RI 9205

REPORT OF INVESTIGATIONS/1988

Subsidence Due to Undermining of Sloping Terrain: A Case Study

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BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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Donald Paul Hodel, Secretary

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Library of Congress Cataloging in Publication Data:

Jeran, P. W.

Subsidence due to undermining of sloping terrain.

(Report of investigations; 9205)

Bibliography: p. 10

Supt. of Docs. no.: I 28.23:9205.

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TN23.U43 [TN319] 622 s [622'.334] 88-600252

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	mm/m	millimeter per meter
in	inch		

SUBSIDENCE DUE TO UNDERMINING OF SLOPING TERRAIN: A CASE STUDY

By Paul W. Jeran[1] and Vladimir Adamek[2]

ABSTRACT

Subsidence over a series of longwall panels undermining sloping terrain in southwestern Pennsylvania was monitored to verify the Bureau of Mines subsidence prediction model for the northern Appalachian coal region. Comparison of the field data to model output shows close agreement. Vertical movements over each panel ceased with the mining of the adjacent panel. Horizontal movements were significantly affected by topographic slope. The distribution of horizontal strains over each panel were similar, with a zone of compression occurring over the center of each panel. The zones of compression were flanked by zones of tension toward the rib. The magnitude of the tensions were affected by the slope. The strains developed at the completion of each panel were not significantly altered by the mining of subsequent panels.

[1]Geologist.
[2]Mining engineer.
Pittsburgh Mining Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

The topography over the northern Appalachian Coal Basin ranges from nearly level floodplain to narrow ridges. Locally, slopes of up to 40° may occur. In general, most of the terrain is sloping. The undermining of this type of topography causes subsidence, and the effect of local slope on the resulting ground movement has not been resolved.

The Bureau of Mines has monitored subsidence movements over several longwall mining operations in this region. The comparison of subsidence data from these different locales, each with its own topographic characteristics, indicates differences in the ground movement. Unfortunately, data from areas with similar slope characteristics can also exhibit differing ground movements. This may be due to local geologic differences in the strata between the surface and the coalbeds being mined.

Others have reported that ground movements due to subsidence caused by the undermining of sloping surfaces can differ from those observed at more level surfaces (*1-3*).[3] Kahir (*4*) has recently reported that, at a site in the northern Appalachian region under less than 300 ft of overburden, slopes affected the horizontal component of surface subsidence but not the vertical.

The Bureau has developed a predictive model of vertical subsidence movements based upon 11 Bureau longwall panel studies (*5*). A program in BASIC, for use on a personal computer, has been written to facilitate the use of the model by the mining industry (*6*). This study was undertaken to obtain data to verify the application of the Bureau model to sloping terrain. The study area is located in southwestern Pennsylvania. A set of four contiguous longwall panels, each 625 ft wide, composed the study area. The average reported extracted thickness was 6 ft. The Pittsburgh Coalbed is the only coal mined in the study area. Overburden thickness within the study area ranged from 680 to 1,010 ft.

The topography over this set of panels ranged from stream floodplain over the first panel to a narrow ridge over the third panel. Comparison of the ground movement data from the individual panels allows some insight into the effect of slope on subsidence ground movements.

DISCUSSION

The study site was sufficiently remote from prior mining so as to preclude any subsidence-induced surface movement before monitoring commenced. The project lasted 26 months and 65 data sets were collected. For this report, only the data collected at the completion of each panel are used because the Bureau's model predicts final subsidence. The total data are being used to study the dynamics of subsidence. During the study, four contiguous longwall panels were mined. Figure 1 shows the topography over the panels and the survey lines used in the study. Topographic relief in the study area is over 300 ft.

Two coreholes were drilled on the centerlines of the first and second panels, within the study area, to verify the lateral continuity of strata between panels. Columnar diagrams of these holes show that there were no drastic lithology changes present and that the bulk of the resistant strata are contained within the lower half of the overburden (fig. 2). The information from these holes coupled with corehole data obtained from the mine operator verified that the overburden within the study area is typical of the northern Appalachian Coal Basin and free from stratigraphic anomalies. Therefore, any differences in observed subsidence movements could not be attributed to local stratigraphic changes. Soil cover in the study area ranges from a few inches on the slopes to a few feet on the stream floodplain. This is underlain by weathered rock to varying depths, generally not exceeding 20 ft.

