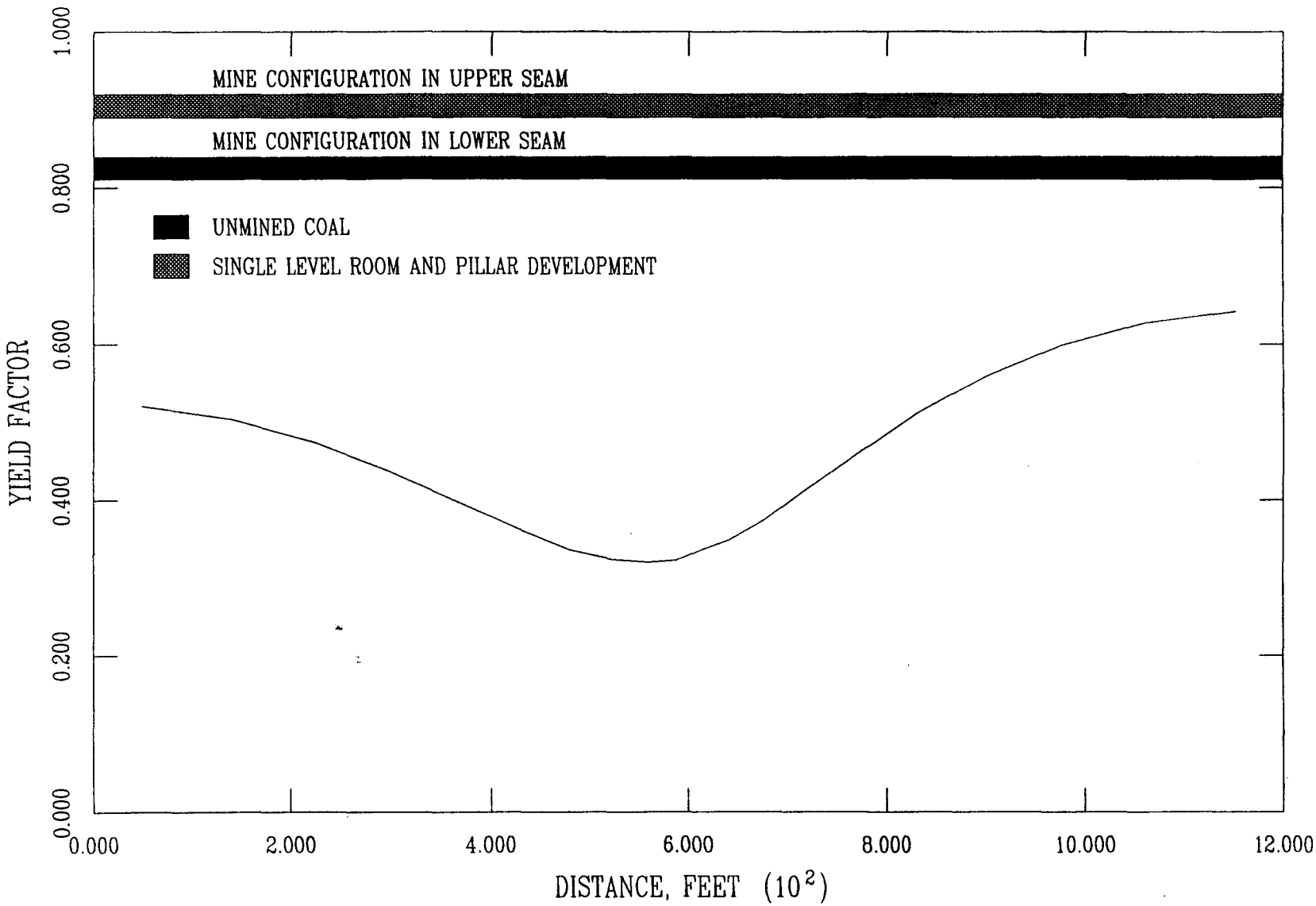

Figure B-10. Profile of yield factor in overburden above upper seam after complete development of the top coal of the upper seam. Overburden Quality = "GOOD".

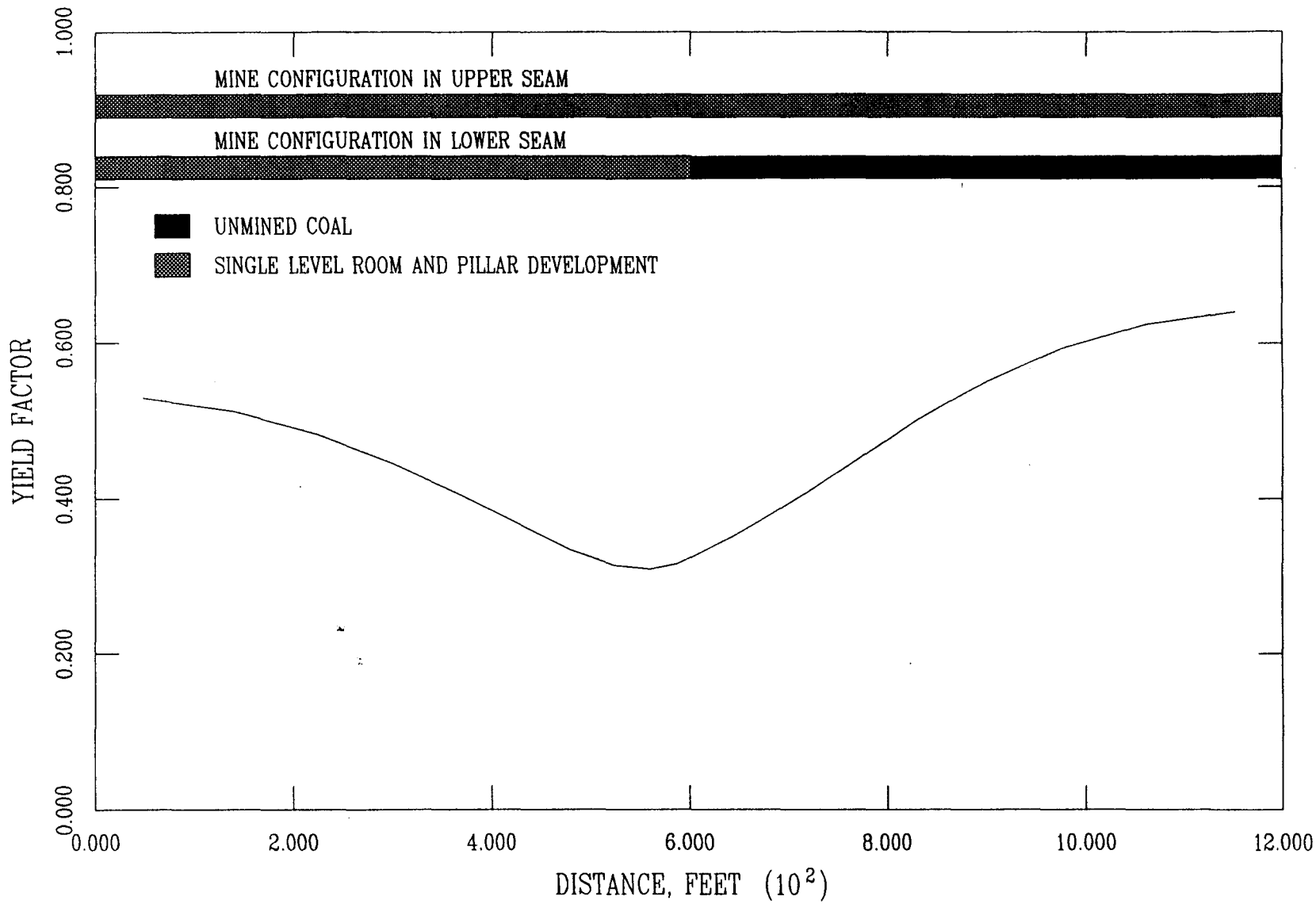

Figure B-11. Profile of yield factor in overburden above upper seam after complete development of the top coal in the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

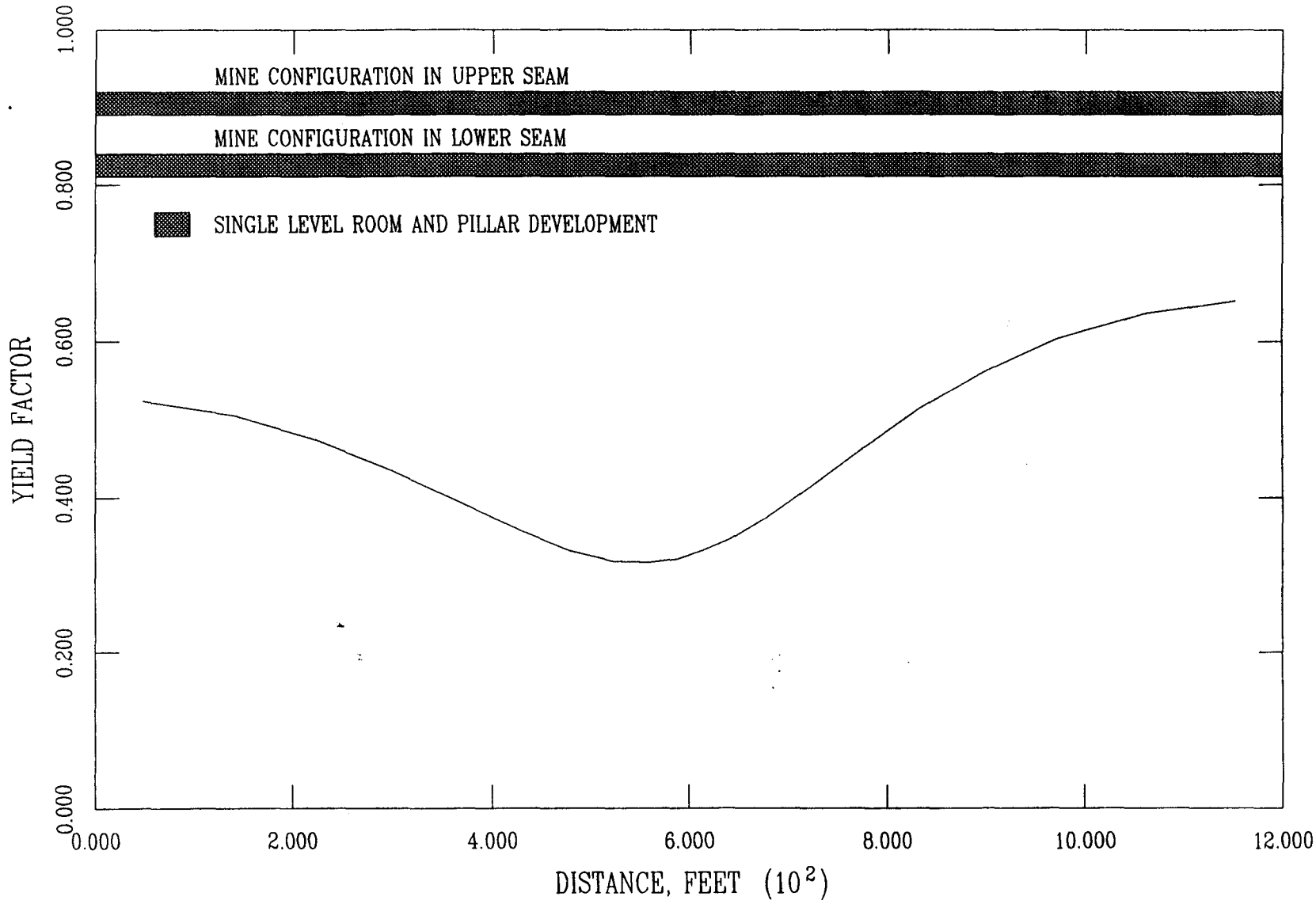

Figure B-12. Profile of yield factor in overburden above upper seam after complete development of the top coal in both the upper and lower seams. Overburden Quality = "GOOD".

APPENDIX C

ANALYSIS OF DOUBLE LEVEL MINING IN BOTH SEAMS WITH OVERBURDEN QUALITY = "GOOD"

The figures contained in this appendix show profiles of stress in both the upper and lower seam at various stages of development for full seam development. Overburden quality is assumed to be "GOOD" for these results. Diagrams at the top of each figure schematically indicate the configuration of mine development to which the results apply. Also shown are profiles of yield factor in the overburden immediately above the upper coal seam. Yield factor is defined as the ratio of maximum shear stress at a location to the existing shear strength at that location. Consequently, a yield factor of 1 would indicate that the rock is yielding, and a yield factor of less than 1 indicates that the rock has not yet been loaded to its full capacity. A yield factor in excess of 1 is not possible in an ideally plastic model in that plastic flow would modify the stress state back to a yield factor of 1.

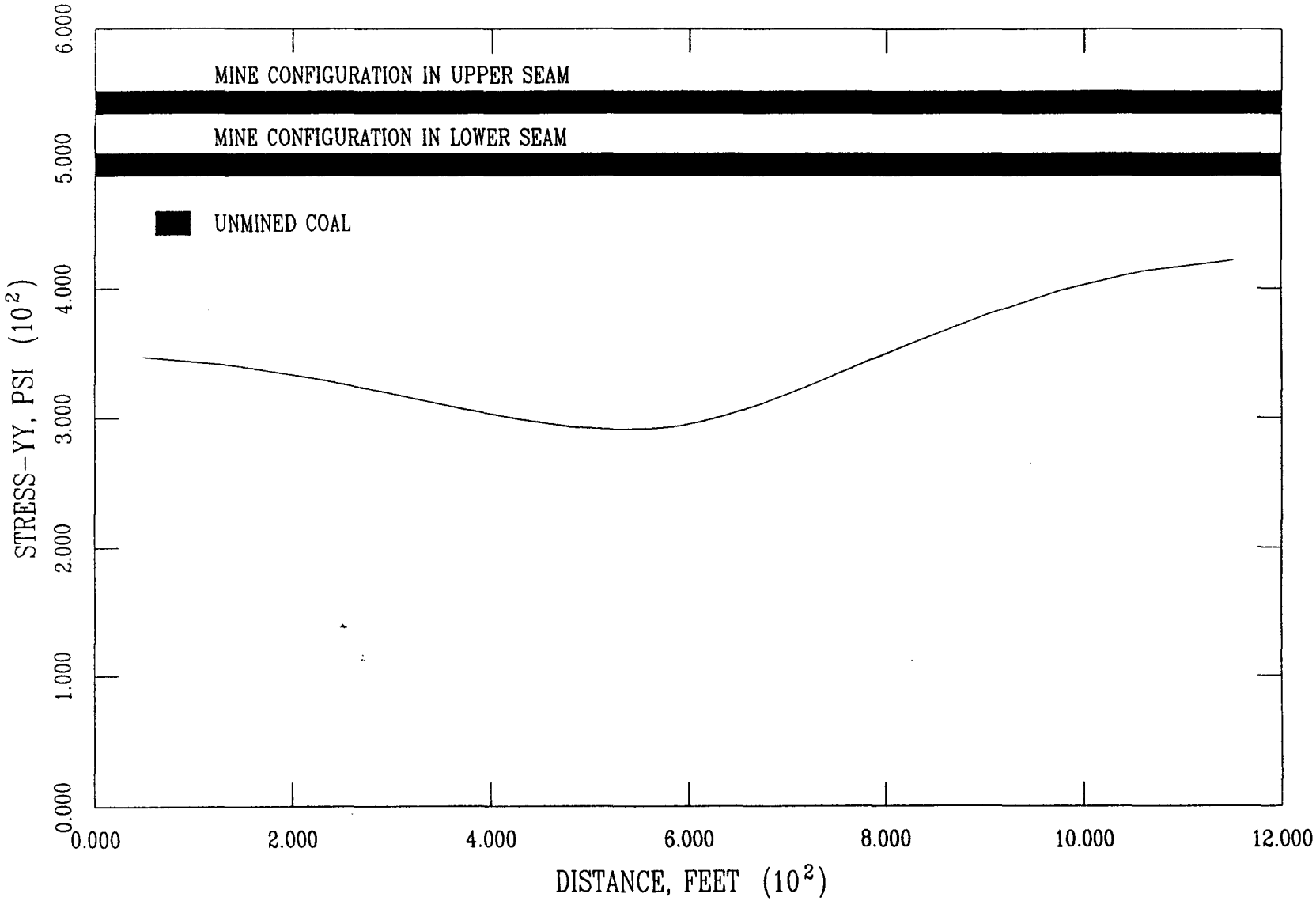

Figure C-1. Profile of vertical equivalent stress in the upper seam prior to any mining activity. Overburden Quality = "GOOD".

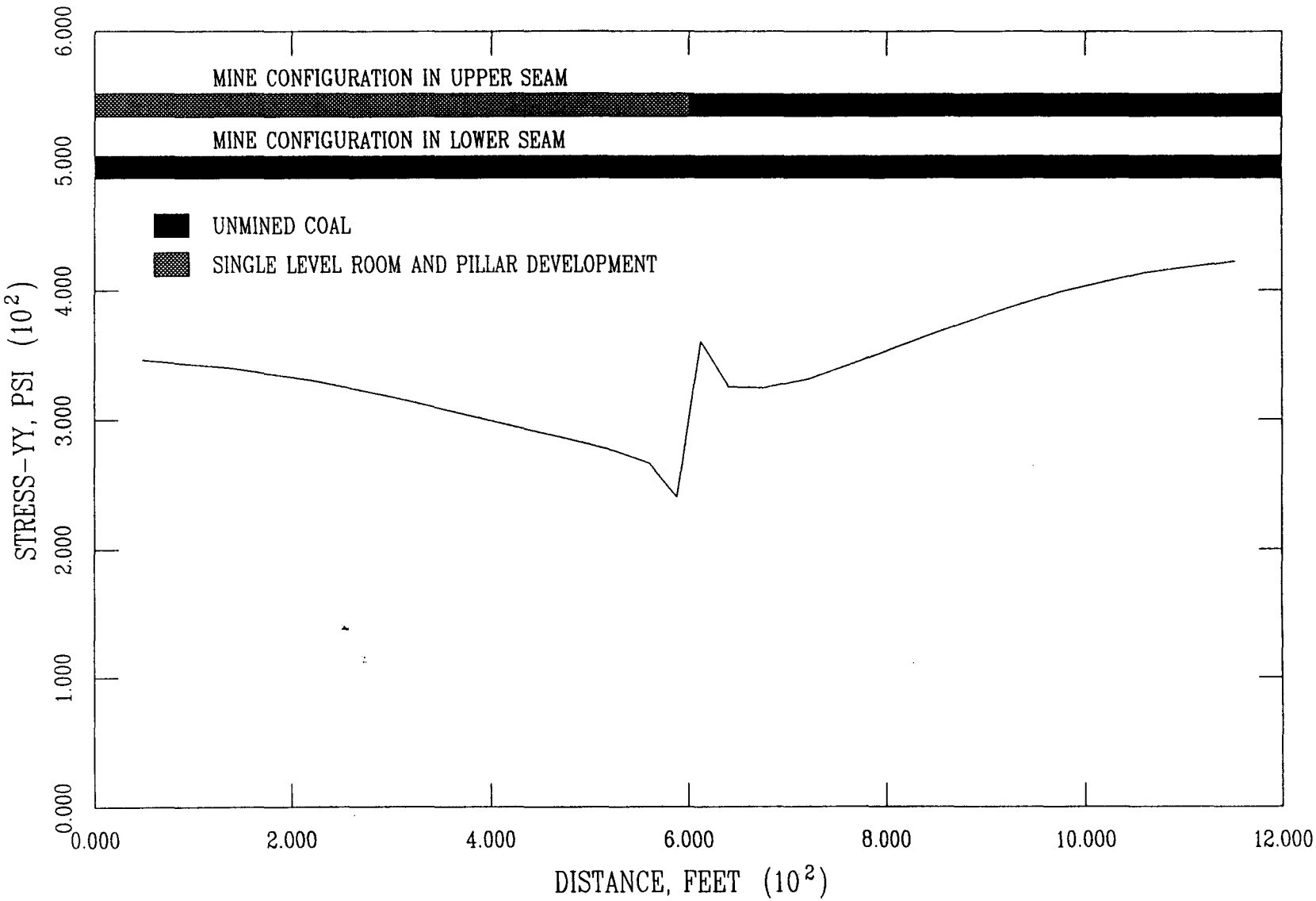

Figure C-2. Profile of vertical equivalent stress in the upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

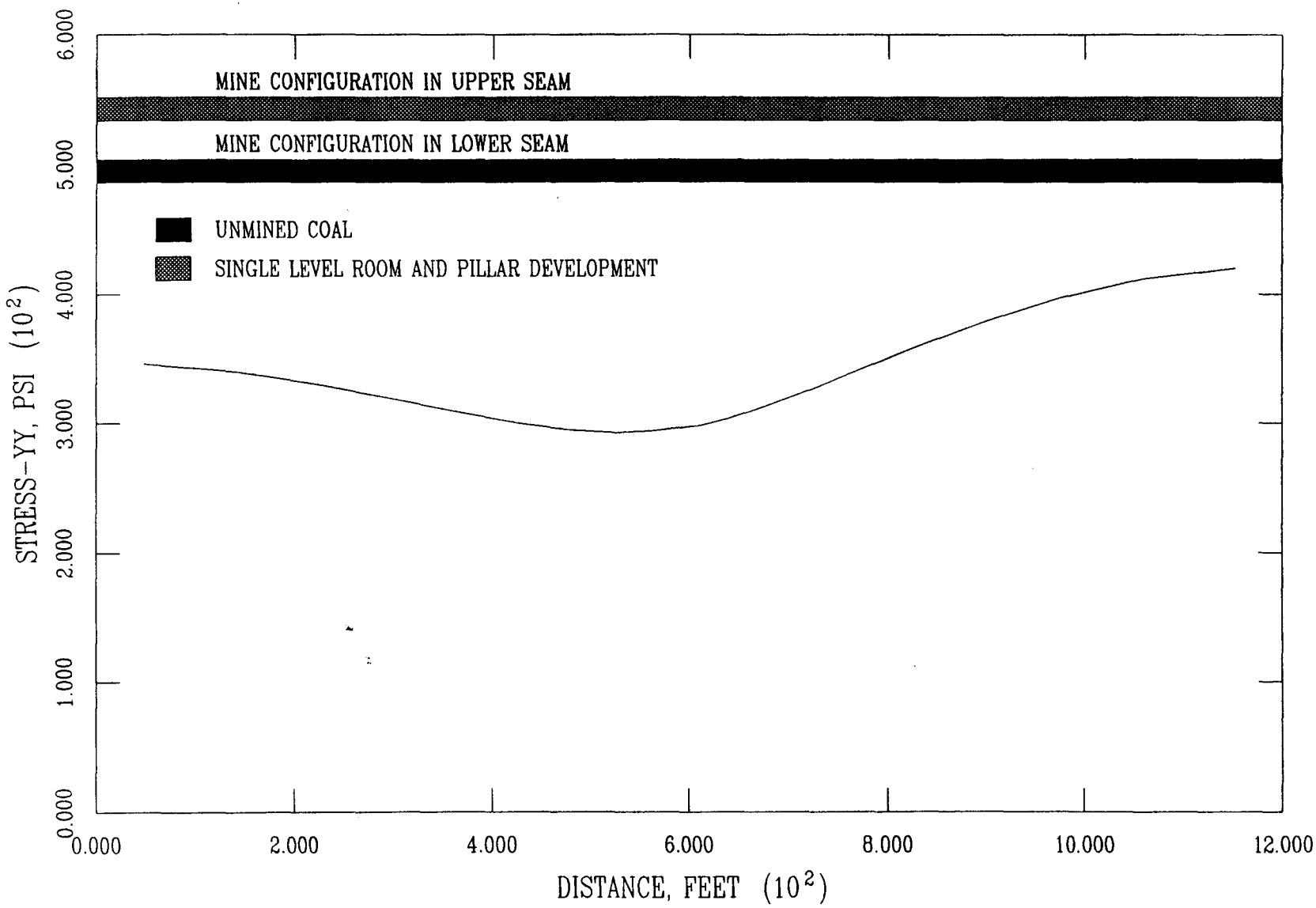

Figure C-3. Profile of vertical equivalent stress in the upper seam after complete development of the top coal of the upper seam. Overburden Quality = "GOOD".

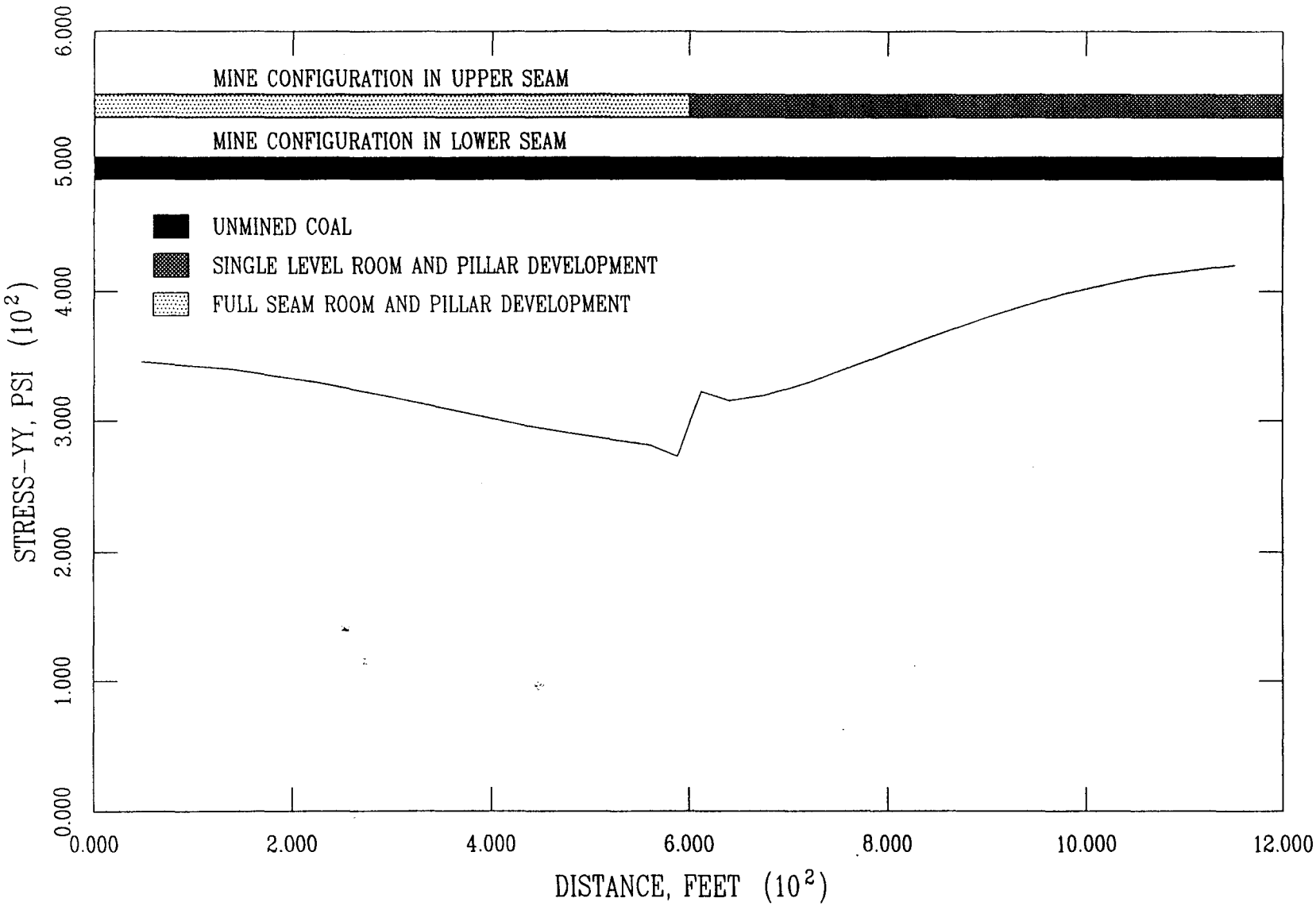

Figure C-4. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in the upper seam, and development of the bottom coal in the upper seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

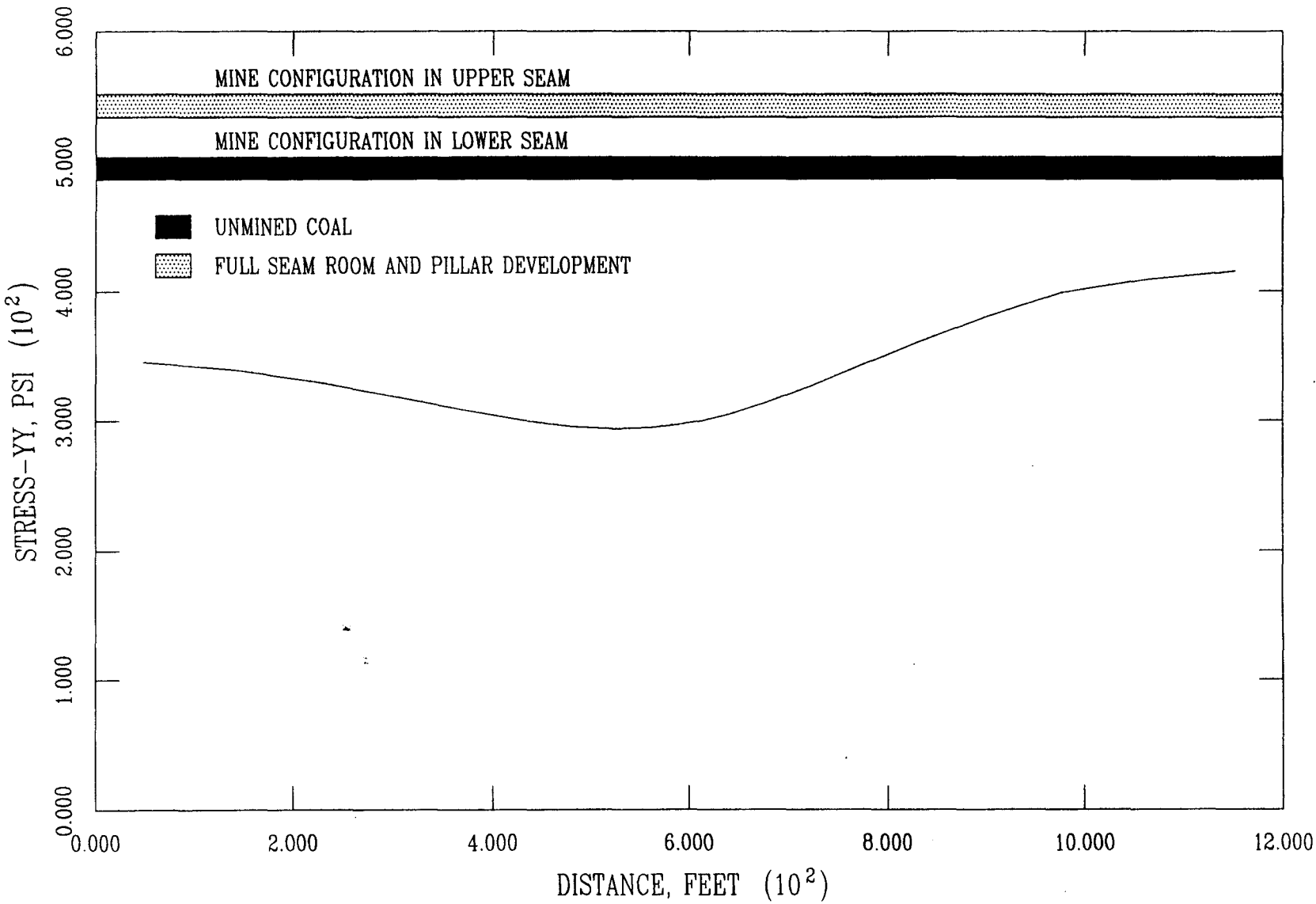

Figure C-5. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam. Overburden Quality = "GOOD".

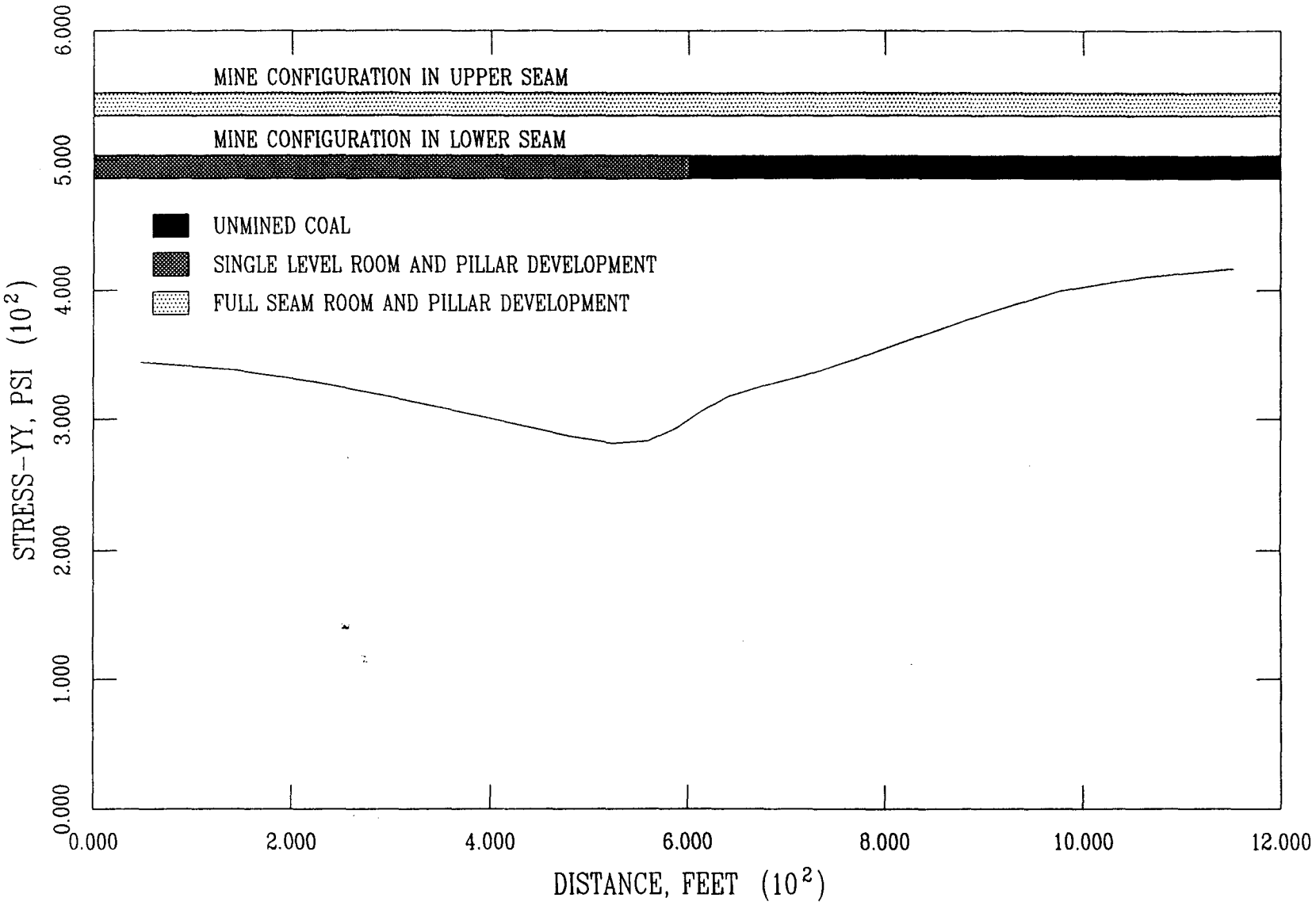

Figure C-6. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek.
Overburden Quality = "GOOD".

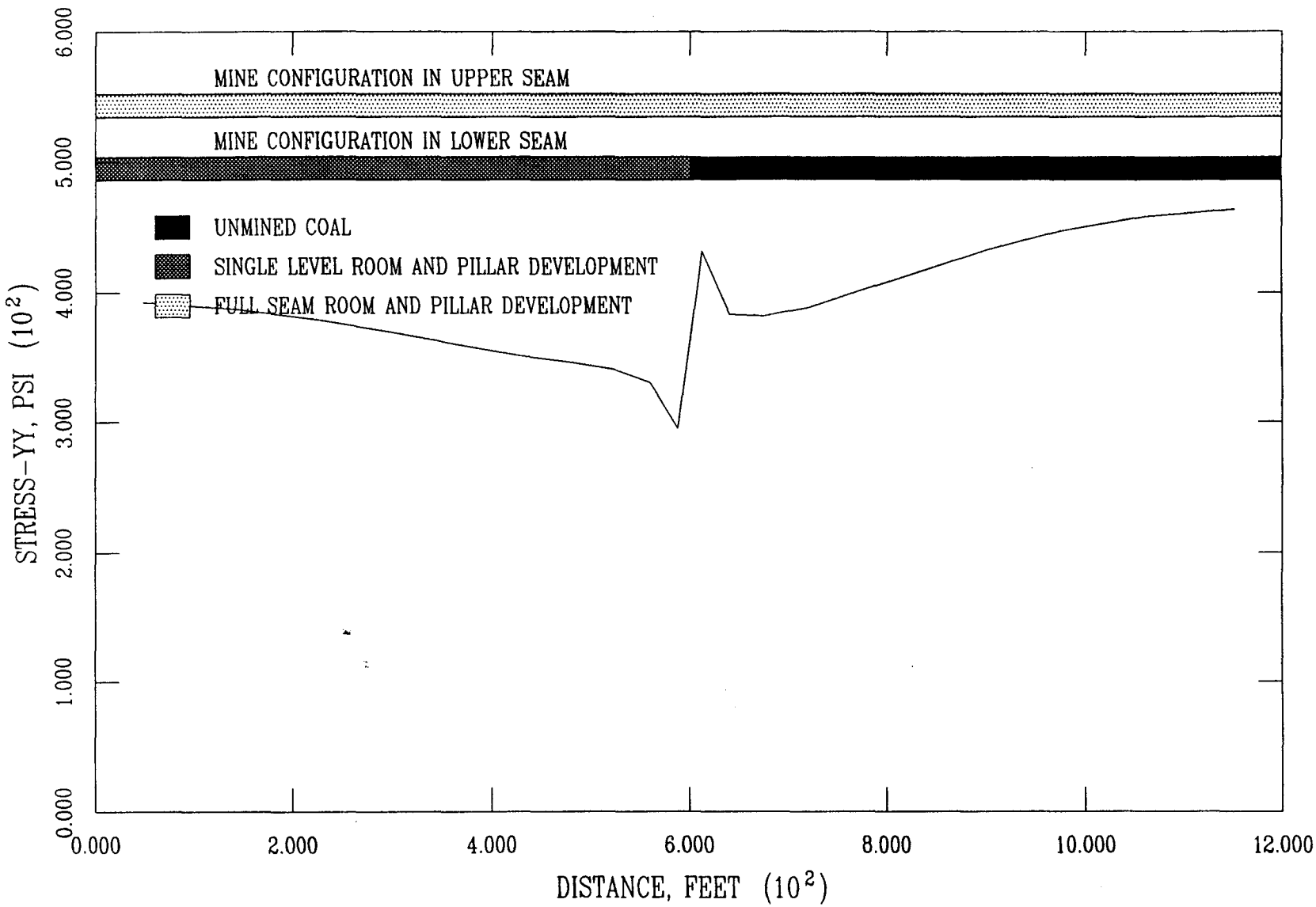

Figure C-7. Profile of vertical equivalent stress in the lower seam after complete full seam development of the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek.
Overburden Quality = "GOOD".

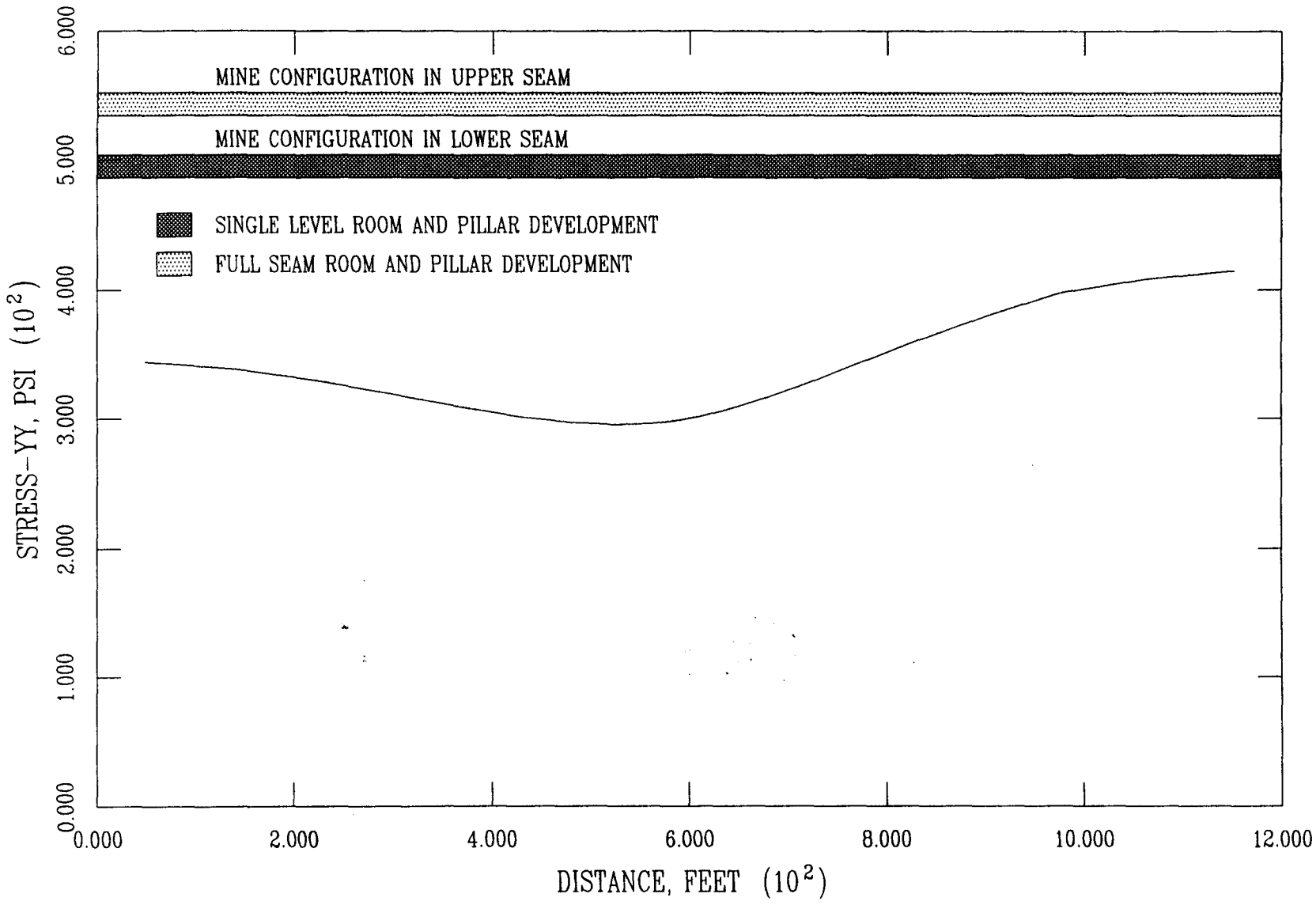

Figure C-8. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam, and complete development of the top coal in the lower seam. Overburden Quality = "GOOD".

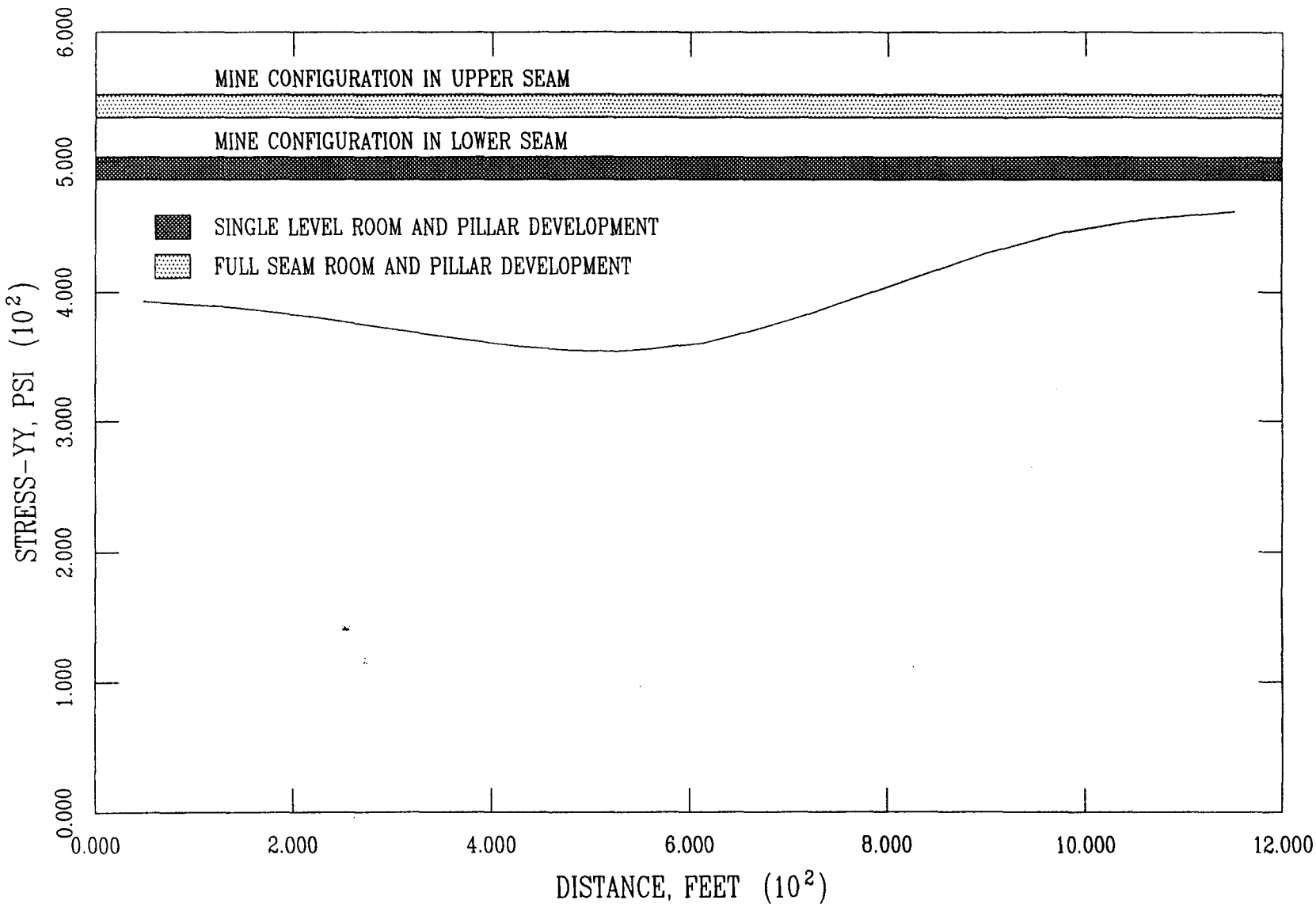

Figure C-9. Profile of vertical equivalent stress in the lower seam after complete full seam development of the upper seam, and complete development of the top coal in the lower seam. Overburden Quality = "GOOD".

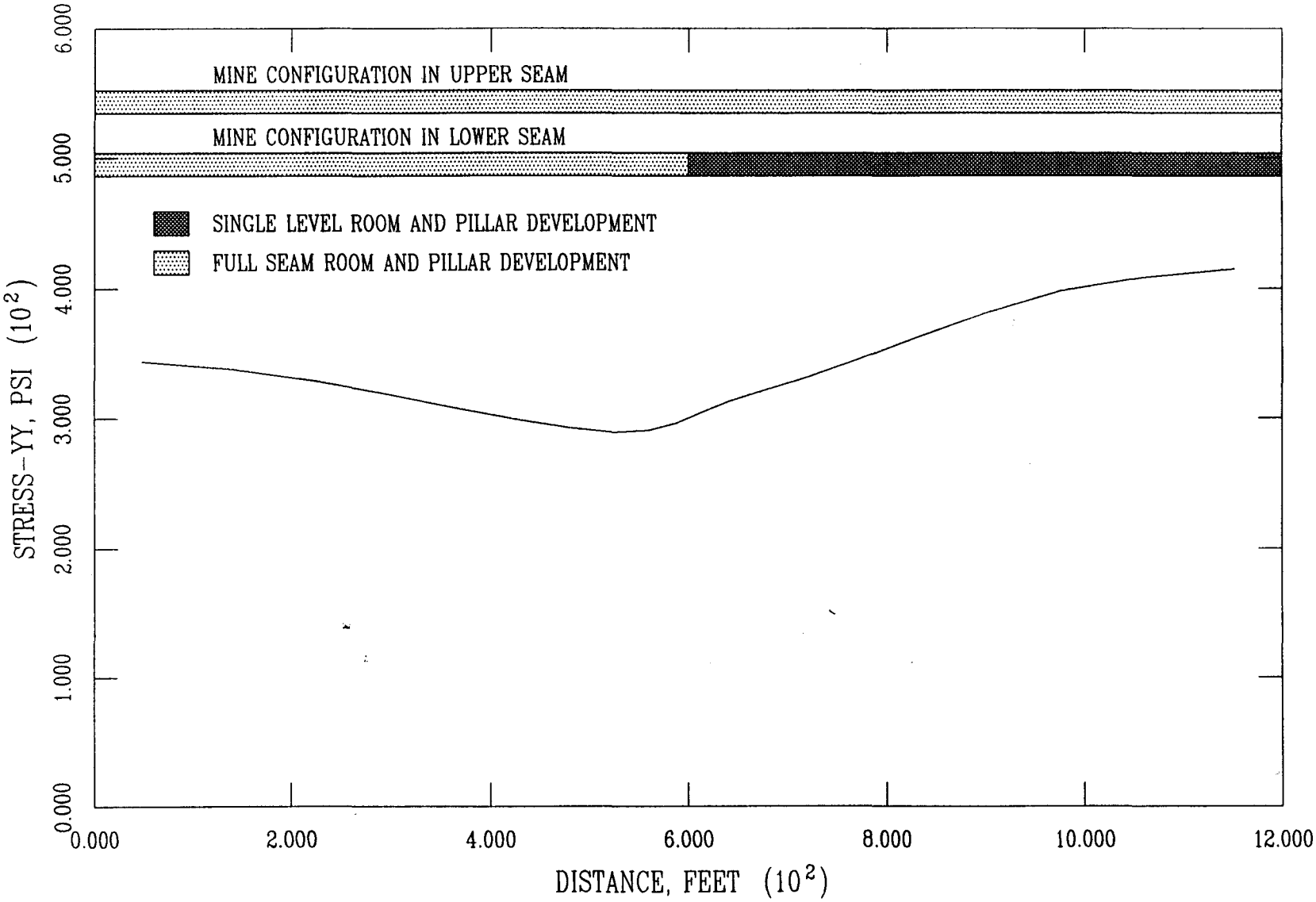

Figure C-10. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam, complete development of the top coal in the lower seam, and development of the bottom coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

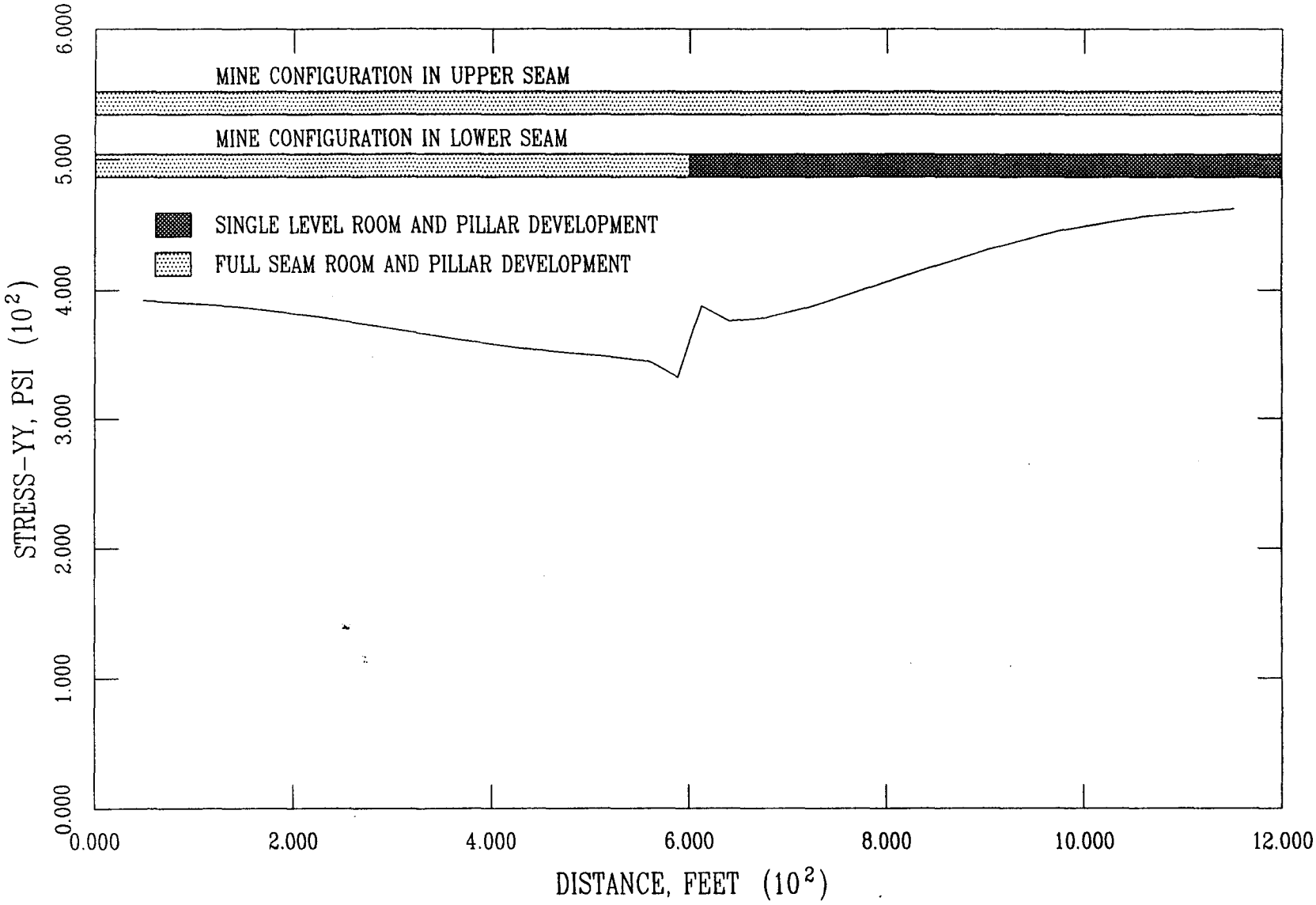

Figure C-11. Profile of vertical equivalent stress in the lower seam after complete full seam development of the upper seam, complete development of the top coal in the lower seam, and development of the bottom coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