Control points were established on permanent structures outside the influence of subsidence and used throughout the study to maintain vertical and horizontal control. The survey lines were installed in three phases as mining progressed. Four-foot-long pieces of 3/4-in rebar were used as survey pins. These were driven flush to the ground or to refusal at 25-ft intervals along all survey lines. Initial position data were established prior to any movement caused by mining. Monitoring was begun when the face was a distance equal to the overburden thickness (700 to 1,000 ft) in front of the array and continued at weekly intervals during the active movement. A final survey of all points was made at the completion of mining of the fourth panel.

The initial array covered the centerline over the first panel and included a profile. Phase 2 included the centerline of the second panel and two half profiles toward panel 3, one of which extended the profile used in phase 1. Phase 3 included the centerline of panel 3. Further extension of the monitoring was precluded by restricted surface access. At each survey, the vertical and horizontal position of each pin located on the centerline of the panel being mined and between the centerlines of the adjacent longwall panels was measured and recorded. The location of the face position during each survey was also recorded.

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

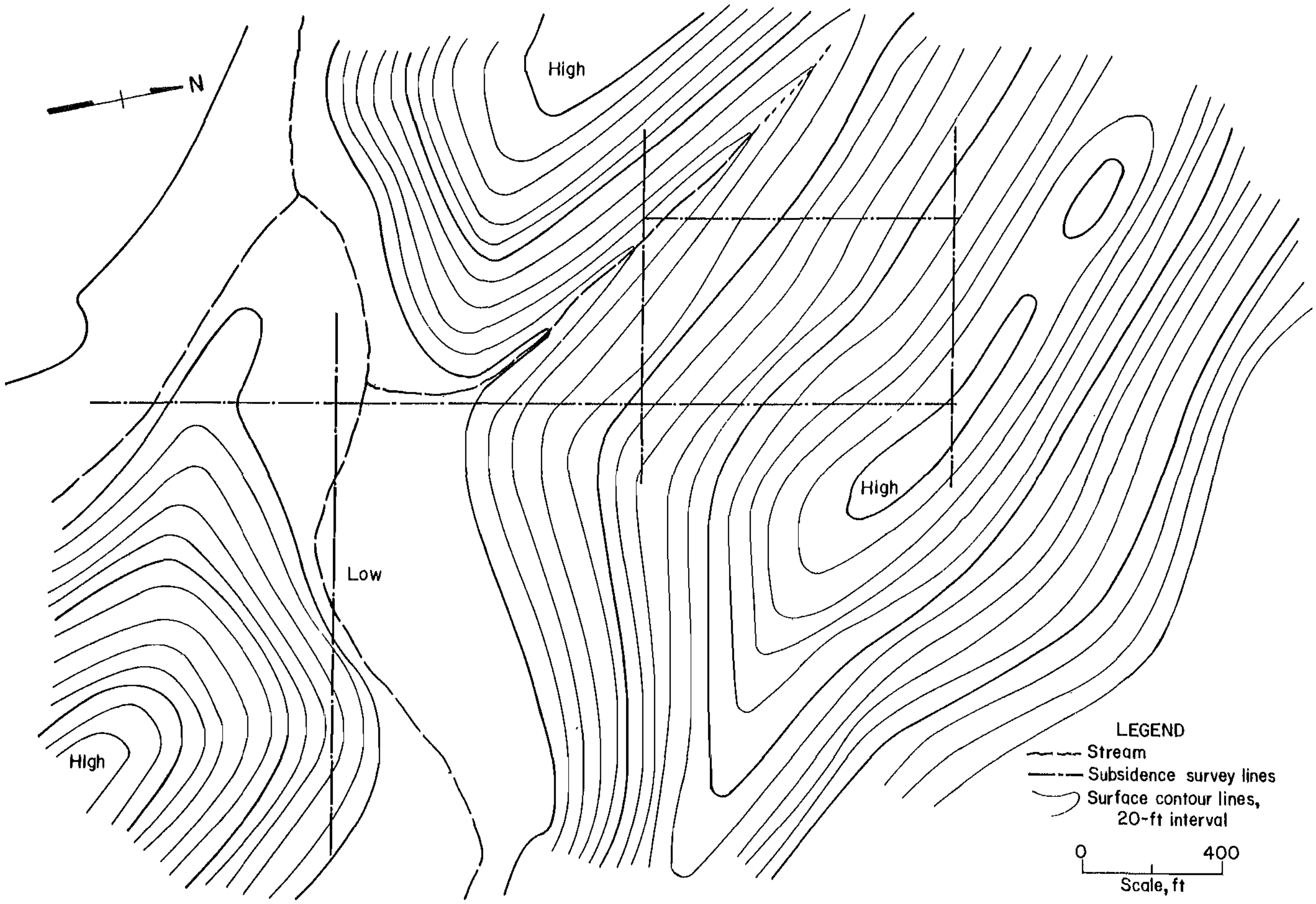

Figure 1.—Study site topography.