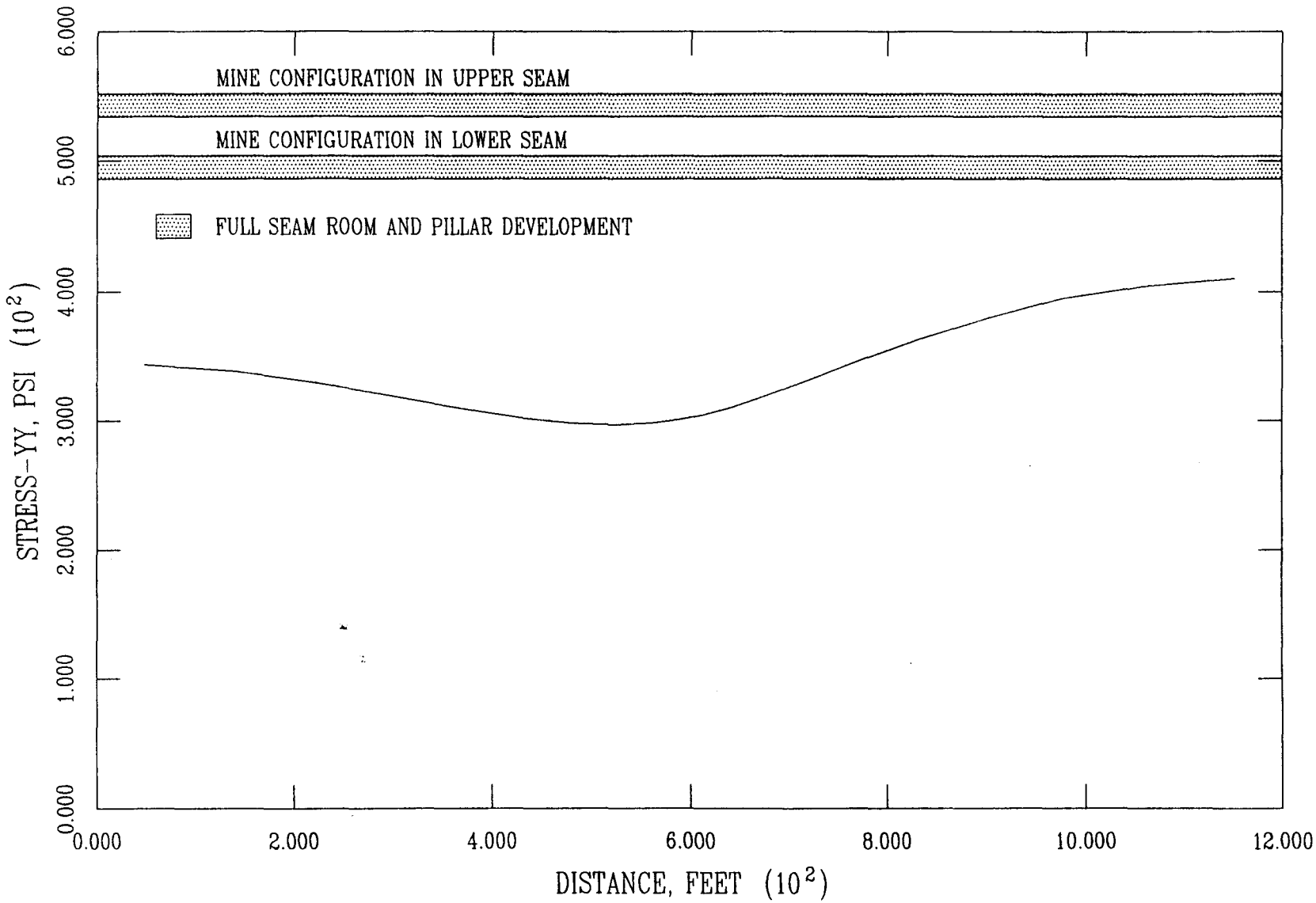

Figure C-12. Profile of vertical equivalent stress in the upper seam after complete full seam development of both seams. Overburden Quality = "GOOD".

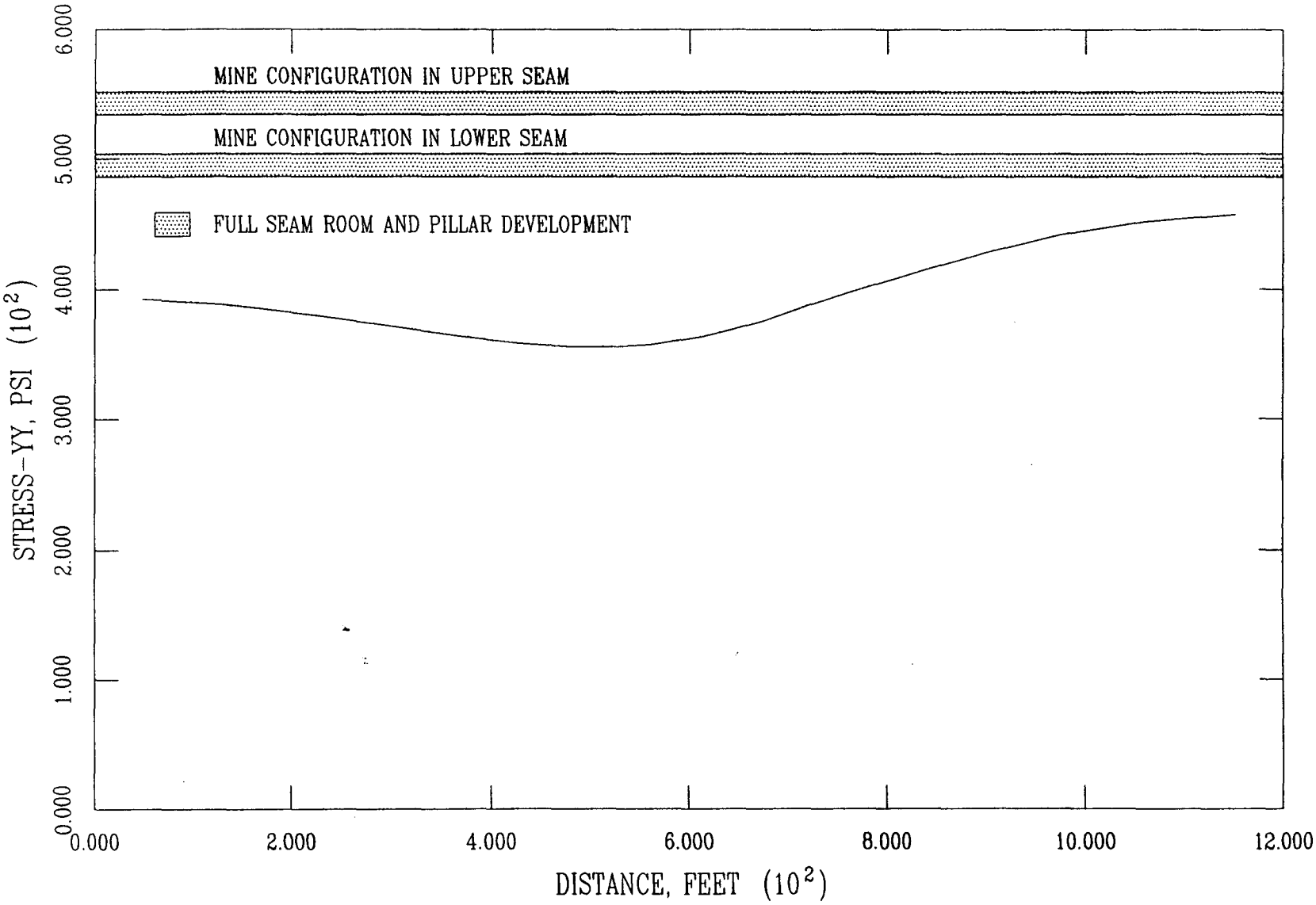

Figure C-13. Profile of vertical equivalent stress in the lower seam after complete full seam development of both seams. Overburden Quality = "GOOD".

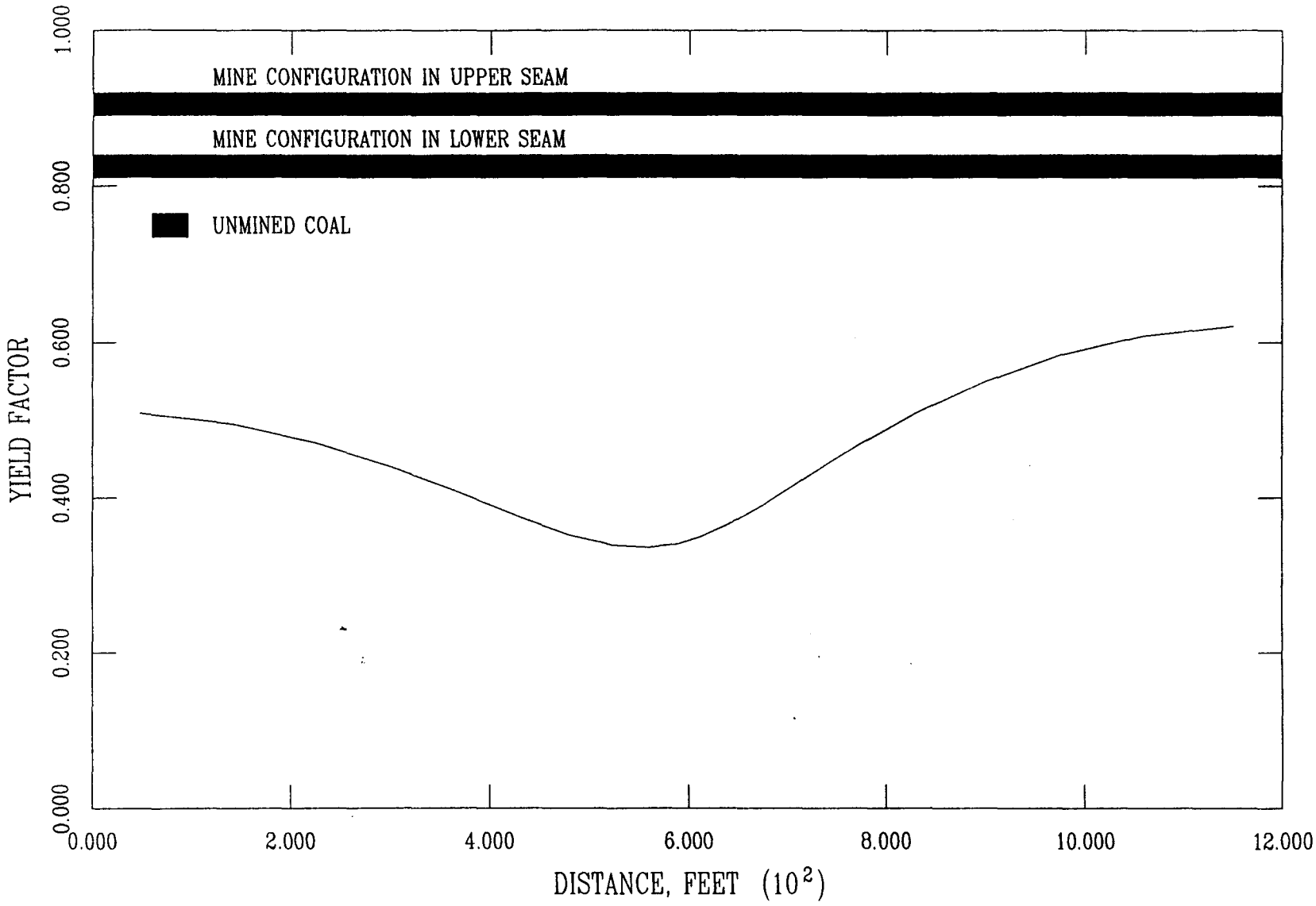

Figure C-14. Profile of yield factor in overburden above upper seam prior to any mining activity. Overburden Quality = "GOOD".

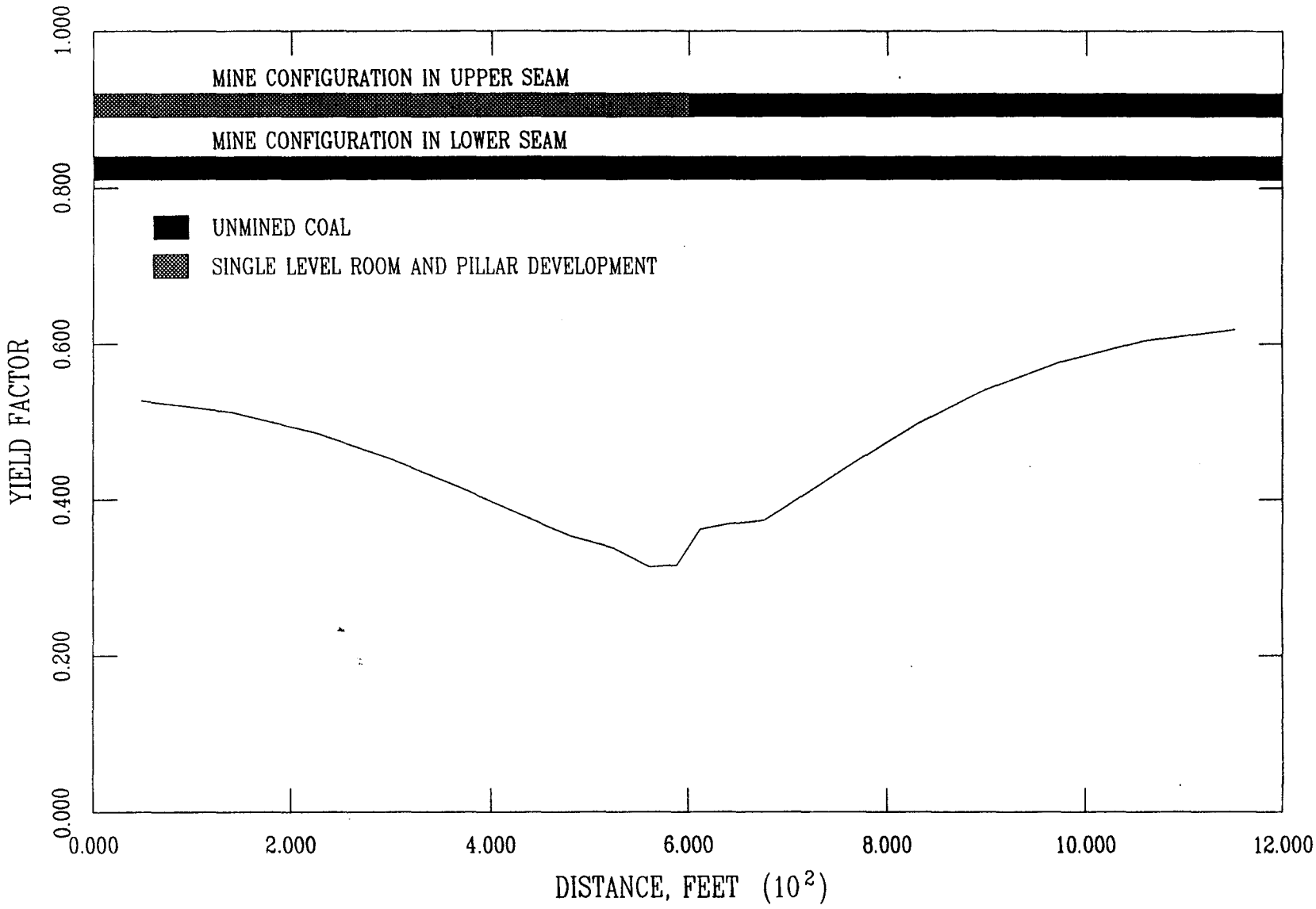

Figure C-15. Profile of yield factor in overburden above upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

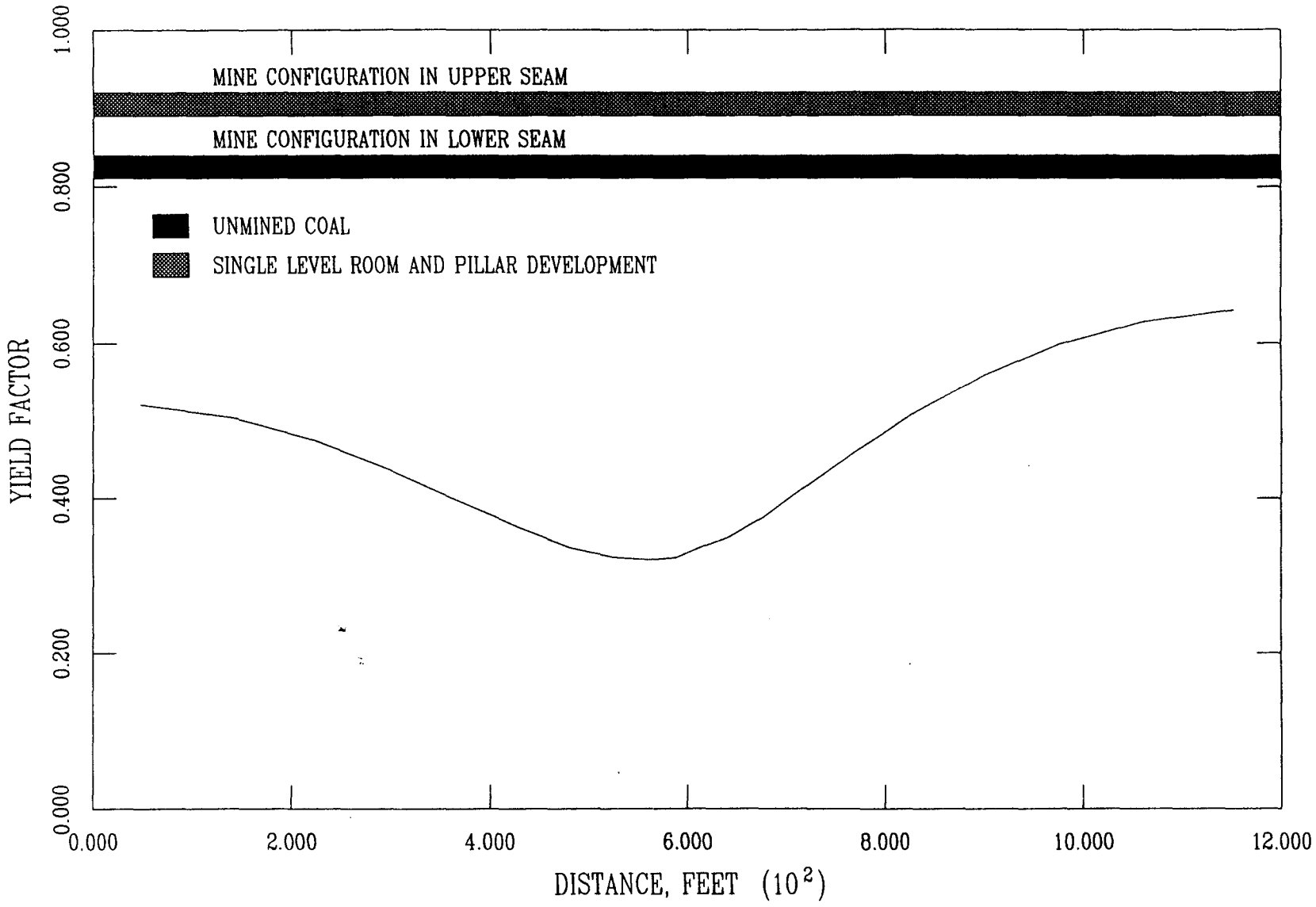

Figure C-16. Profile of yield factor in overburden above upper seam after complete development of the top coal of the upper seam. Overburden Quality = "GOOD".

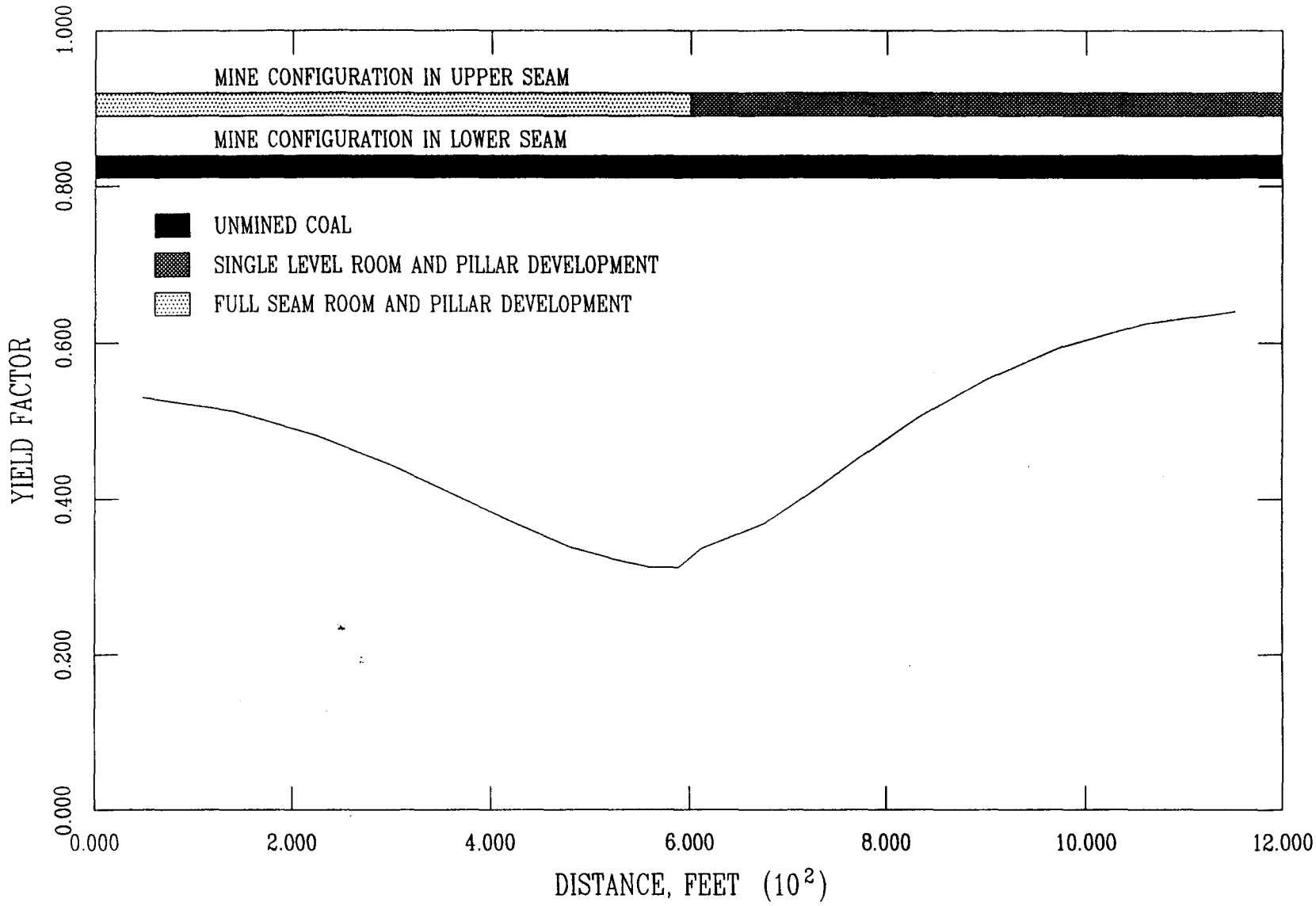

Figure C-17. Profile of yield factor in overburden above upper seam after complete development of the top coal in the upper seam, and development of the bottom coal in the upper seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

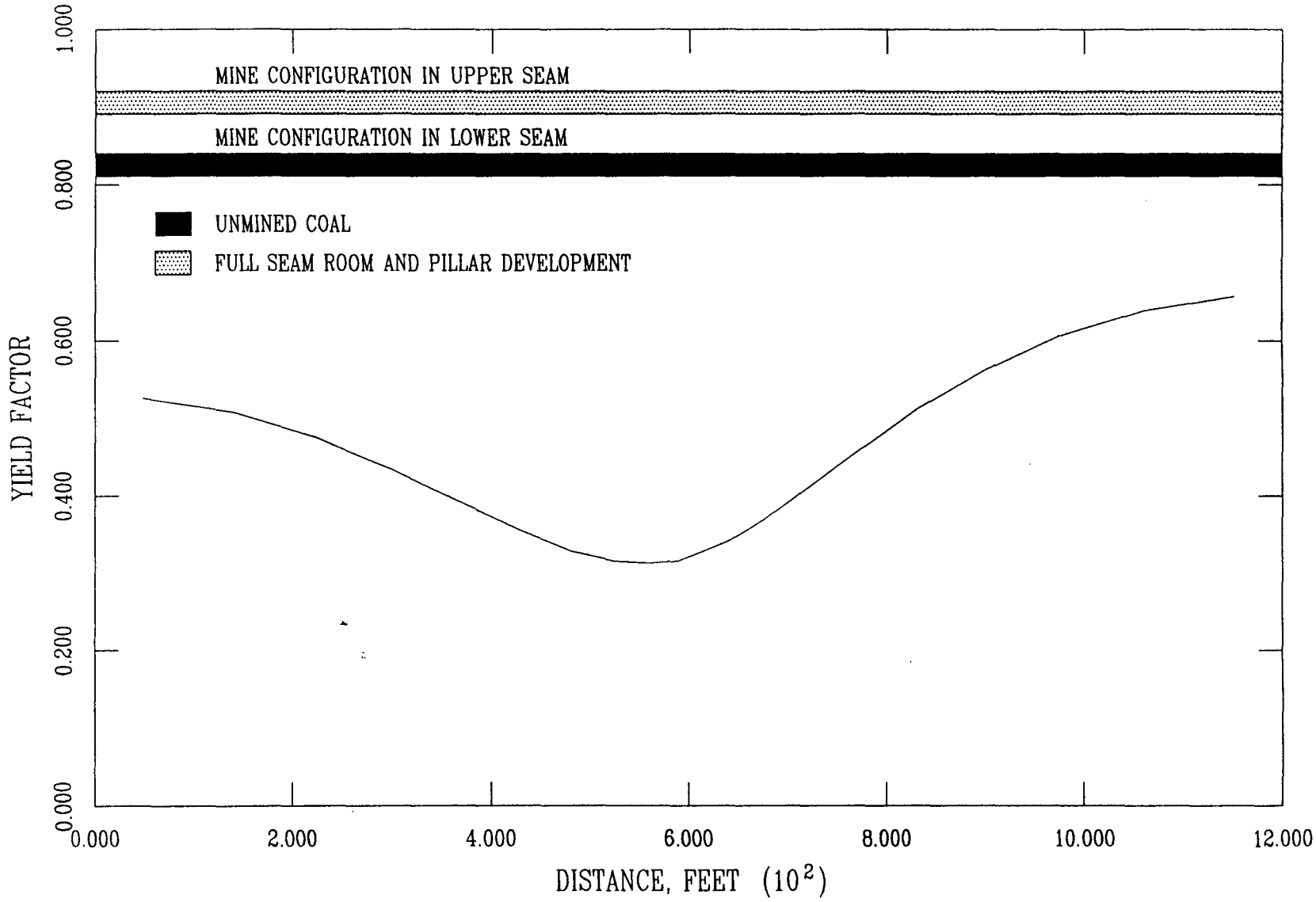

Figure C-18. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam. Overburden Quality = "GOOD".

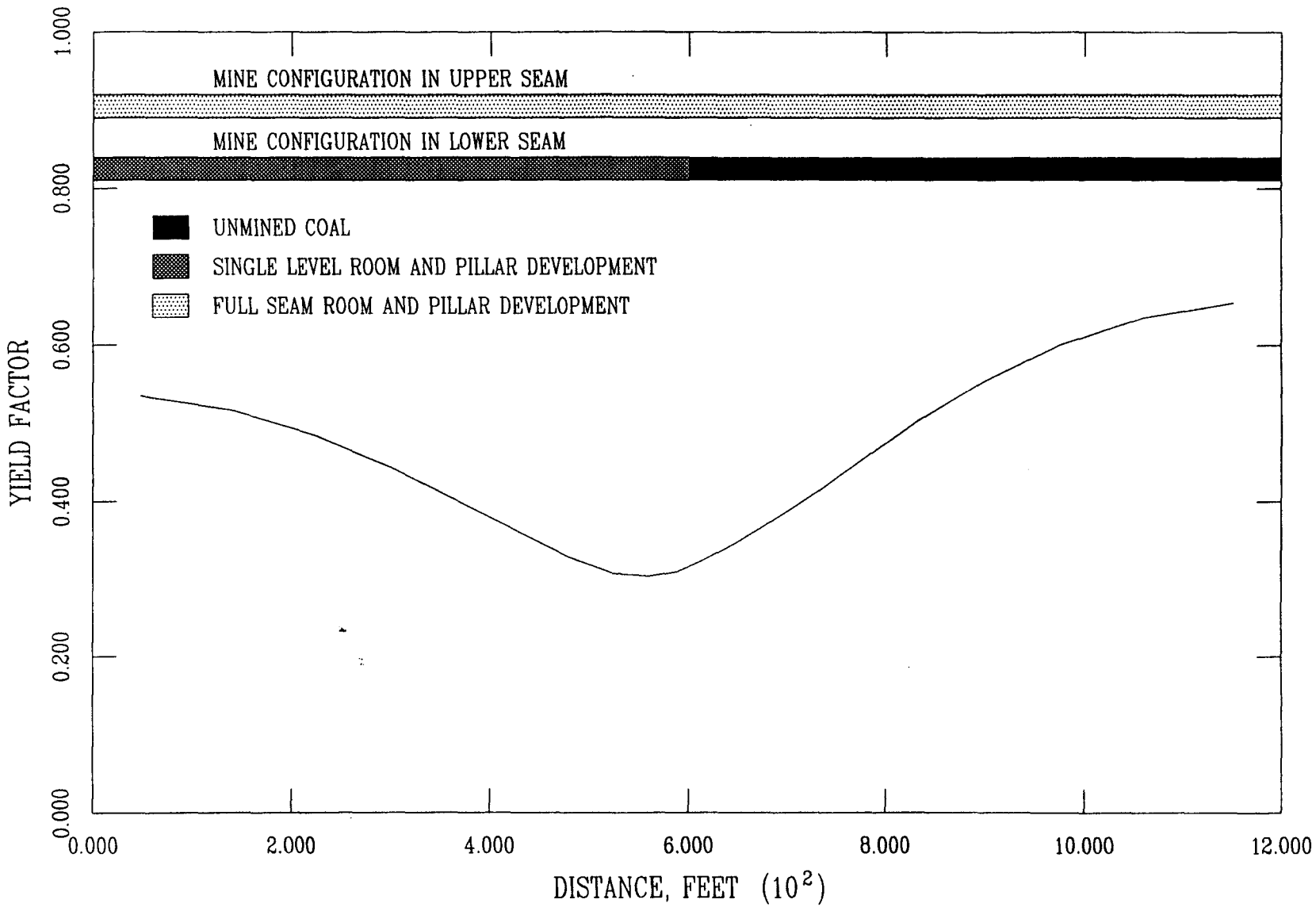

Figure C-19. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek.
Overburden Quality = "GOOD".

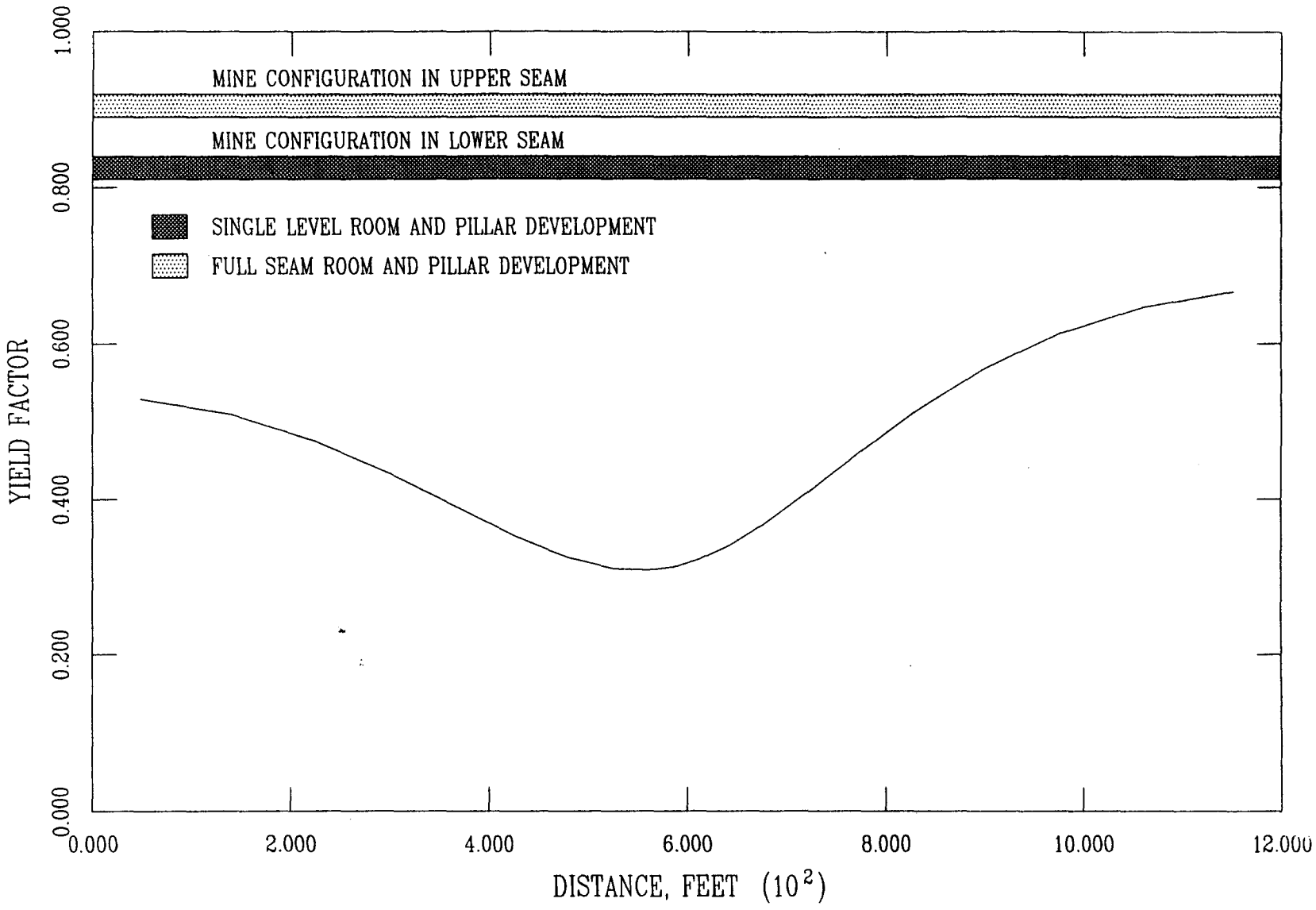

Figure C-20. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam, and complete development of the top coal in the lower seam. Overburden Quality = "GOOD".

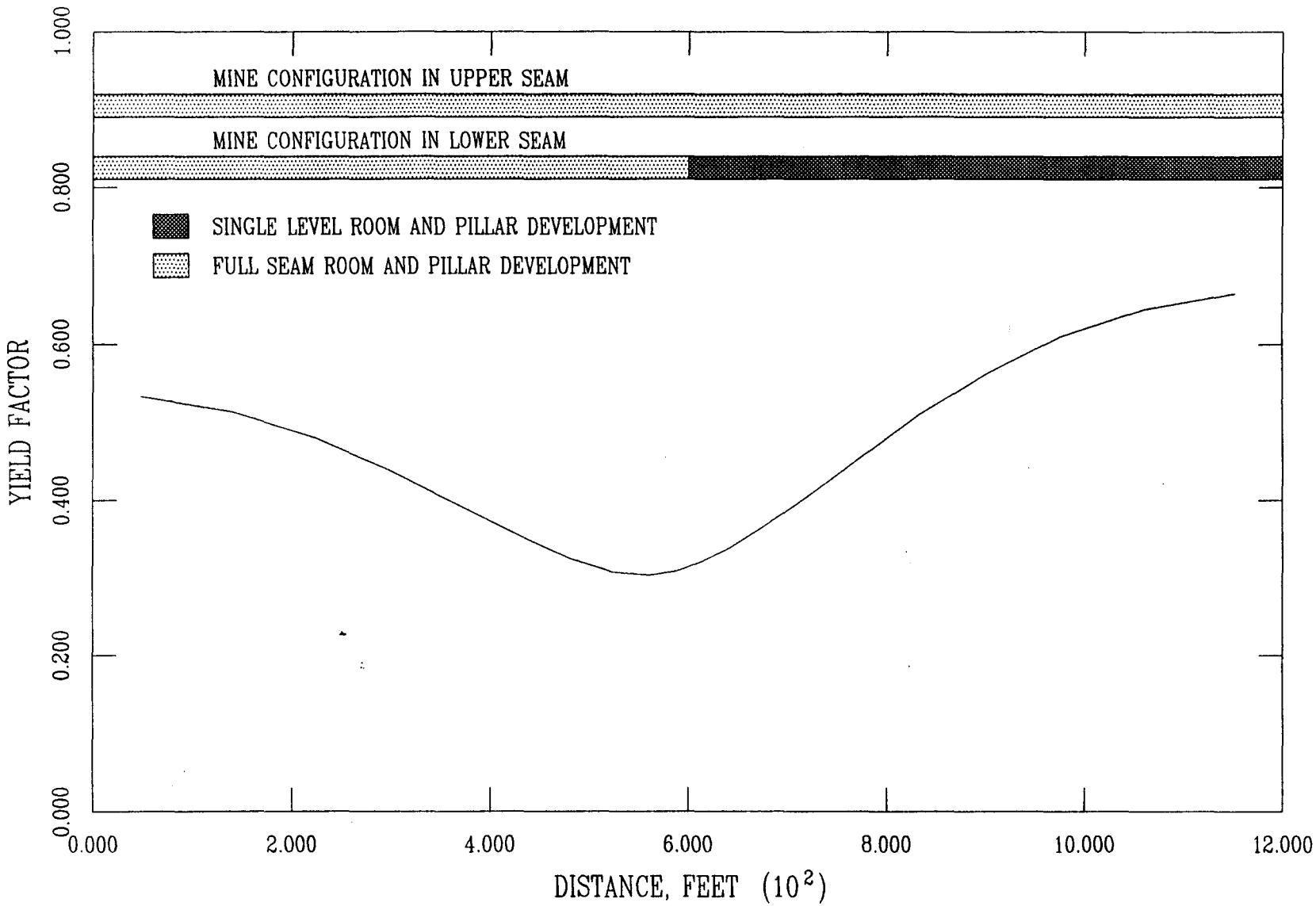

Figure C-21. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam, complete development of the top coal in the lower seam, and development of the bottom coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "GOOD".

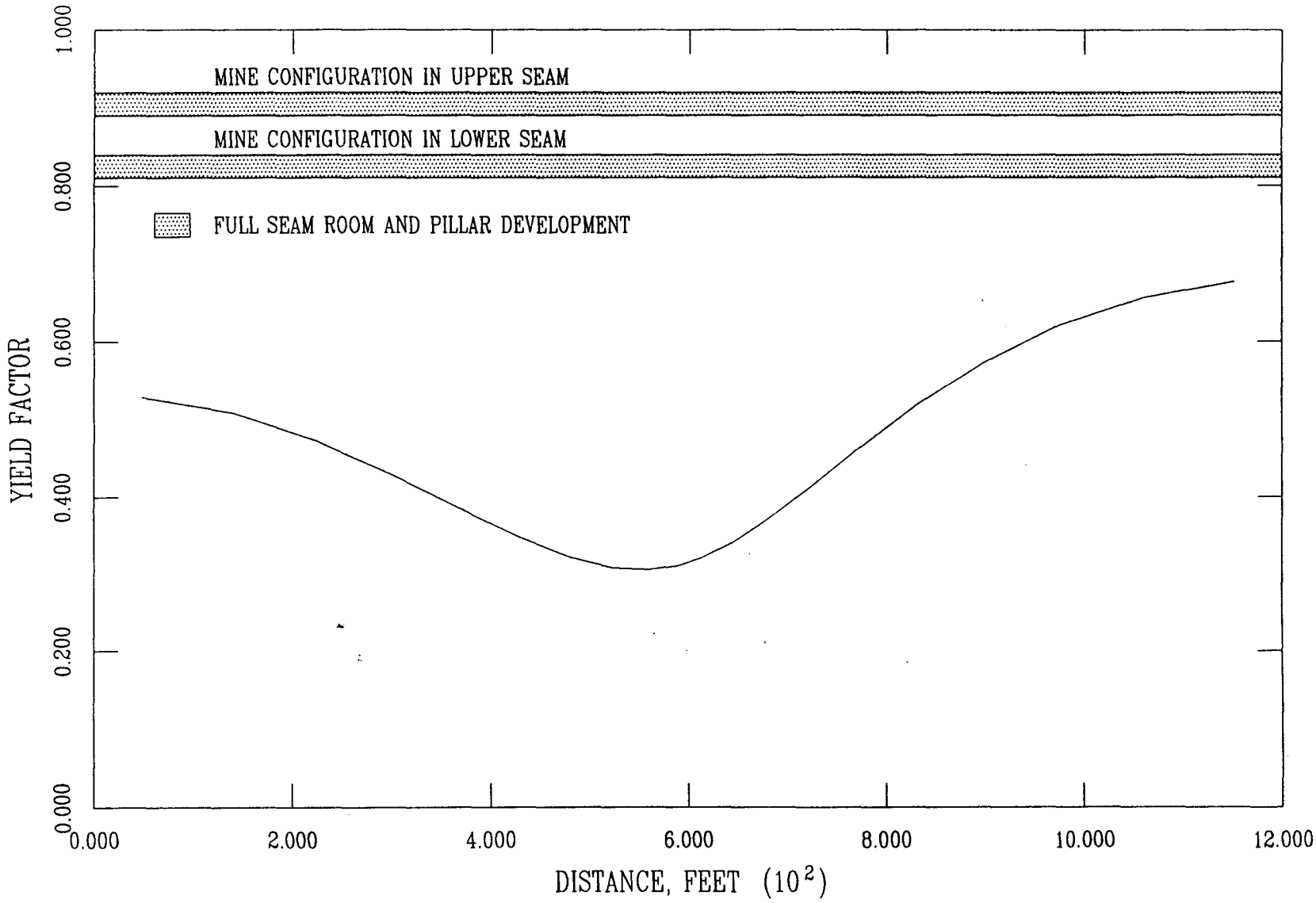

Figure C-22. Profile of yield factor in overburden above upper seam after complete full seam development of both seams. Overburden Quality = "GOOD".

APPENDIX D

ANALYSIS OF SINGLE LEVEL MINING IN BOTH SEAMS WITH OVERBURDEN QUALITY = "FAIR"

The figures contained in this appendix show profiles of stress in both the upper and lower seam at various stages of development for top coal development only. Overburden quality is assumed to be "FAIR" for these results. Diagrams at the top of each figure schematically indicate the configuration of mine development to which the results apply. Also shown are profiles of yield factor in the overburden immediately above the upper coal seam. Yield factor is defined as the ratio of maximum shear stress at a location to the existing shear strength at that location. Consequently, a yield factor of 1 would indicate that the rock is yielding, and a yield factor of less than 1 indicates that the rock has not yet been loaded to its full capacity. A yield factor in excess of 1 is not possible in an ideally plastic model in that plastic flow would modify the stress state back to a yield factor of 1.

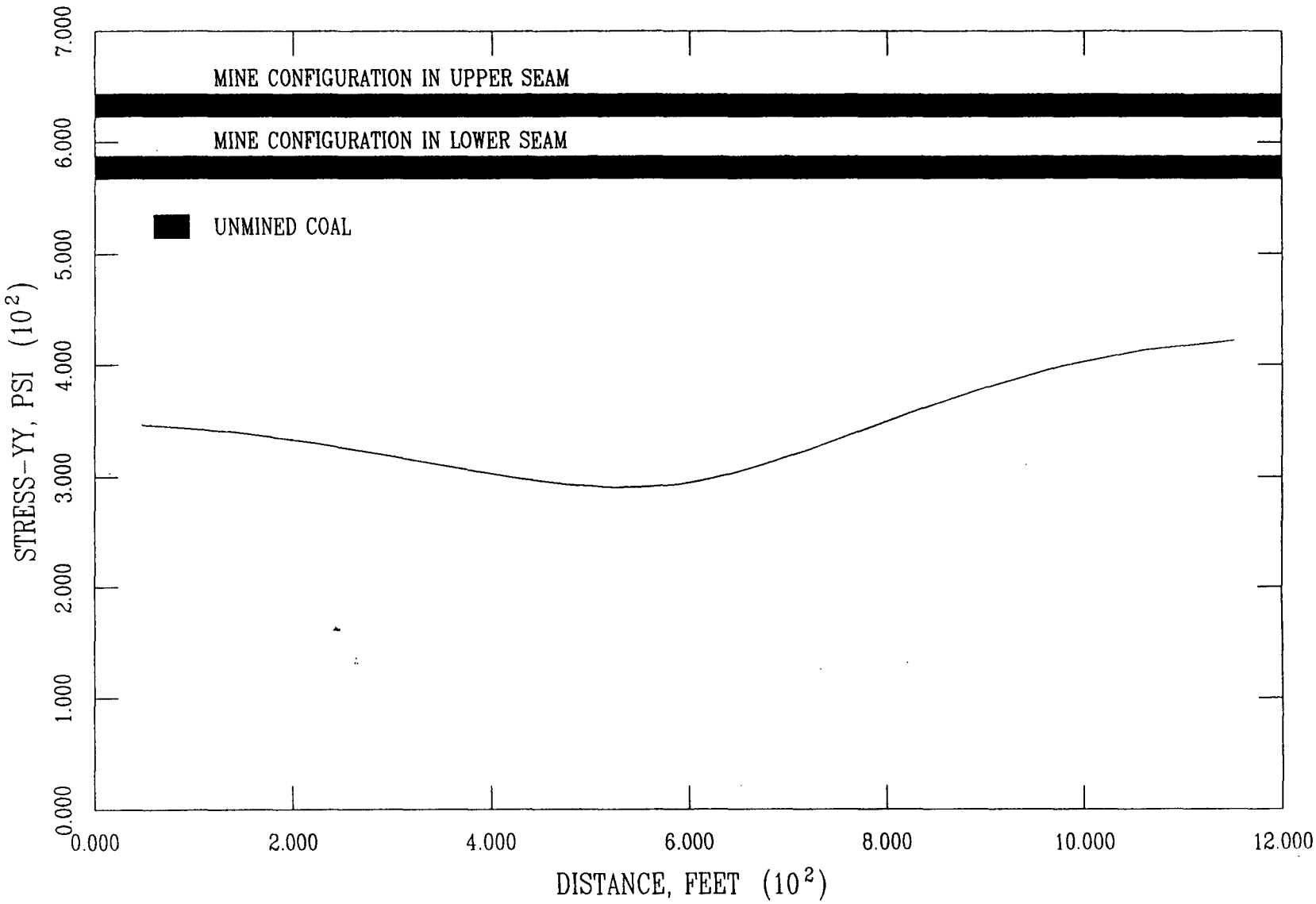

Figure D-1. Profile of vertical equivalent stress in the upper seam prior to any mining activity. Overburden Quality = "FAIR".

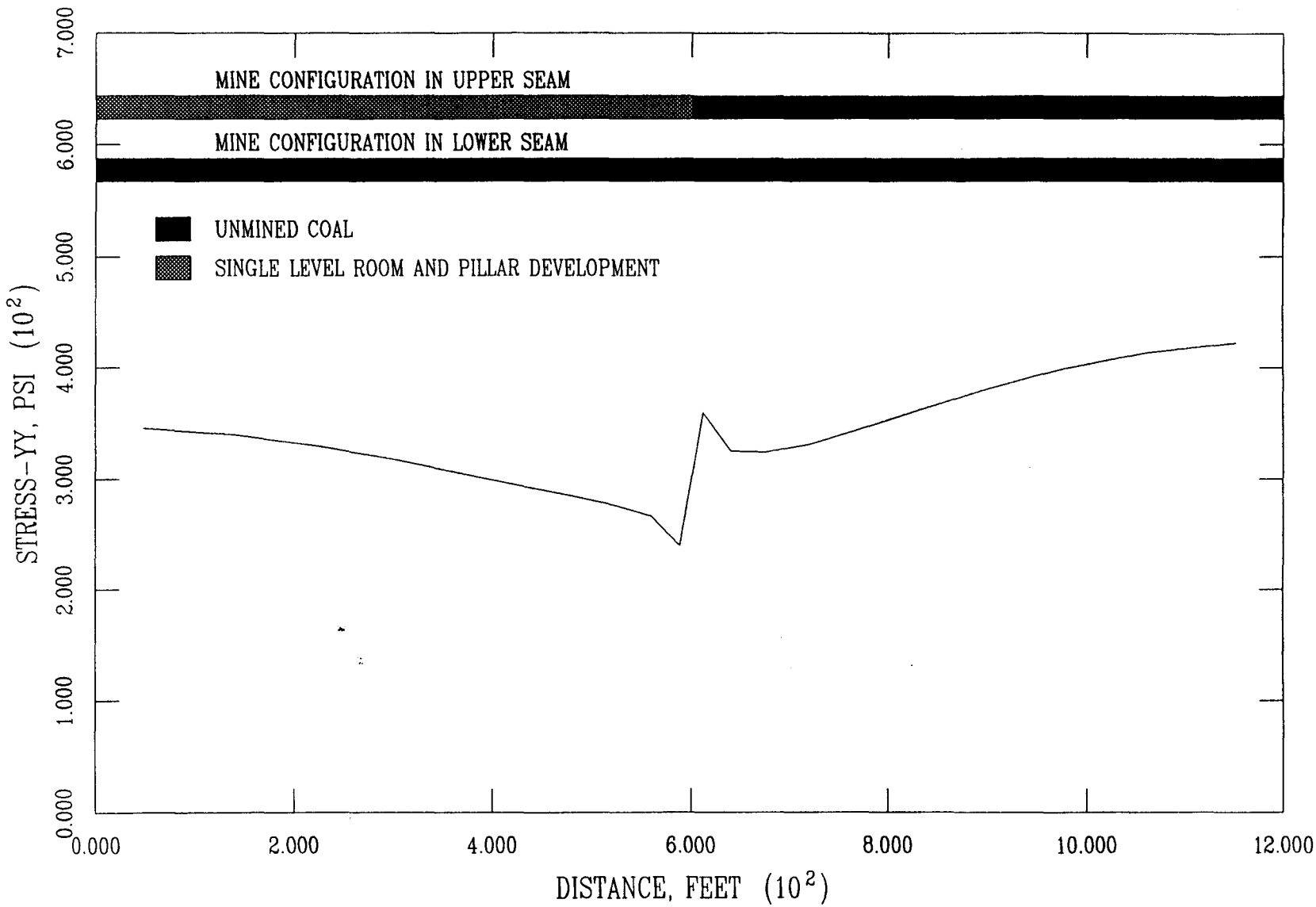

Figure D-2. Profile of vertical equivalent stress in the upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

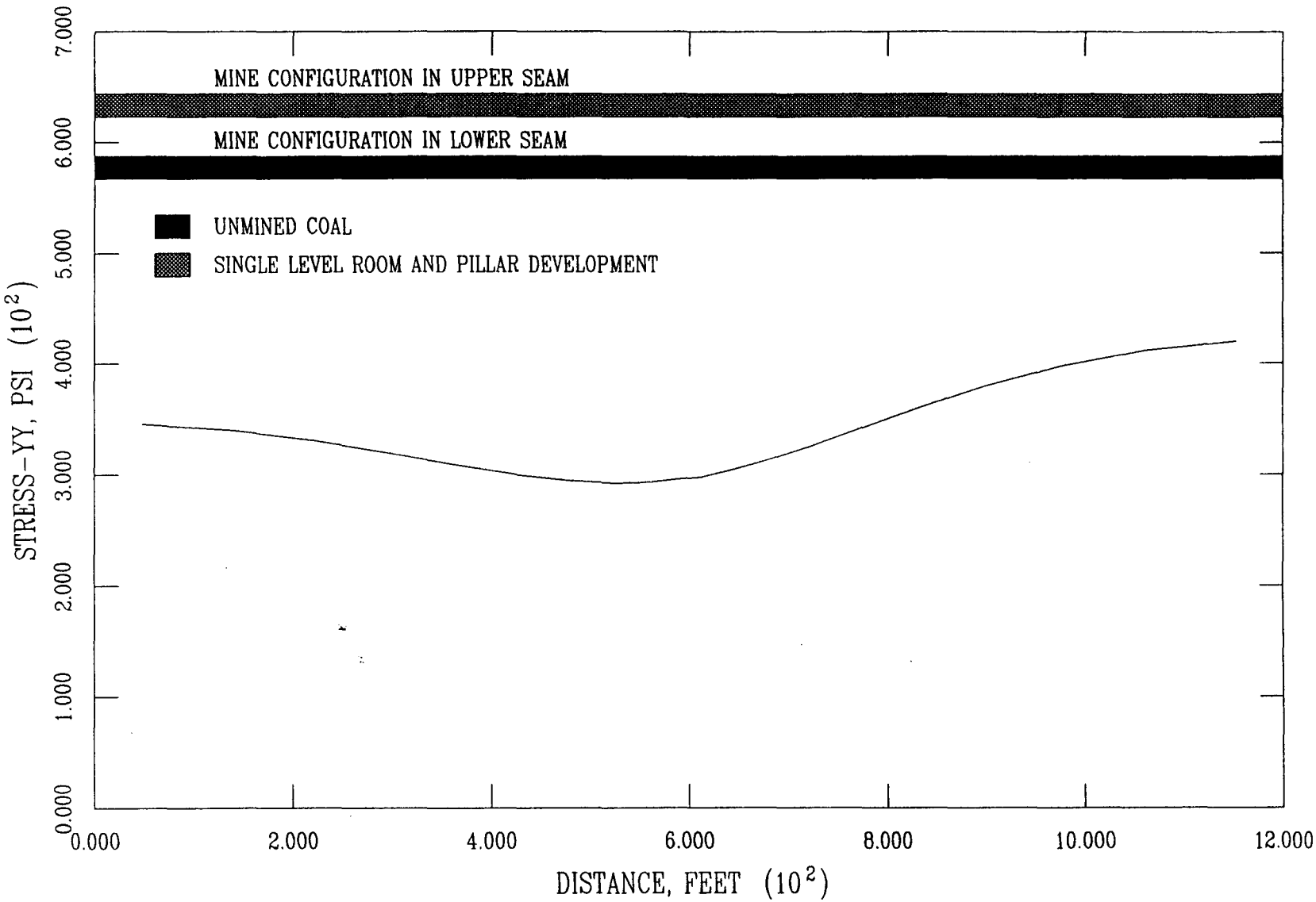

Figure D-3. Profile of vertical equivalent stress in the upper seam after complete development of the top coal of the upper seam. Overburden Quality = "FAIR".