As previously mentioned, one purpose of this project was to verify the Bureau's vertical subsidence prediction model, particularly for varying overburden. The model is set up for profiles, and predictions were made using the panel widths and overburdens for each panel. Shown in figure 3 are the predicted values of subsidence across the continuous profile. Figure 4 shows the vertical subsidence measured at the completion of each panel for this line. Comparing these, it can be seen that the model closely predicted the vertical movement over the three panels. Subsidence over panel 1 was less than predicted, but discussions with the mine operator indicated that the extracted thickness was less than 6 ft in this area. As has been reported (*7*), for the same width panel, increasing overburden thickness will yield decreasing maximum subsidence for critical to subcritical geometries. The model predicted lesser maximum subsidence as the overburden increased and the field data are in agreement. The same results were obtained for the profile line extending from the centerline of panel 2 to the centerline of panel 3. It can therefore be concluded that critical to subcritical geometries are being dealt with at this site.

Jeran (*8*) noted that the subsidence over the chain pillars separating two adjacent longwall panels can be predicted using the model and the principle of superposition. This assumes that the chain pillars have not deformed. The field data indicate there has been some deformation of the chain pillars as evidenced by the greater than predicted subsidence observed between the panels. The surface over the chain pillars between panels 2 and 3 subsided more than that over the chain pillars between panels 1 and 2. The difference in overburden thickness is a probable cause.

The process of subsidence causes the surface to move downward and toward the area of excavation. The direction of horizontal displacements should therefore be toward the center of the subsidence trough. The horizontal movements measured over panel 1 (level,

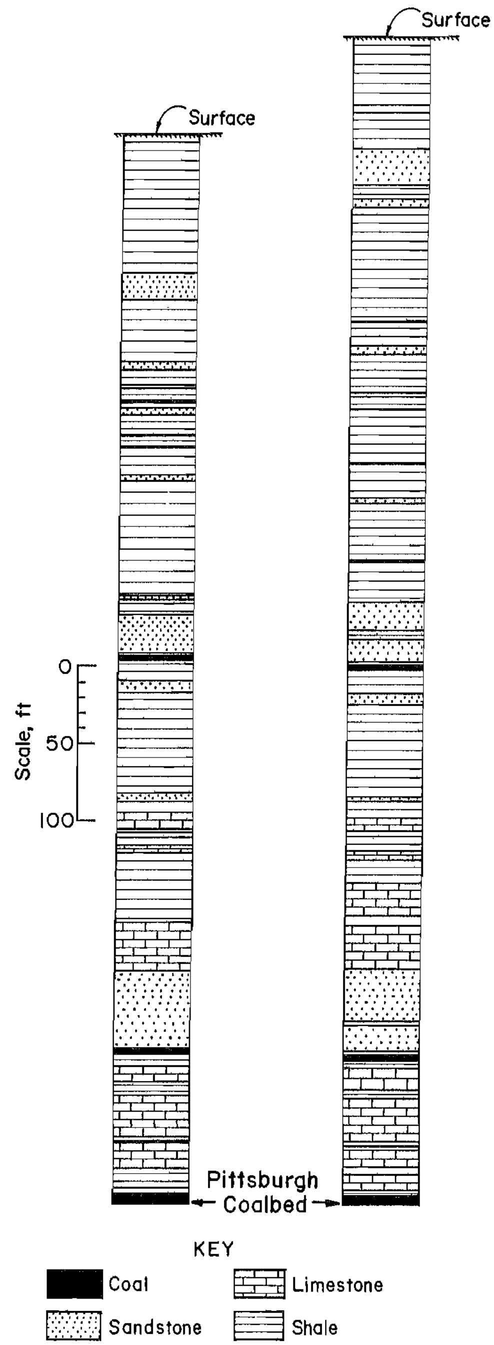

Figure 2.—Columnar diagrams of core test holes.

stream floodplain), after the panel had been mined, generally followed this pattern (fig. 5). Data from selected points have been plotted to avoid confusion. Figure 6 shows the horizontal movements after panel 2 had been completed. Note the effect of slope on the direction and magnitude of the displacements. This is particularly evident in the western part of the centerline where there is a change in slope direction. Figure 7 shows displacements after panel 3 was mined. Note that the easterly portion of the array, located on the crest of the ridge, moved downslope. Again local slope materially affected the direction and magnitude of the horizontal movement.