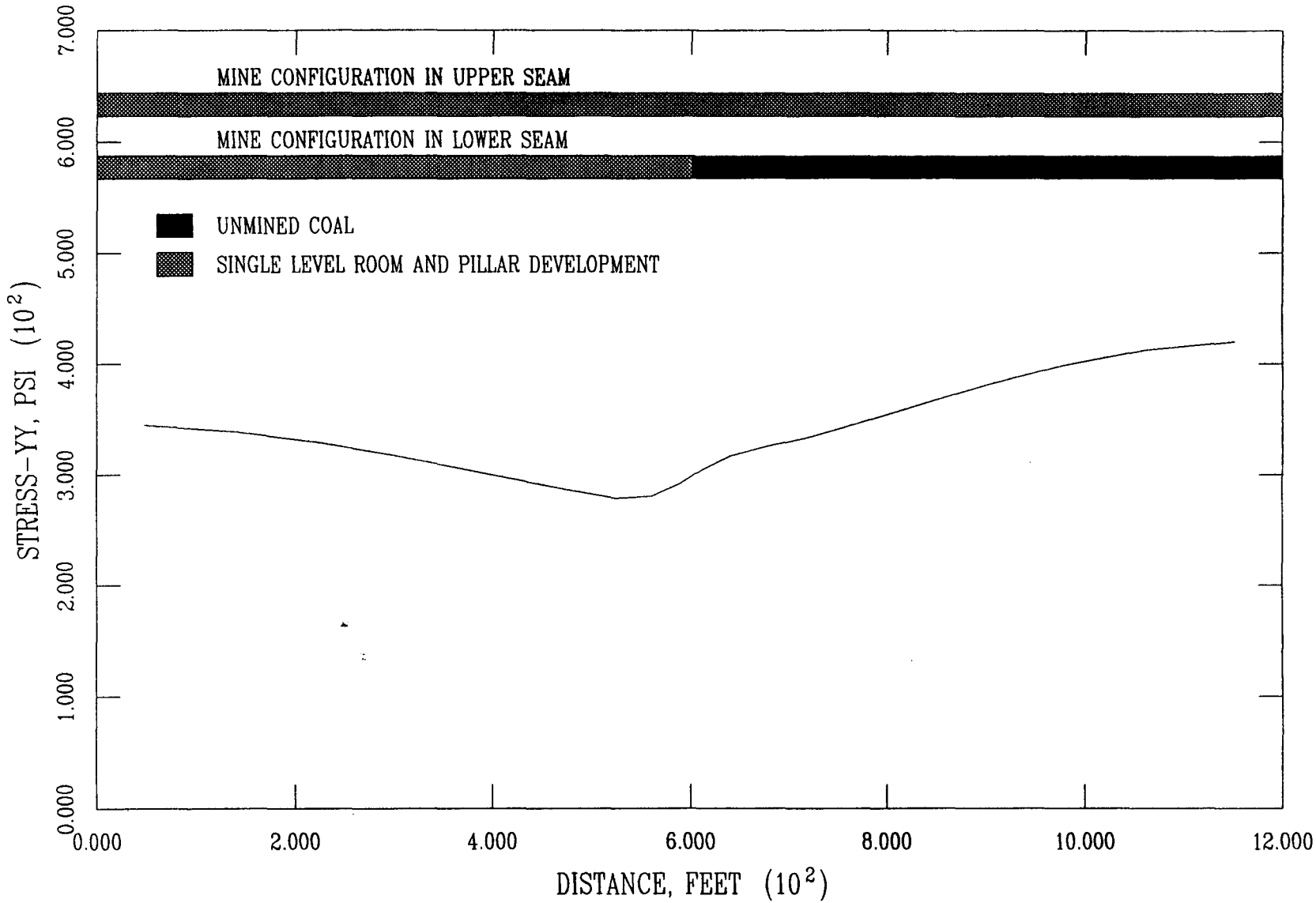

Figure D-4. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

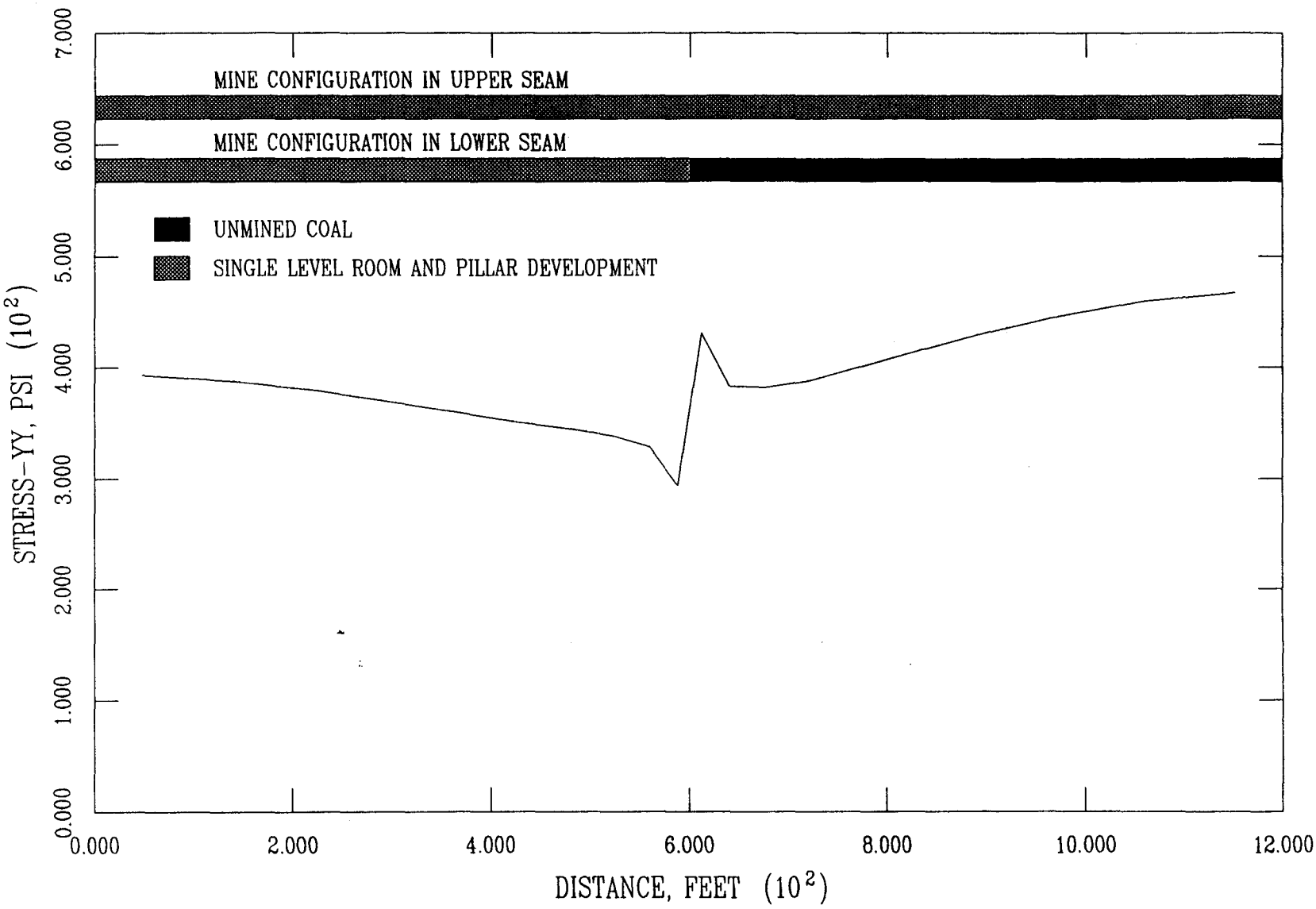

Figure D-5. Profile of vertical equivalent stress in the lower seam after complete development of the top coal in the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

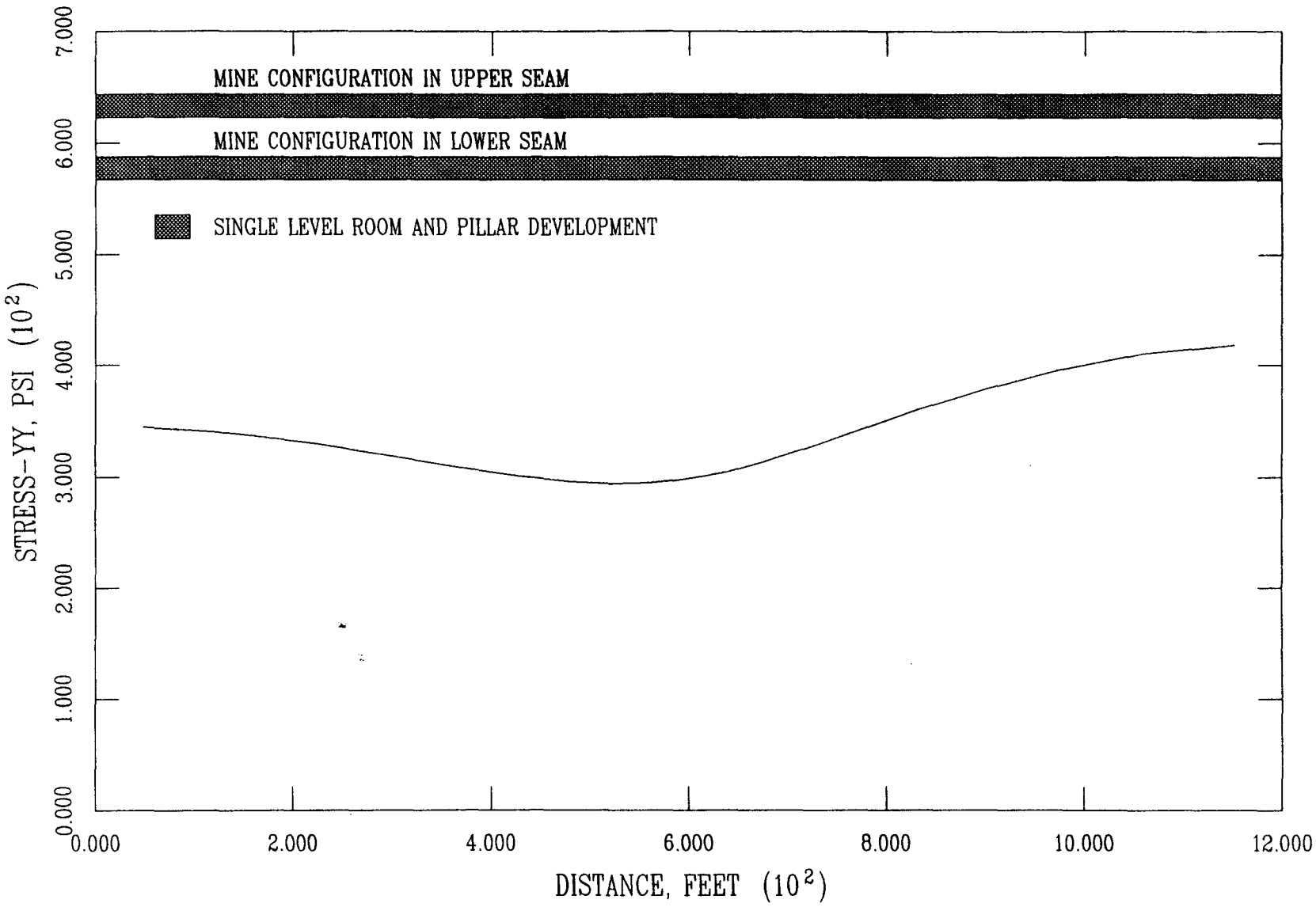

Figure D-6. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in both the upper and lower seams. Overburden Quality = "FAIR".

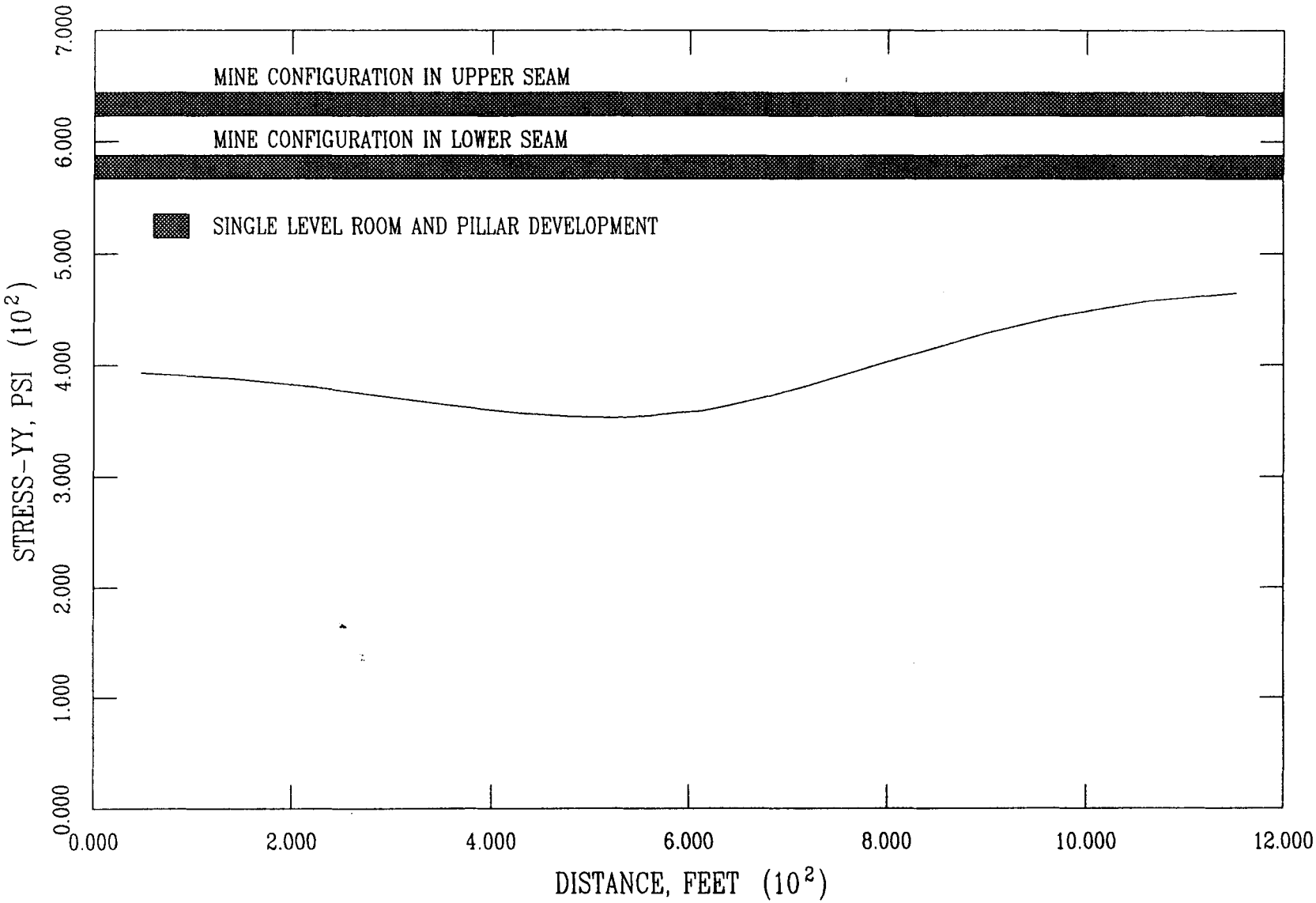

Figure D-7. Profile of vertical equivalent stress in the lower seam after complete development of the top coal in both the upper and lower seams. Overburden Quality = "FAIR".

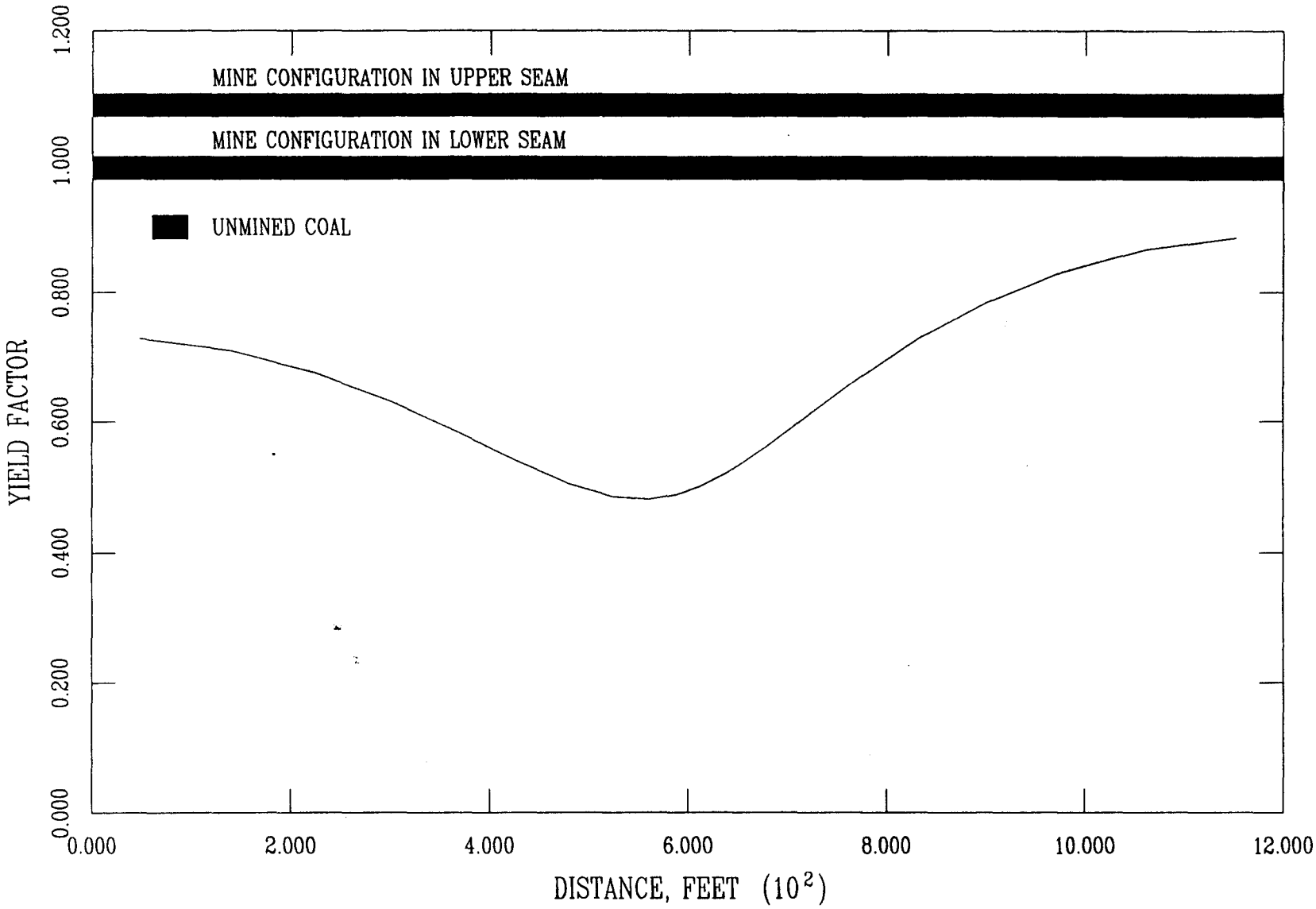

Figure D-8. Profile of yield factor in overburden above upper seam prior to any mining activity. Overburden Quality = "FAIR".

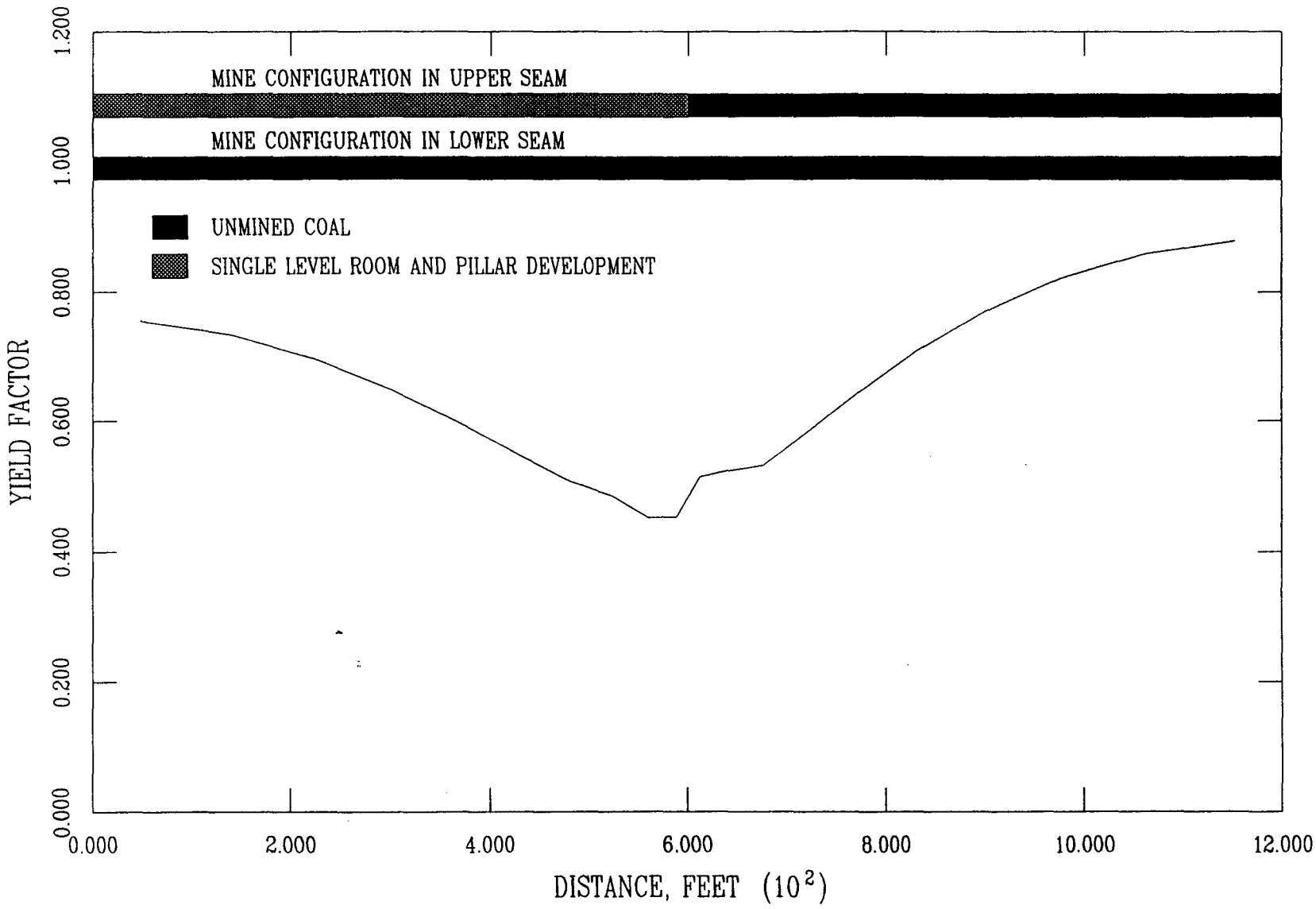

Figure D-9. Profile of yield factor in overburden above upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

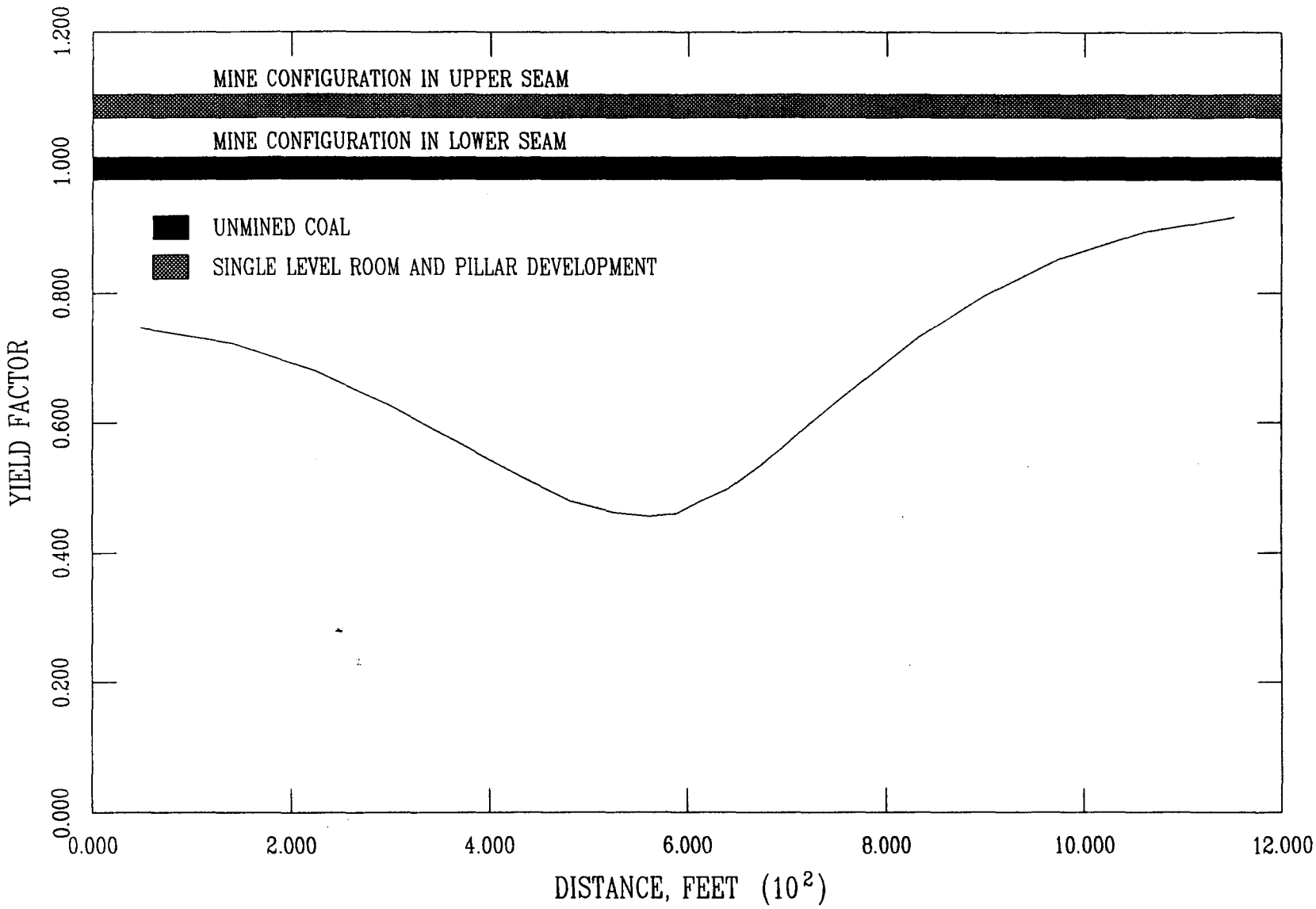

Figure D-10. Profile of yield factor in overburden above upper seam after complete development of the top coal of the upper seam. Overburden Quality = "FAIR".

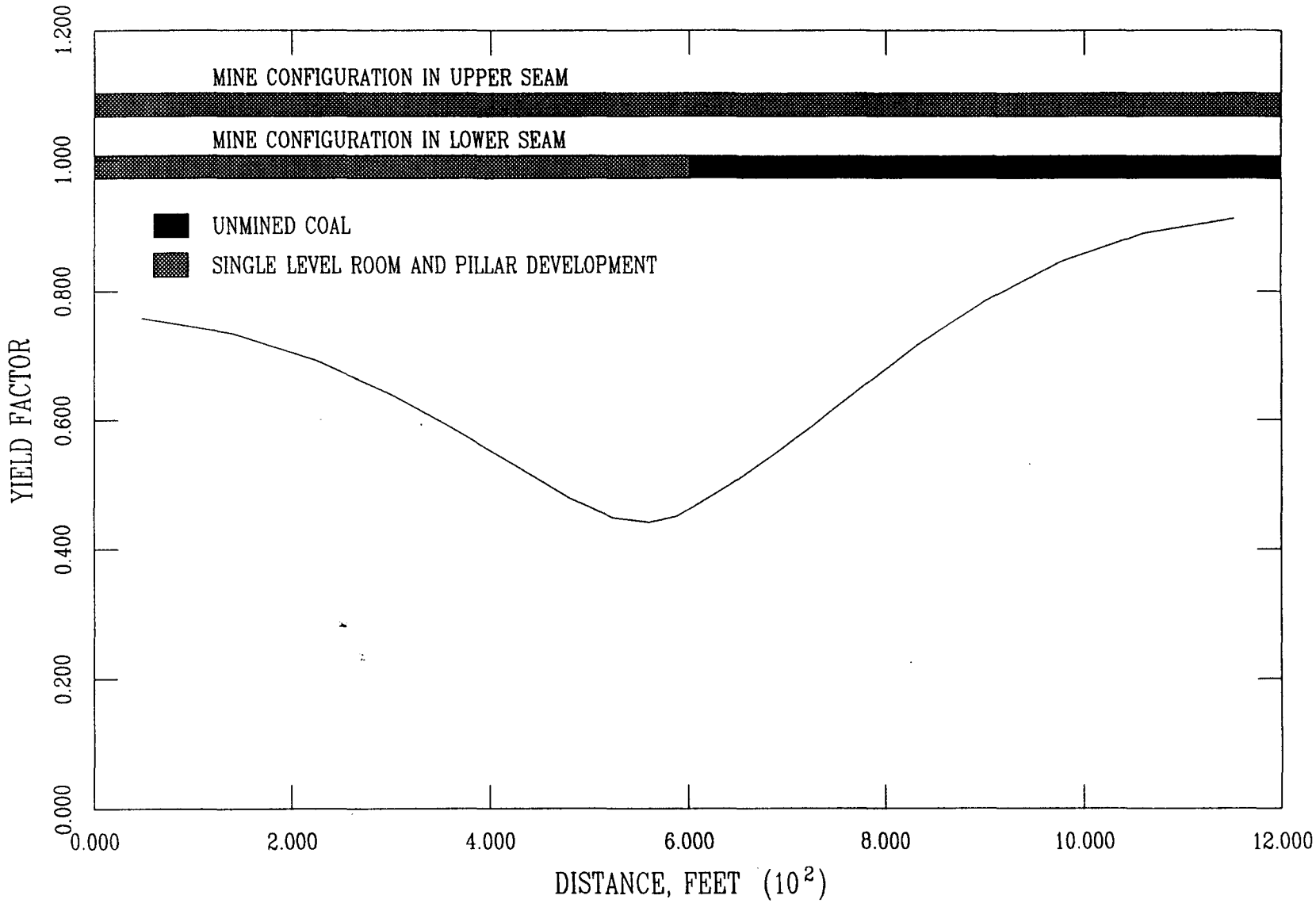

Figure D-11. Profile of yield factor in overburden above upper seam after complete development of the top coal in the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

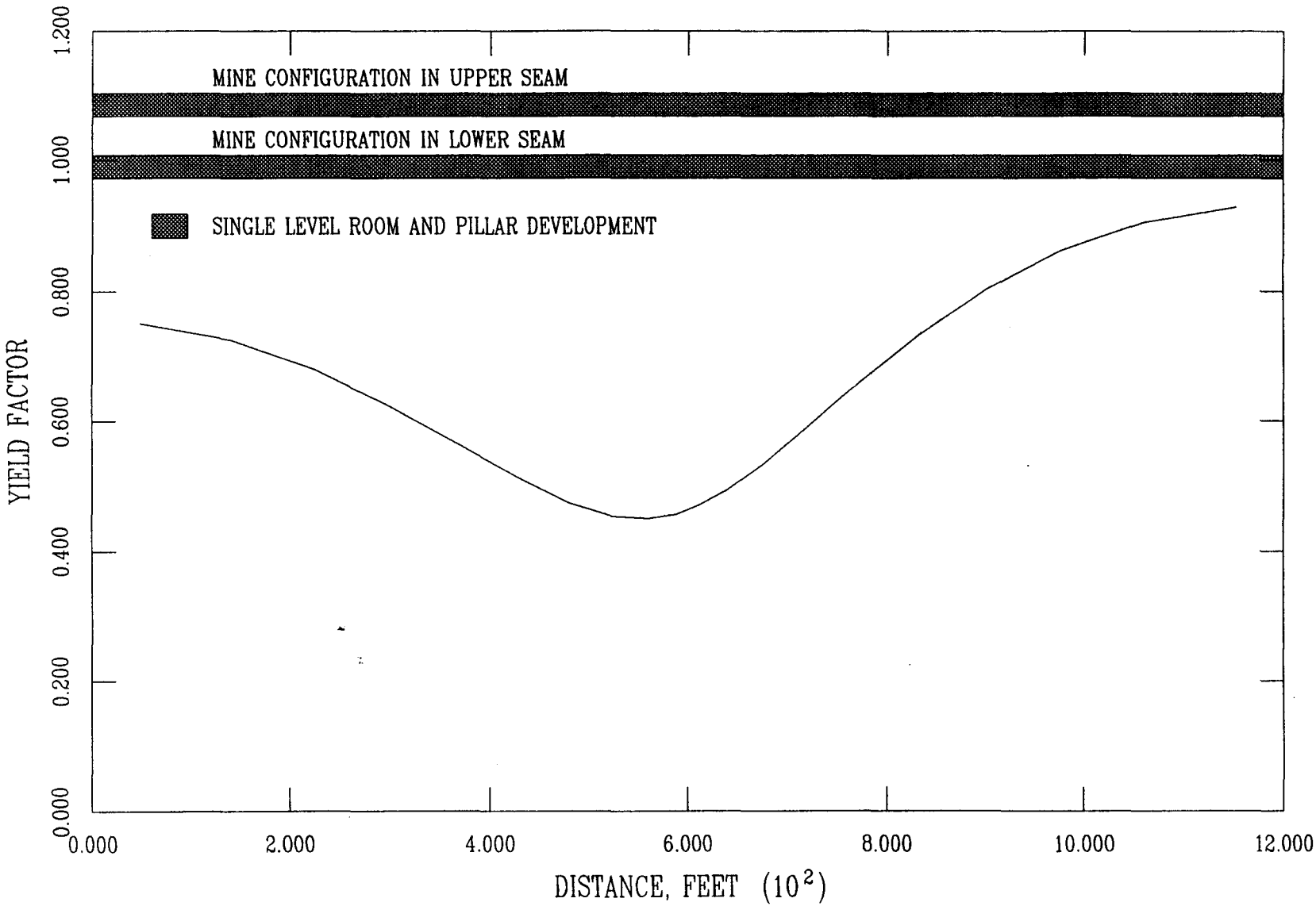

Figure D-12. Profile of yield factor in overburden above upper seam after complete development of the top coal in both the upper and lower seams. Overburden Quality = "FAIR".

APPENDIX E

ANALYSIS OF DOUBLE LEVEL MINING IN BOTH SEAMS WITH OVERBURDEN QUALITY = "FAIR"

The figures contained in this appendix show profiles of stress in both the upper and lower seam at various stages of development for full seam development. Overburden quality is assumed to be "FAIR" for these results. Diagrams at the top of each figure schematically indicate the configuration of mine development to which the results apply. Also shown are profiles of yield factor in the overburden immediately above the upper coal seam. Yield factor is defined as the ratio of maximum shear stress at a location to the existing shear strength at that location. Consequently, a yield factor of 1 would indicate that the rock is yielding, and a yield factor of less than 1 indicates that the rock has not yet been loaded to its full capacity. A yield factor in excess of 1 is not possible in an ideally plastic model in that plastic flow would modify the stress state back to a yield factor of 1.

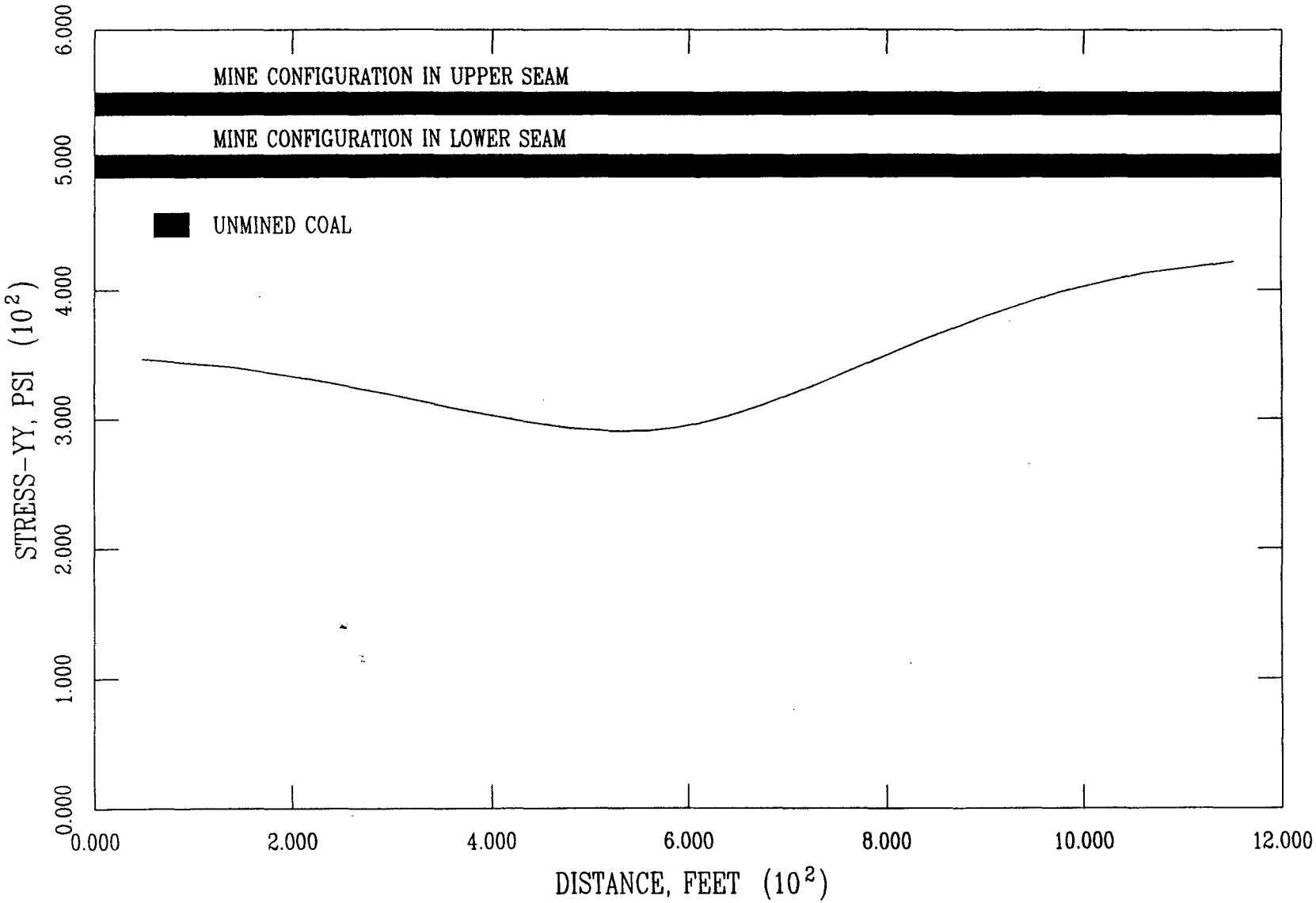

Figure E-1. Profile of vertical equivalent stress in the upper seam prior to any mining activity. Overburden Quality = "FAIR".

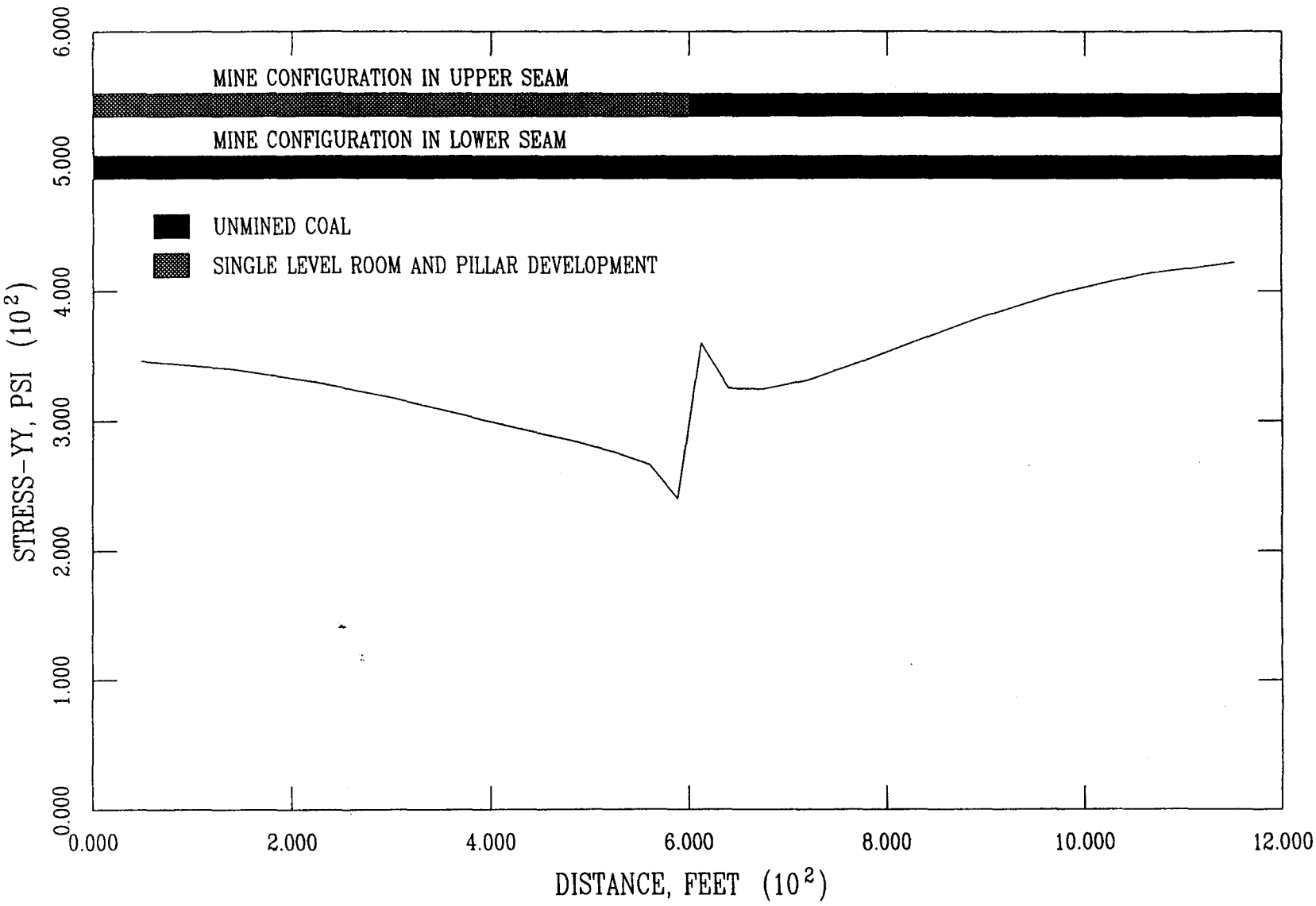

Figure E-2. Profile of vertical equivalent stress in the upper seam after development of the top coal of the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

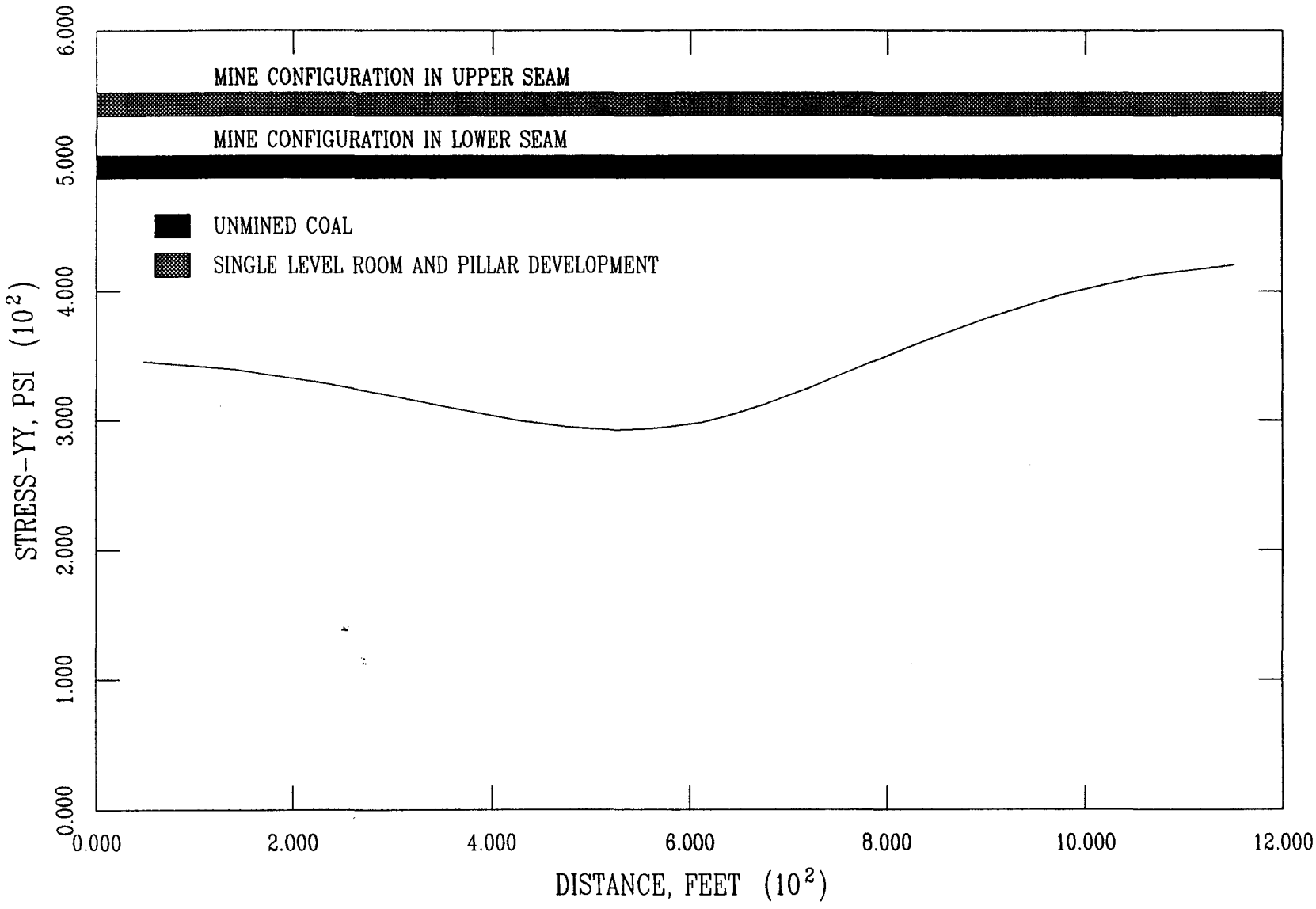

Figure E-3. Profile of vertical equivalent stress in the upper seam after complete development of the top coal of the upper seam. Overburden Quality = "FAIR".

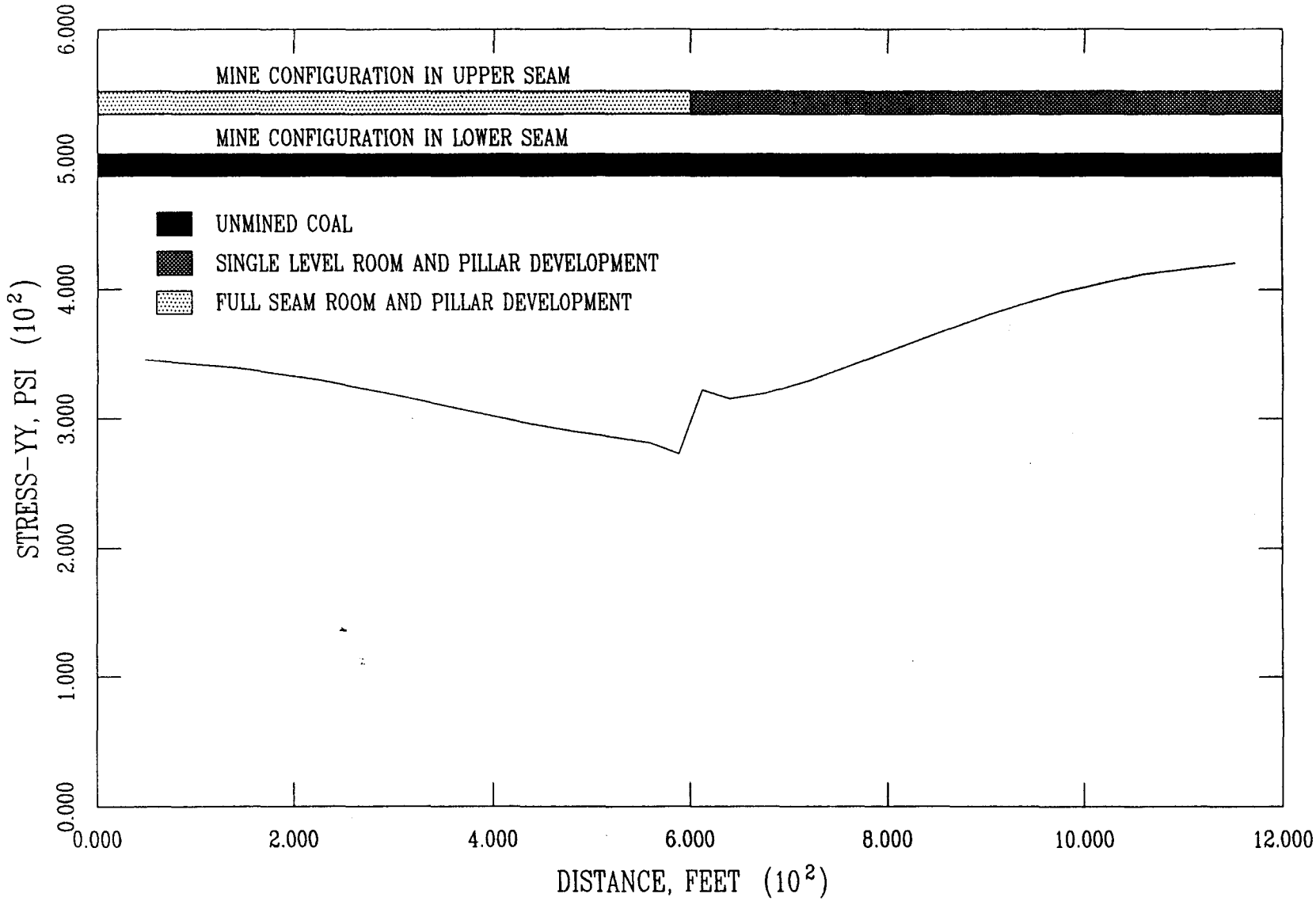

Figure E-4. Profile of vertical equivalent stress in the upper seam after complete development of the top coal in the upper seam, and development of the bottom coal in the upper seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

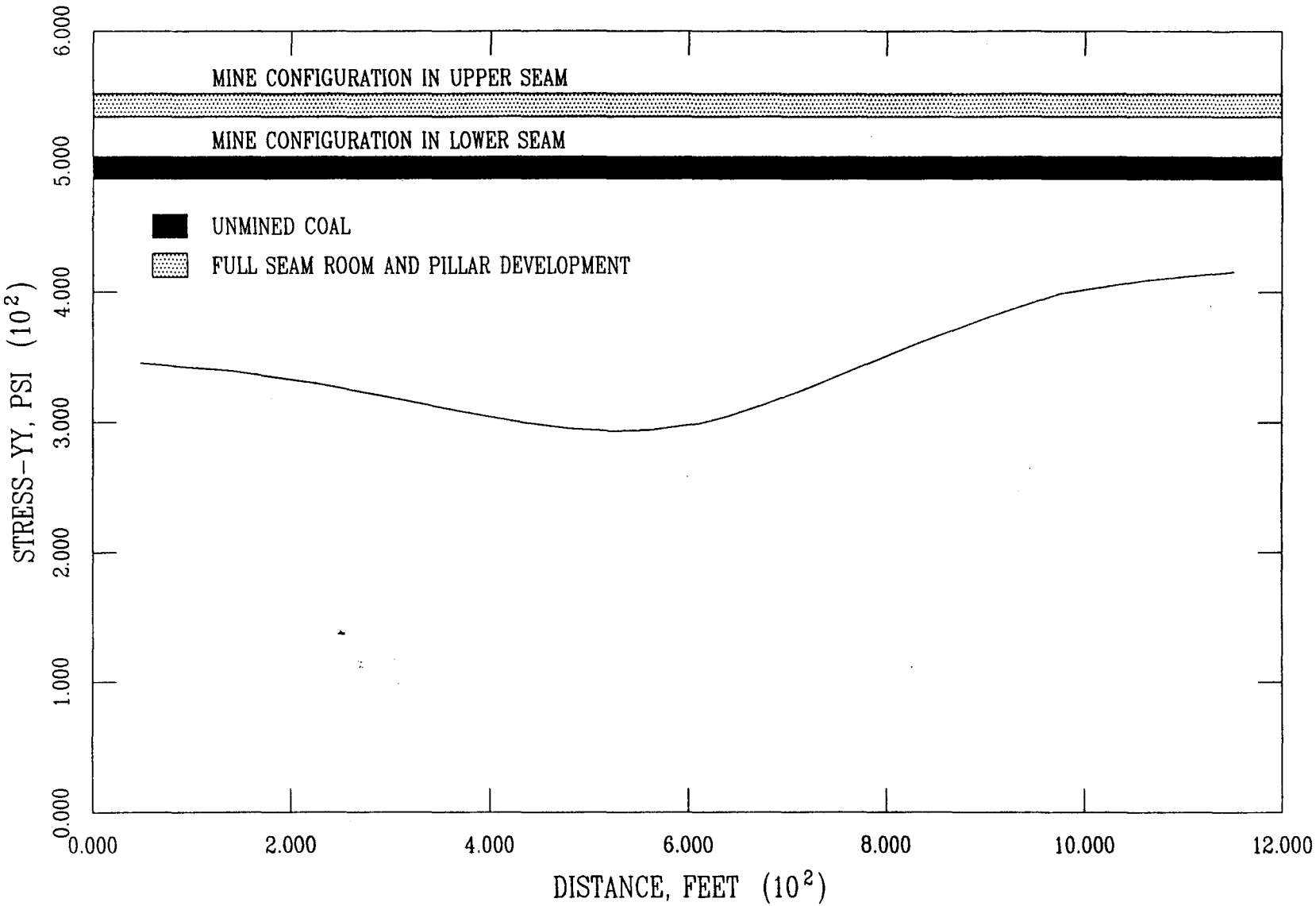

Figure E-5. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam. Overburden Quality = "FAIR".

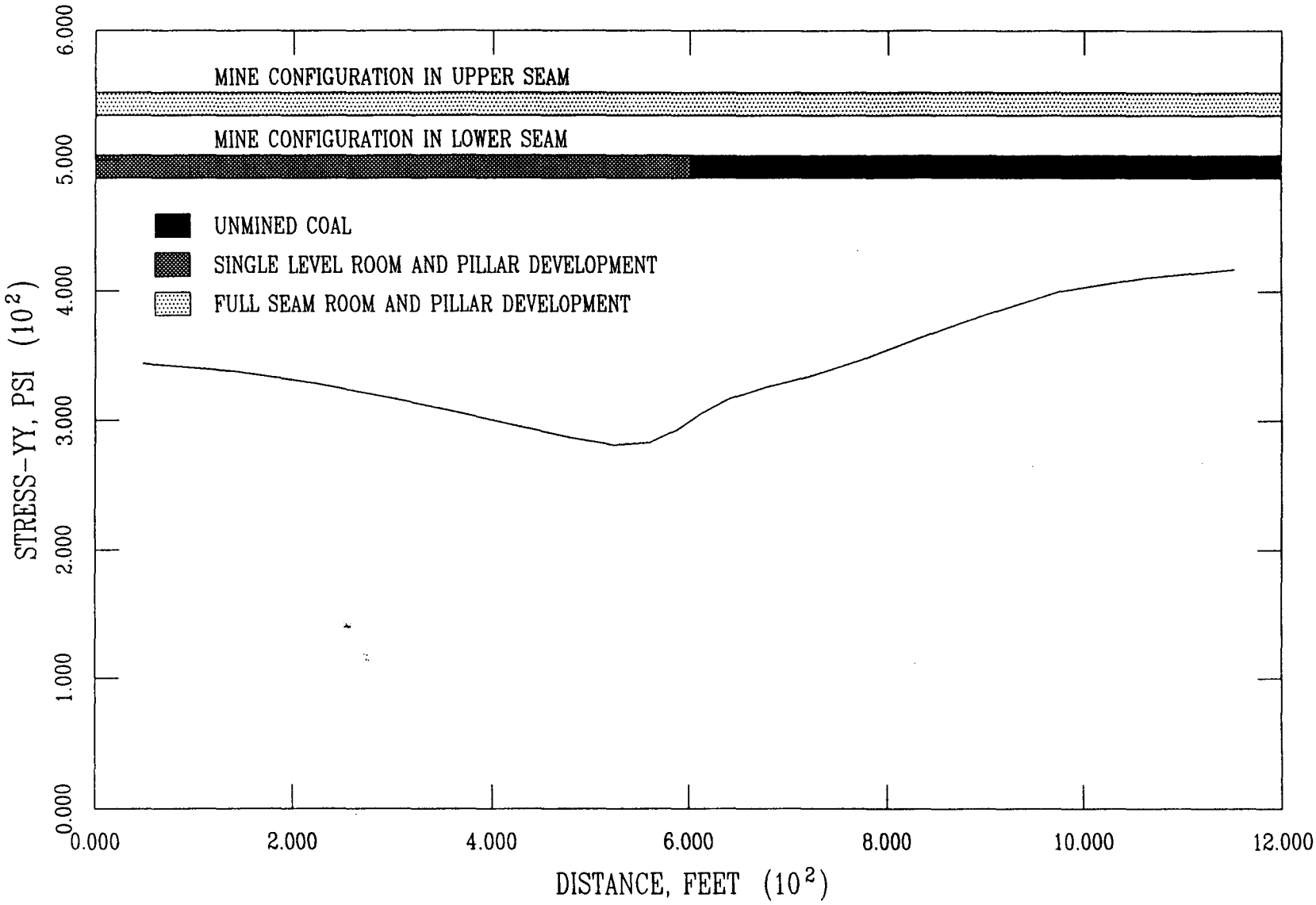

Figure E-6. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek.
Overburden Quality = "FAIR".

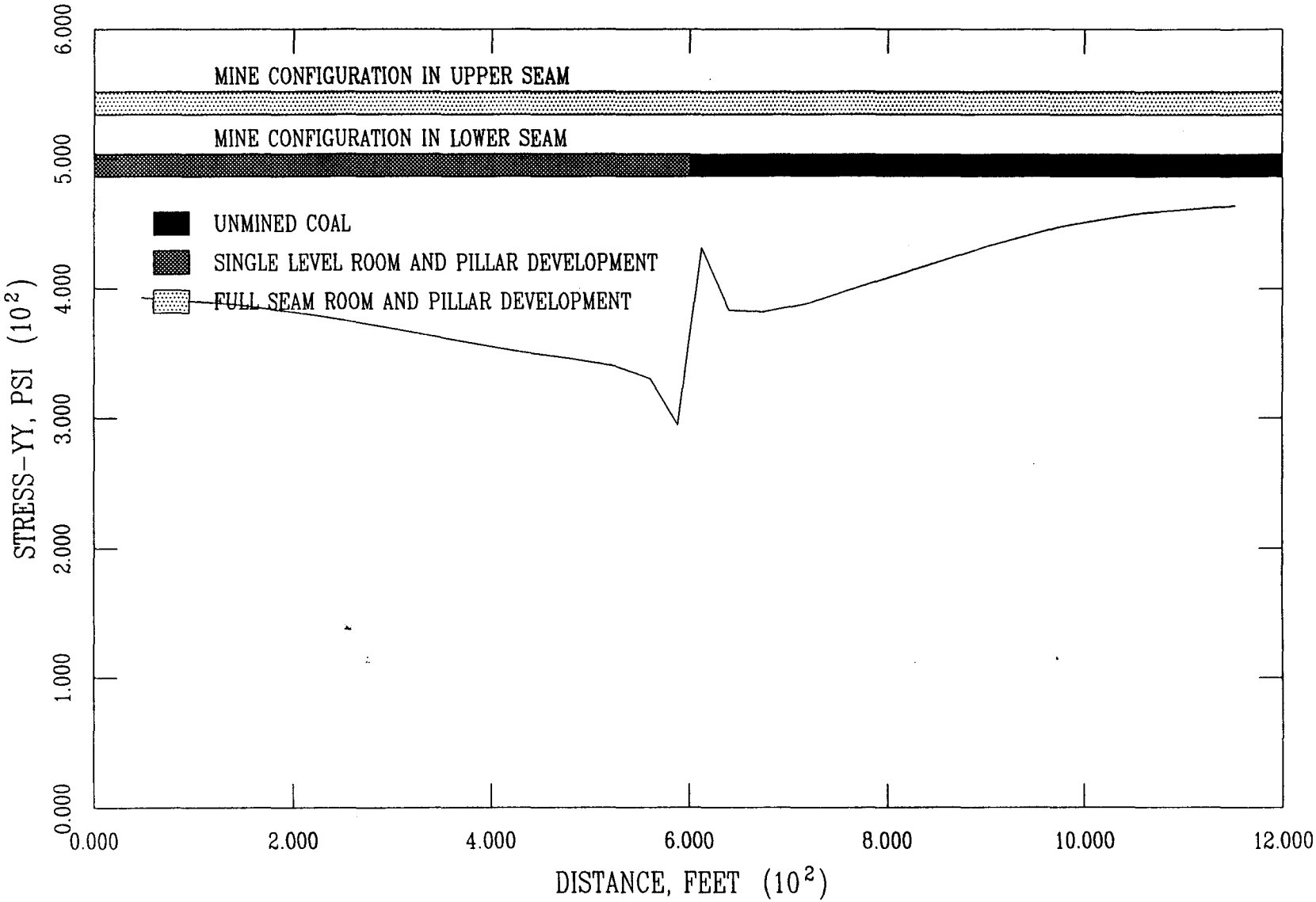

Figure E-7. Profile of vertical equivalent stress in the lower seam after complete full seam development of the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek.
Overburden Quality = "FAIR".

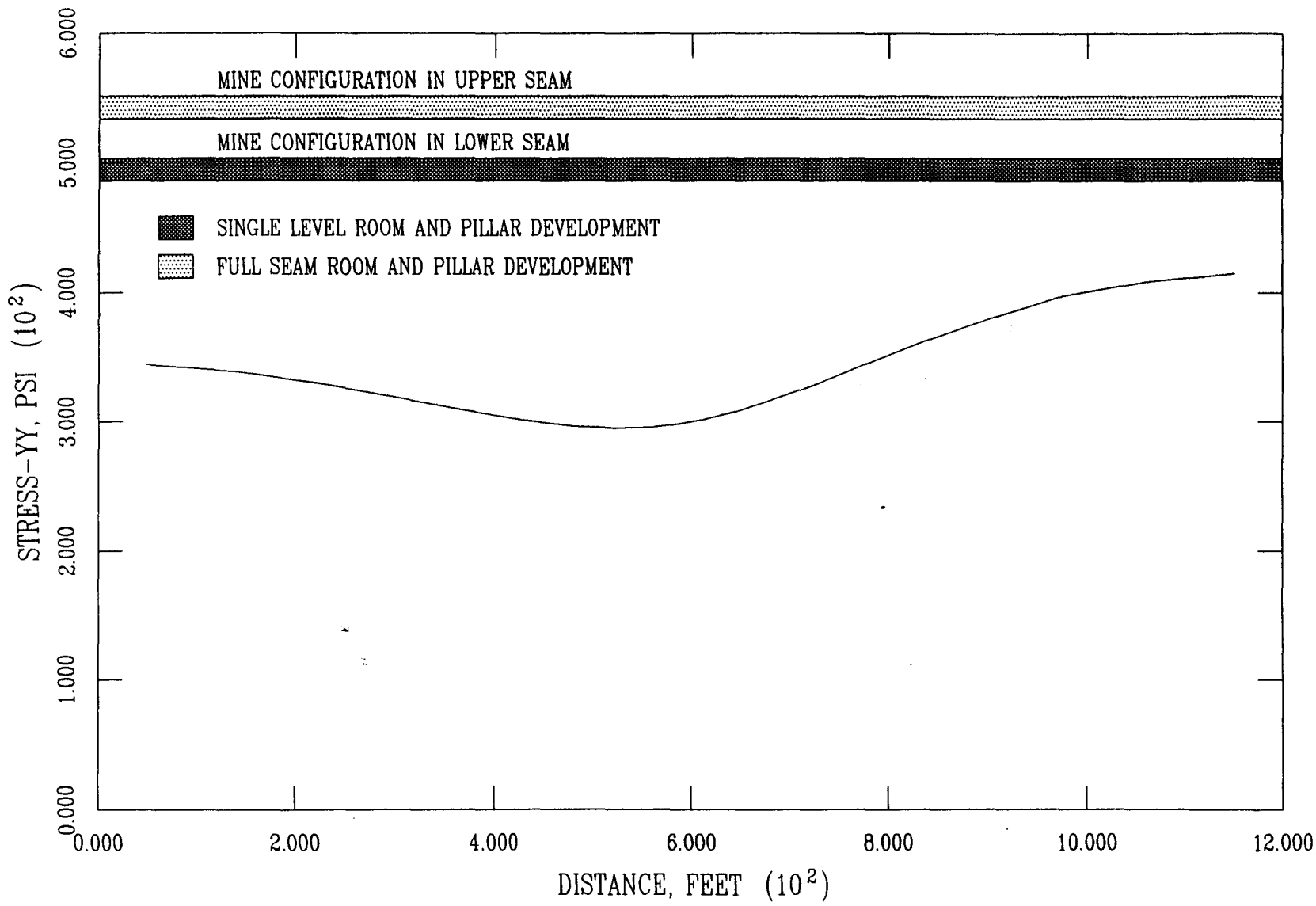

Figure E-8. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam, and complete development of the top coal in the lower seam. Overburden Quality = "FAIR".

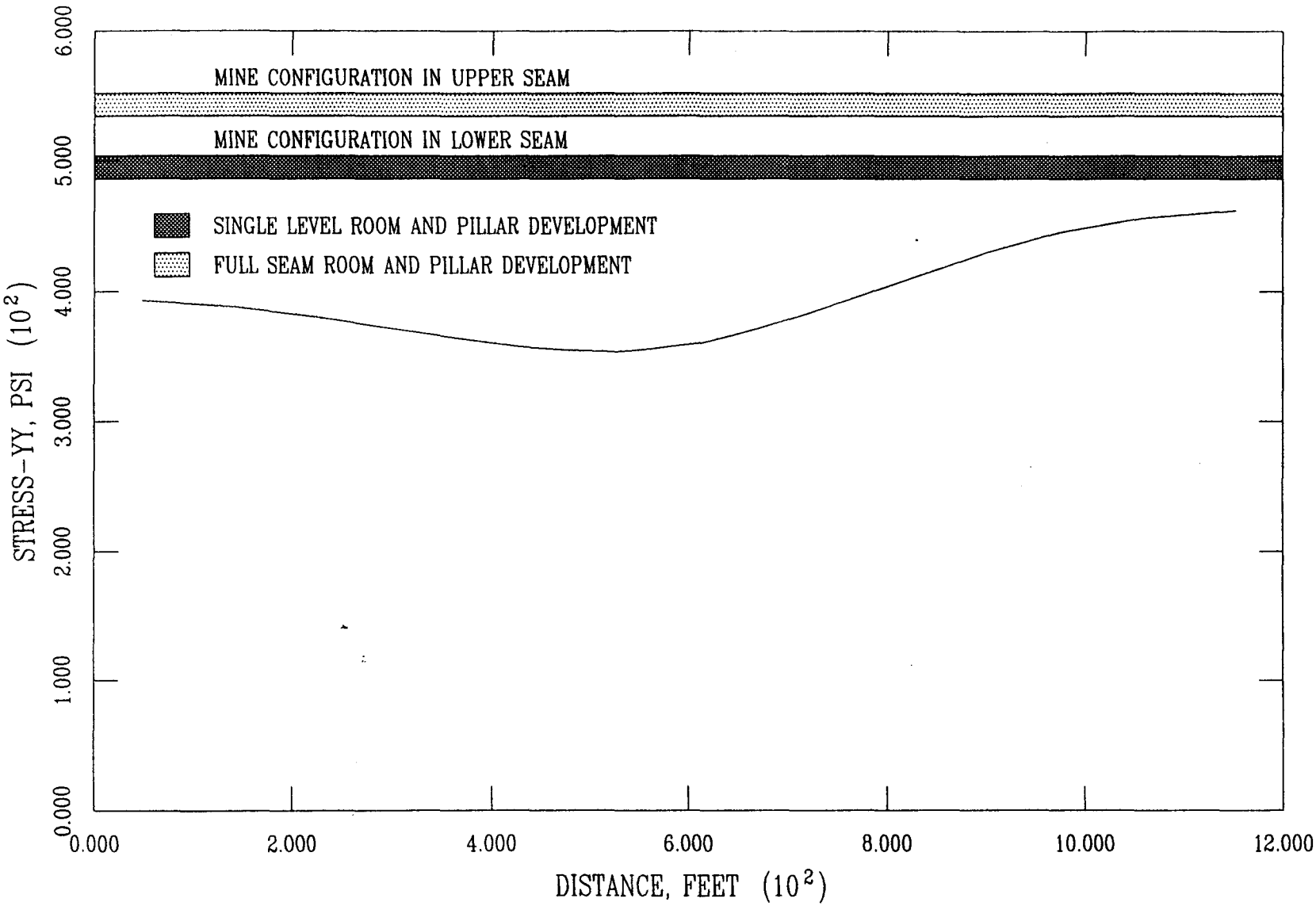

Figure E-9. Profile of vertical equivalent stress in the lower seam after complete full seam development of the upper seam, and complete development of the top coal in the lower seam. Overburden Quality = "FAIR".

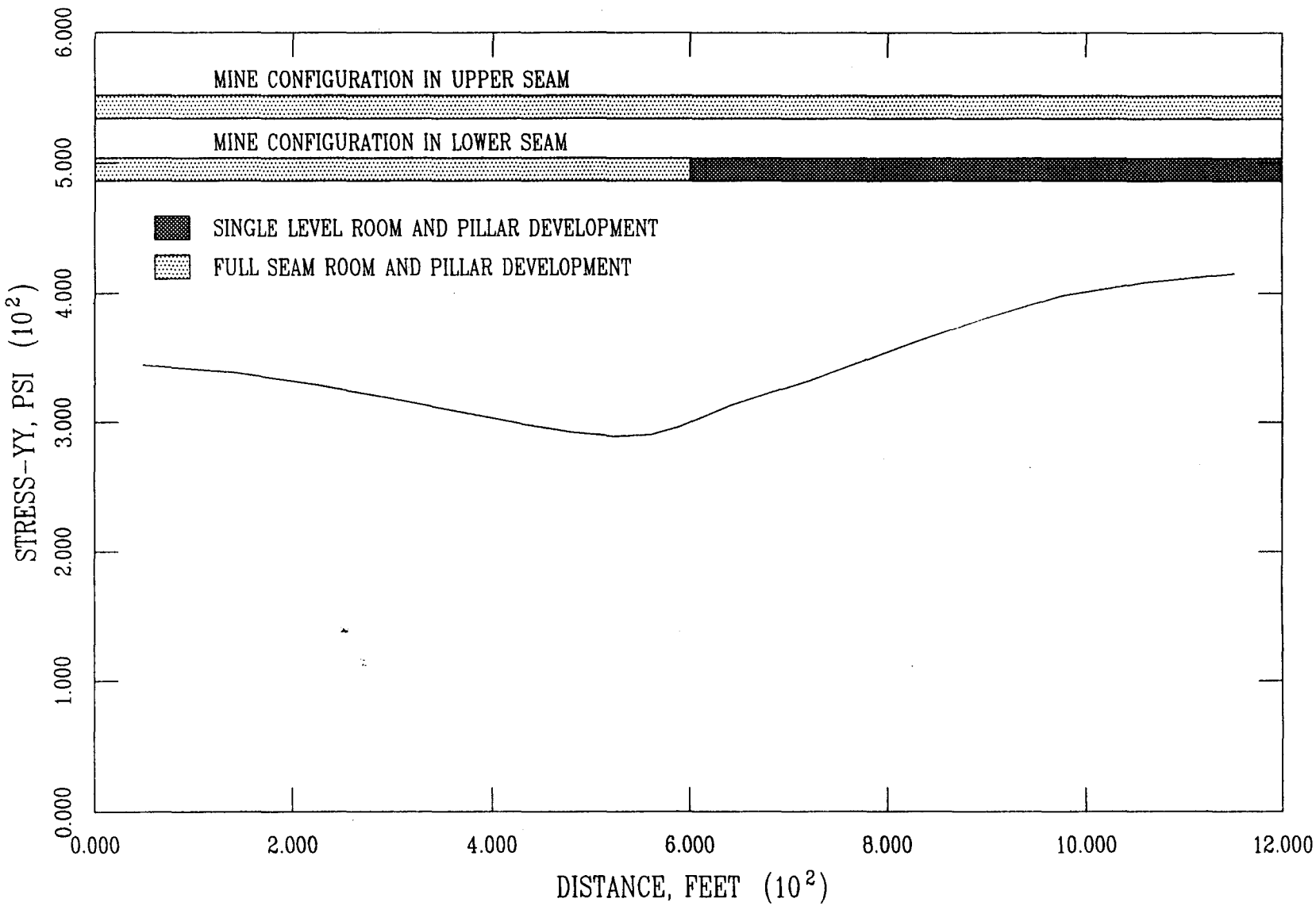

Figure E-10. Profile of vertical equivalent stress in the upper seam after complete full seam development of the upper seam, complete development of the top coal in the lower seam, and development of the bottom coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

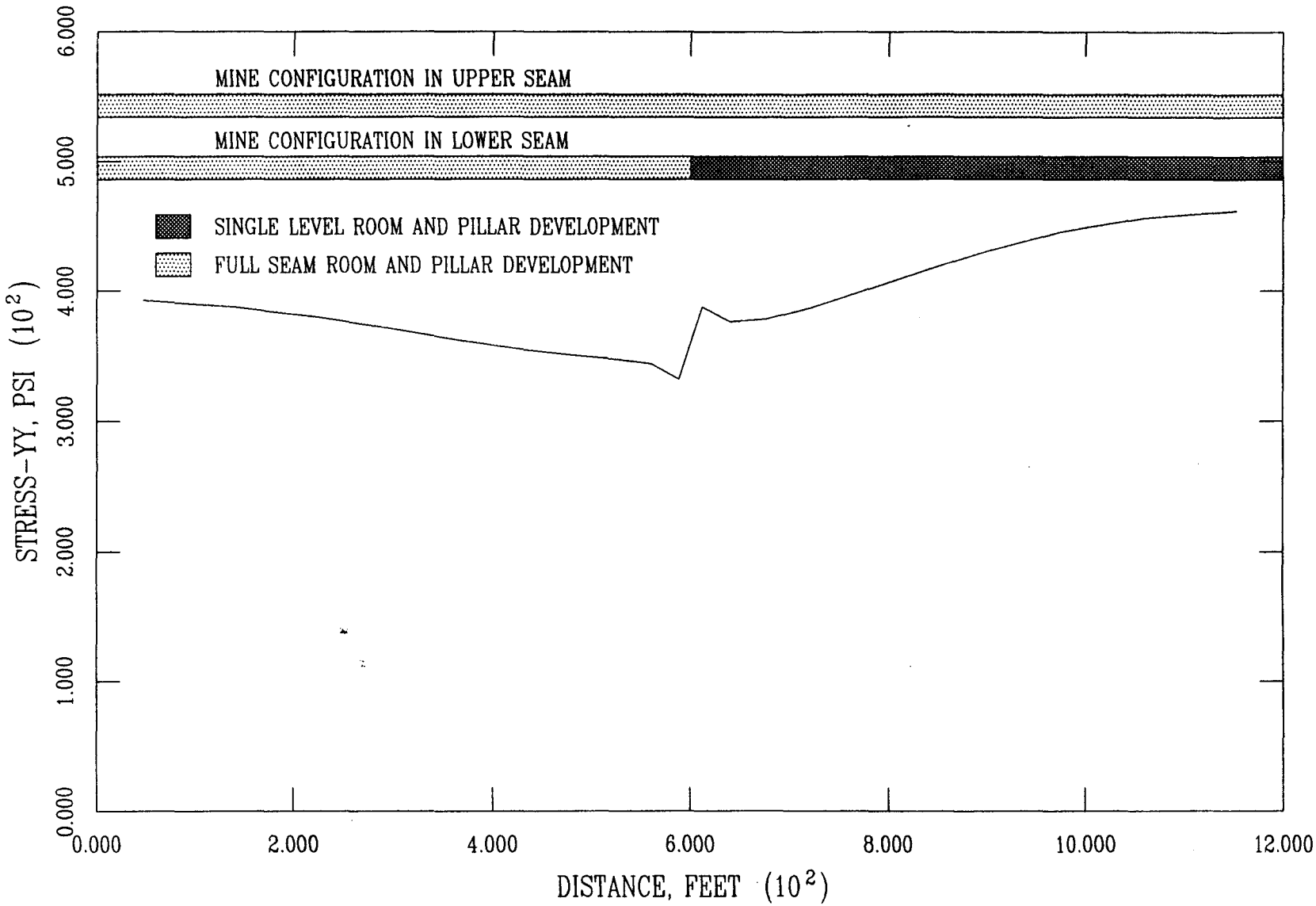

Figure E-11. Profile of vertical equivalent stress in the lower seam after complete full seam development of the upper seam, complete development of the top coal in the lower seam, and development of the bottom coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

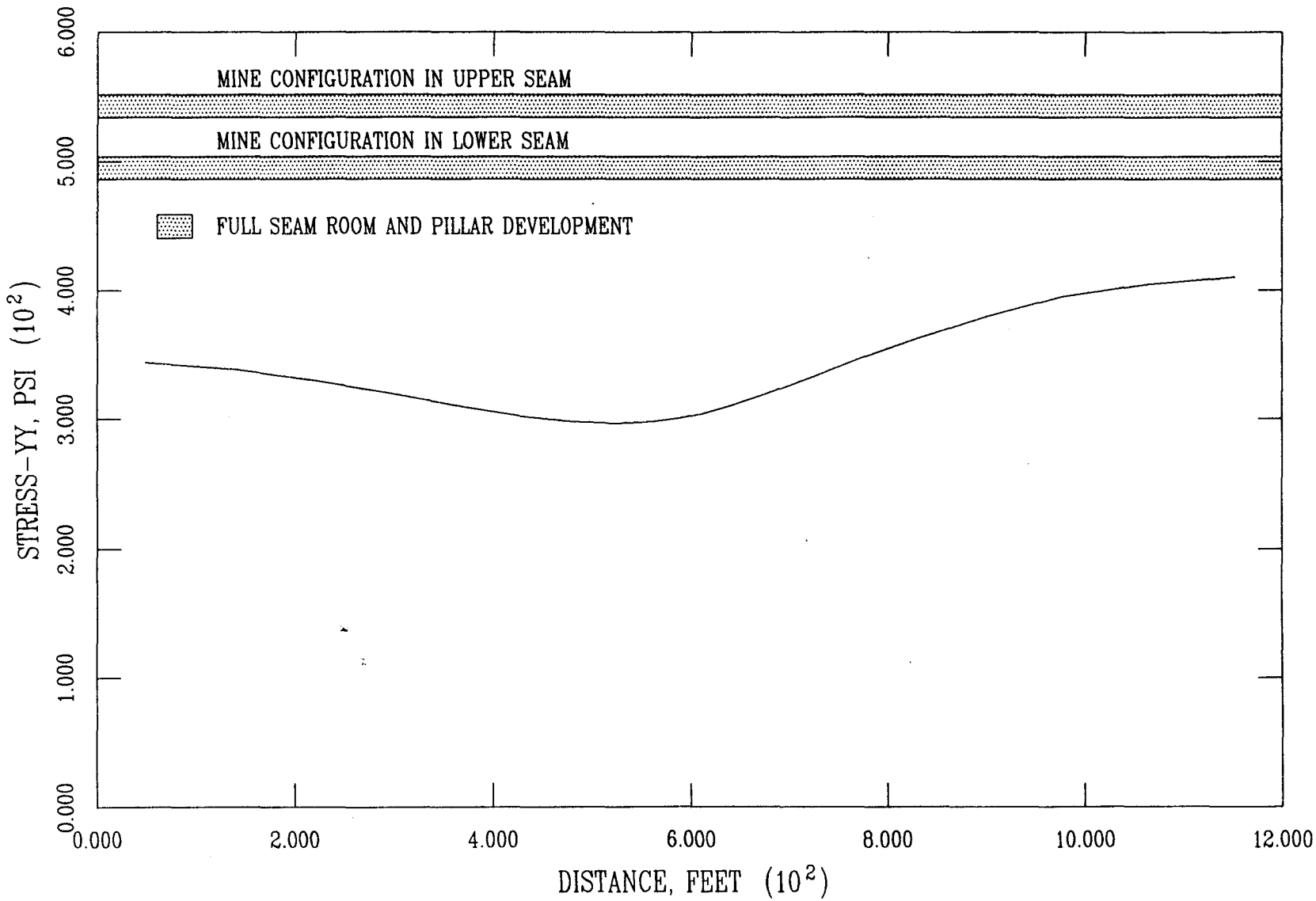

Figure E-12. Profile of vertical equivalent stress in the upper seam after complete full seam development of both seams. Overburden Quality = "FAIR".

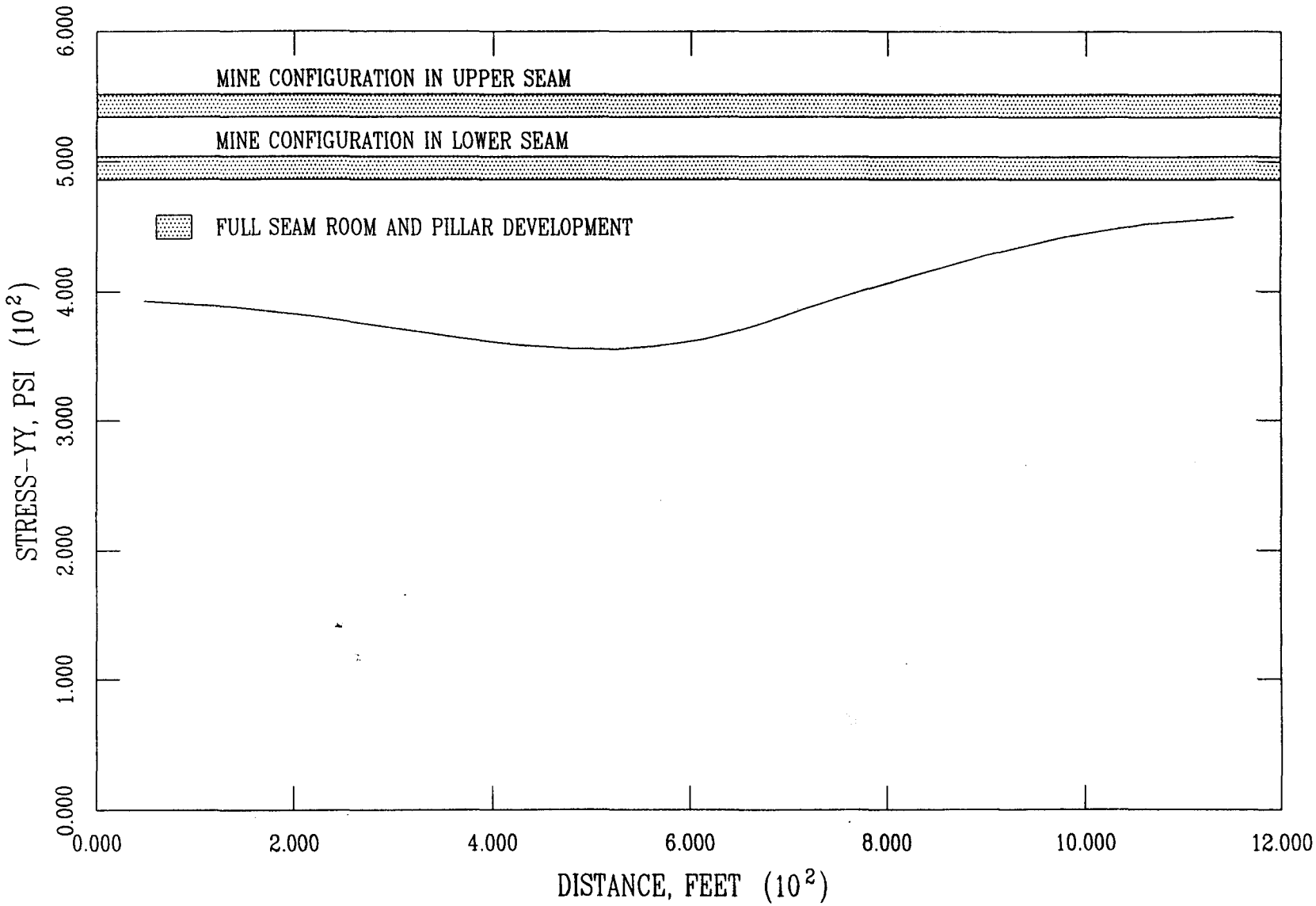

Figure E-13. Profile of vertical equivalent stress in the lower seam after complete full seam development of both seams. Overburden Quality = "FAIR".

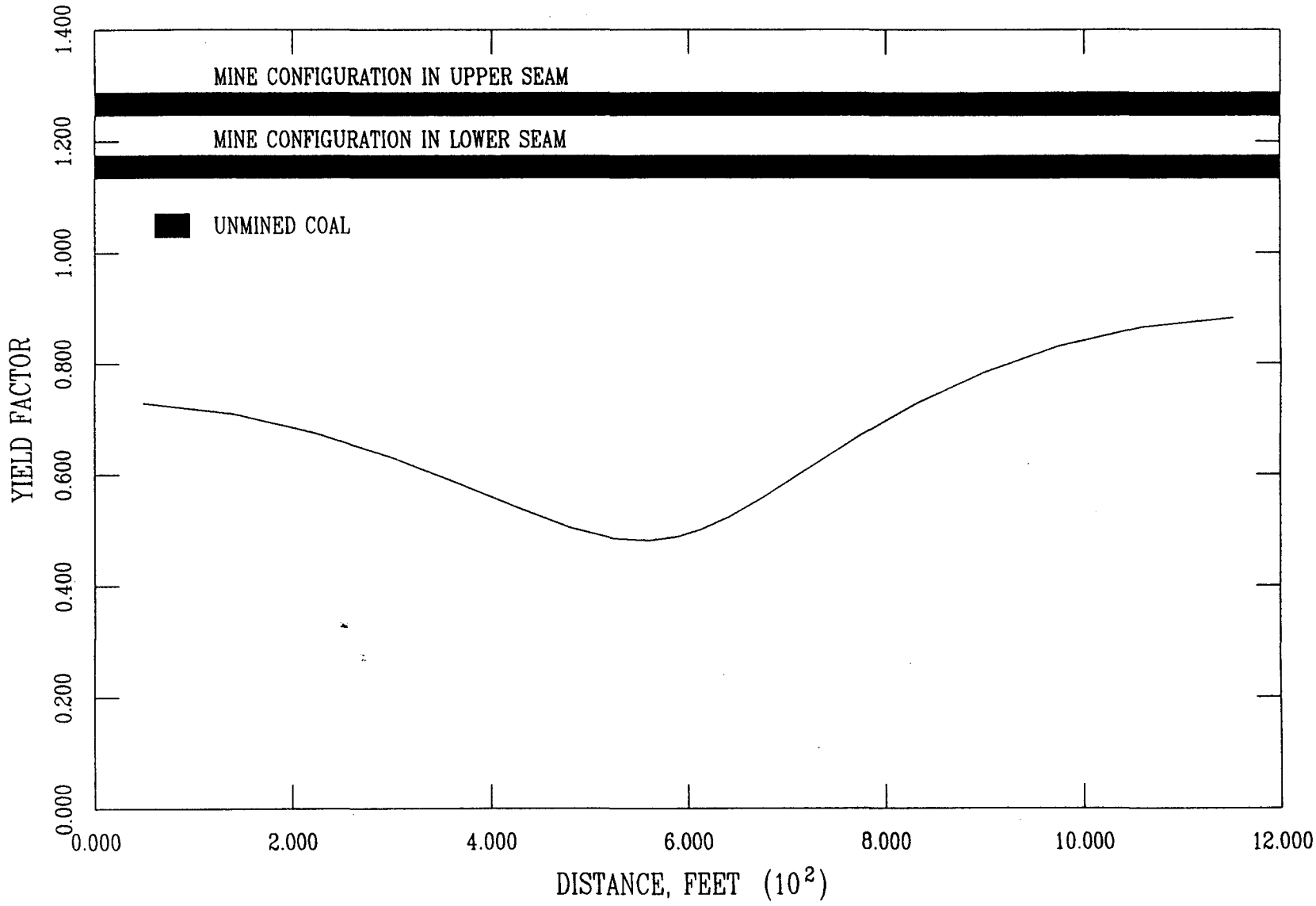

Figure E-14. Profile of yield factor in overburden above upper seam prior to any mining activity. Overburden Quality = "FAIR".

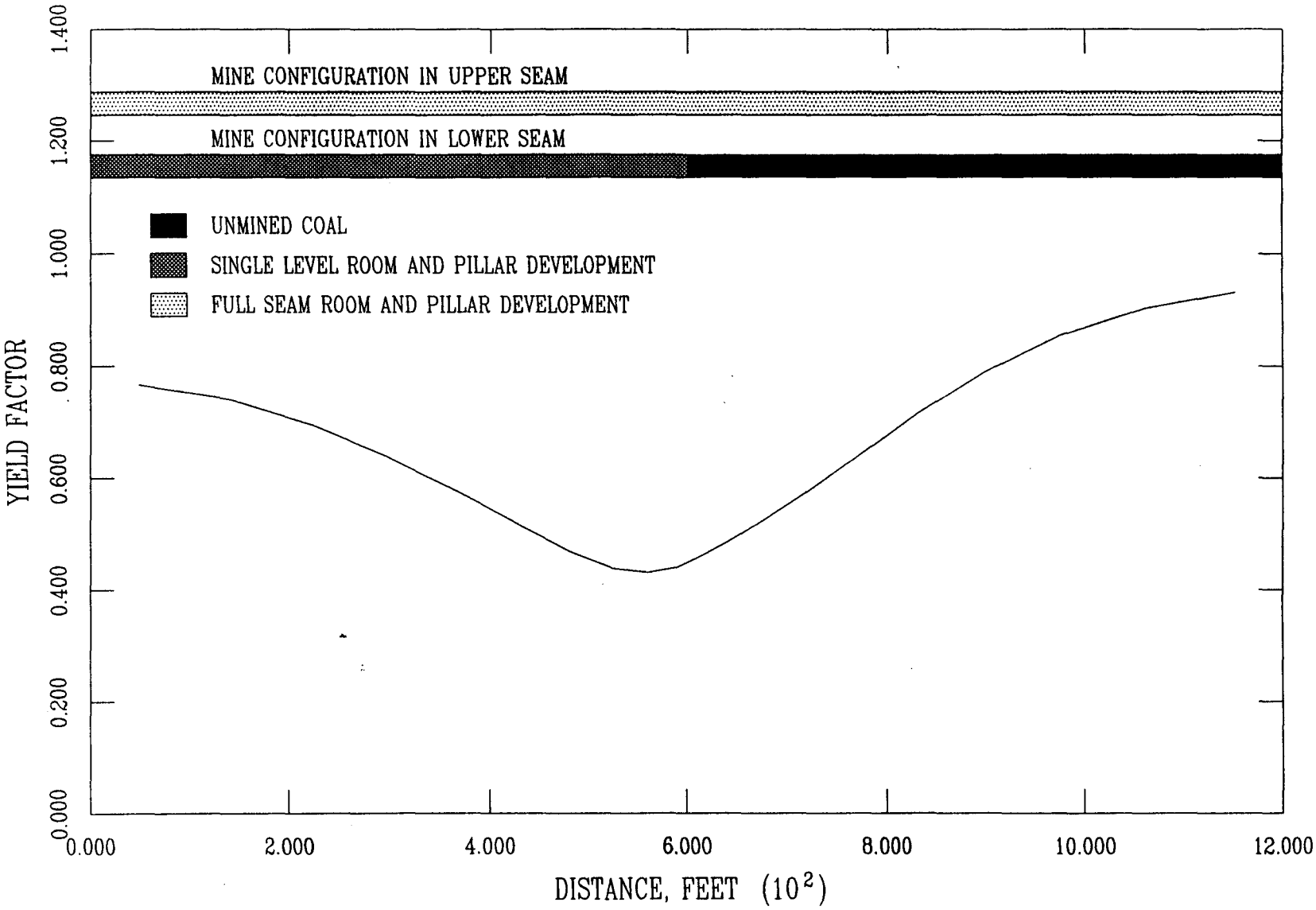

Figure E-19. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam, and development of the top coal in the lower seam to a position below Boardinghouse Creek.
Overburden Quality = "FAIR".

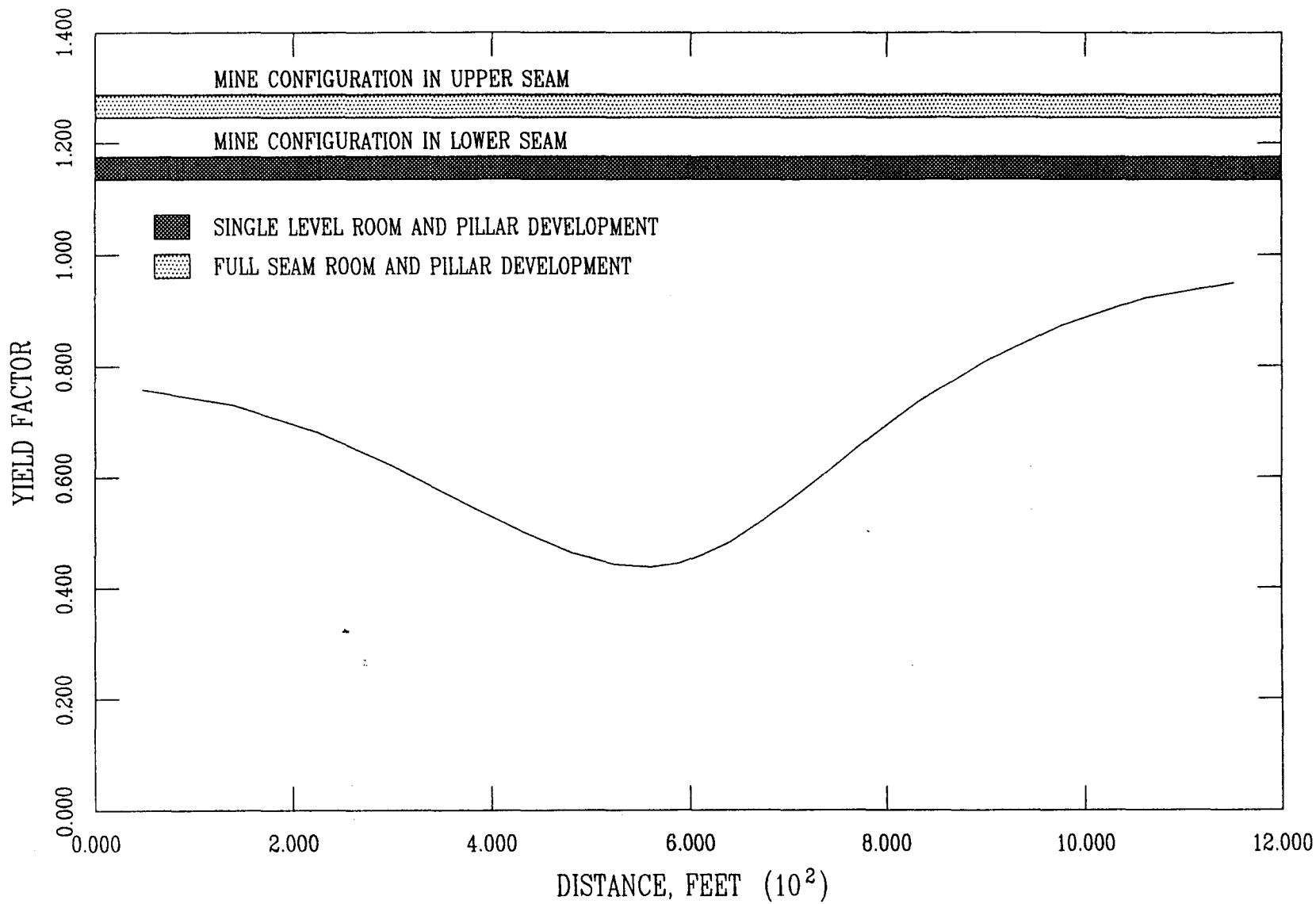

Figure E-20. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam, and complete development of the top coal in the lower seam. Overburden Quality = "FAIR".

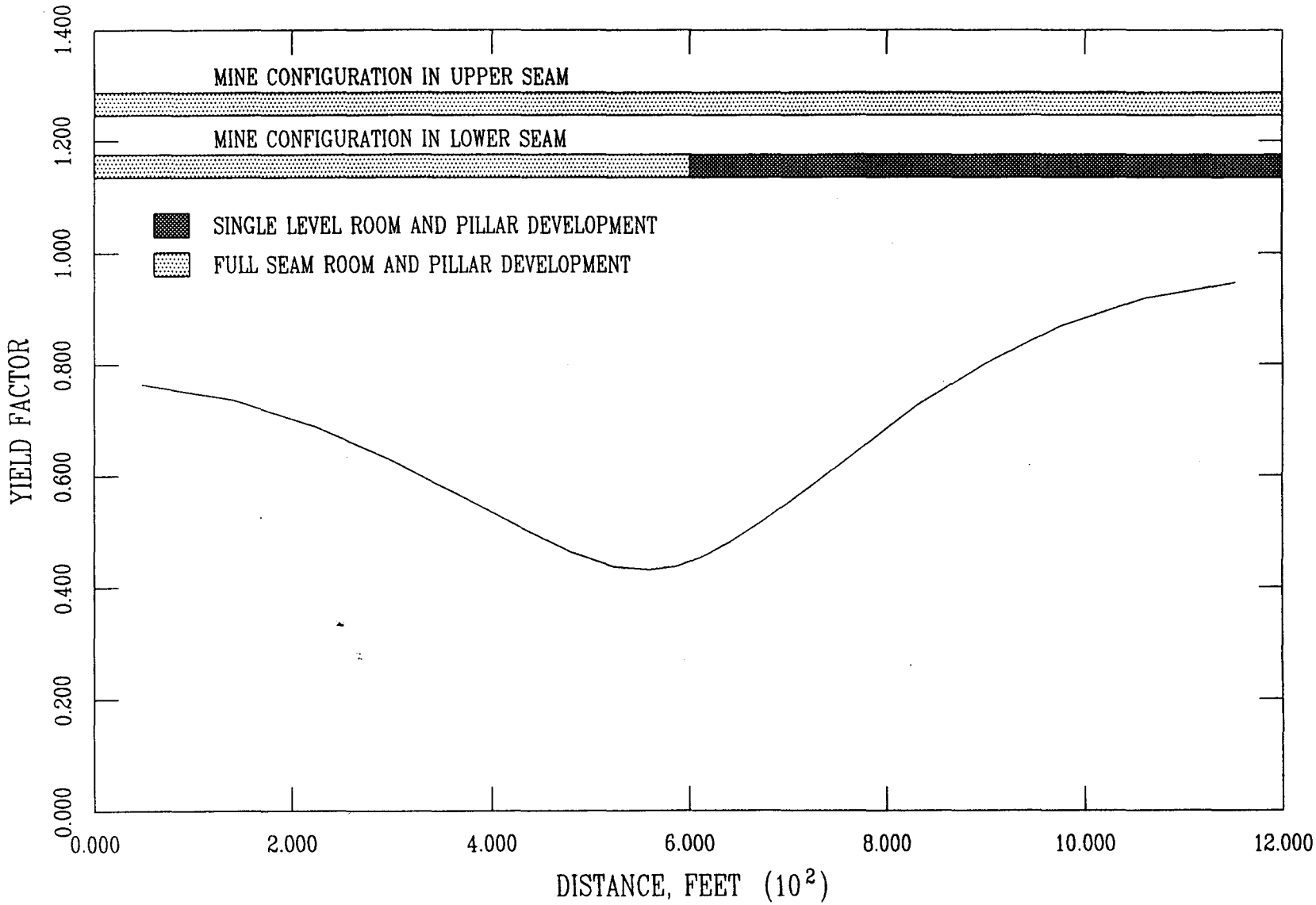

Figure E-21. Profile of yield factor in overburden above upper seam after complete full seam development of the upper seam, complete development of the top coal in the lower seam, and development of the bottom coal in the lower seam to a position below Boardinghouse Creek. Overburden Quality = "FAIR".

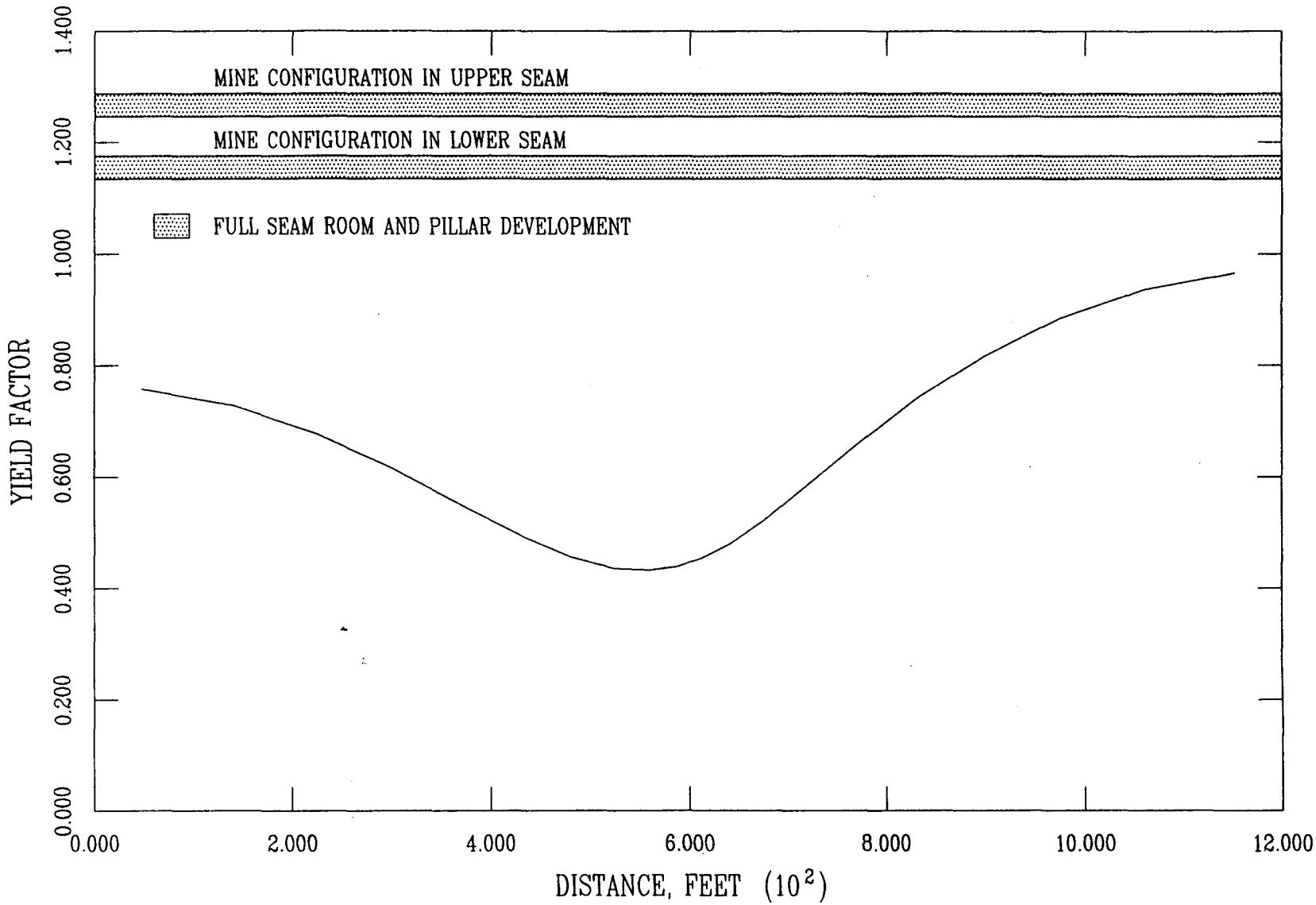

Figure E-22. Profile of yield factor in overburden above upper seam after complete full seam development of both seams. Overburden Quality = "FAIR".

APPENDIX 622.100

Well Logs
(CONFIDENTIAL)

CONSULTANTS/ENGINEERS
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& LUCE INC
SALT LAKE CITY, UTAH