Figure 8 is a composite of figures 5, 6, and 7 and the final displacements measured when panel 4 had been completed. Contour lines are omitted for the sake of clarity. There appears to be a continuing horizontal adjustment of the surface after it is disturbed by subsidence. The horizontal movement directly attributable to subsidence should stop with the cessation of vertical movement. The continued horizontal adjustments without measurable vertical movement may represent a mass movement phenomena in which the surface is adjusting to the changes in slope induced by subsidence.

The physical act of moving does not cause damage to the surface. Damage occurs when differential movements impart strain to the surface. The distribution of horizontal strains computed from the measured differential horizontal movements between adjacent stations at the completion of each panel are plotted in figure 9. This shows that the horizontal strains imposed during the undermining do not change after mining is completed. Also, subsequent adjacent mining does not alter the strain distribution. At all three panels, a zone of compression was developed over the center of the panel flanked by zones of tension toward each rib.

There is a marked asymmetry in the magnitude of tensions developed over panel 2; the upslope zone exhibits a larger magnitude of tension than the downslope zone. This difference is to be expected from the implied mass movement of the surface downslope. The repeat of same pattern is suggested over panel 3, where the downslope tension zone is of the same order of magnitude as that observed over the downslope portion of panel 2. At this site, the greatest imposition of strain to the surface by the process of subsidence occurs during undermining and is essentially completed with the mining of the following panel.

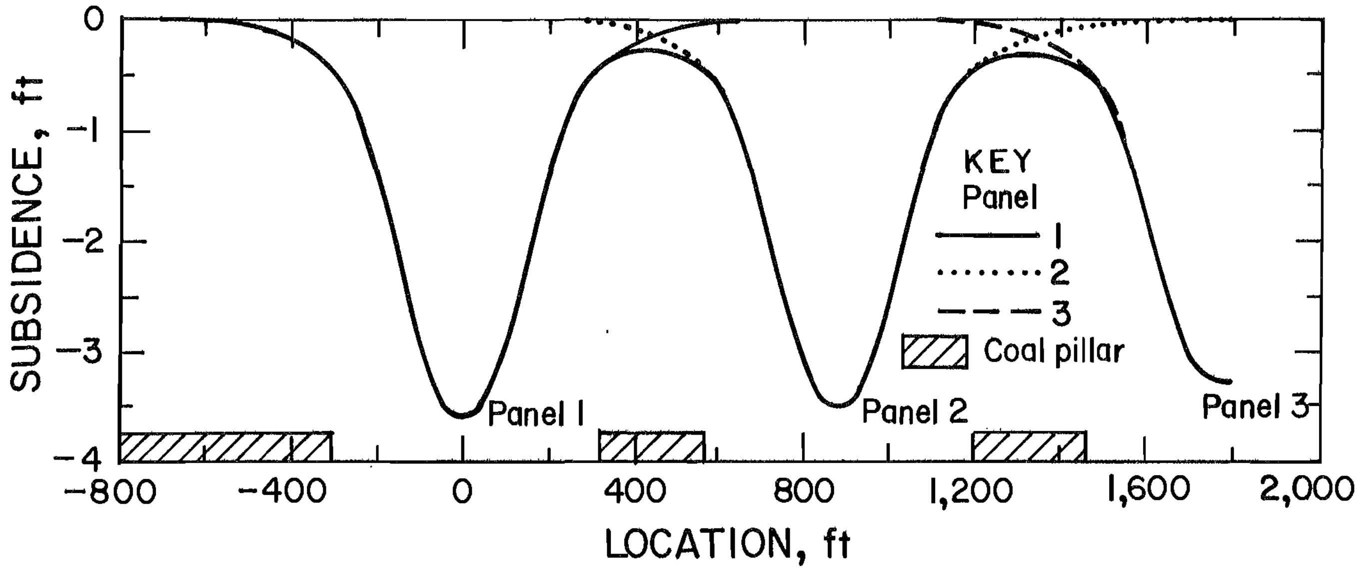

Figure 3.—Predicted subsidence of profile across study site.

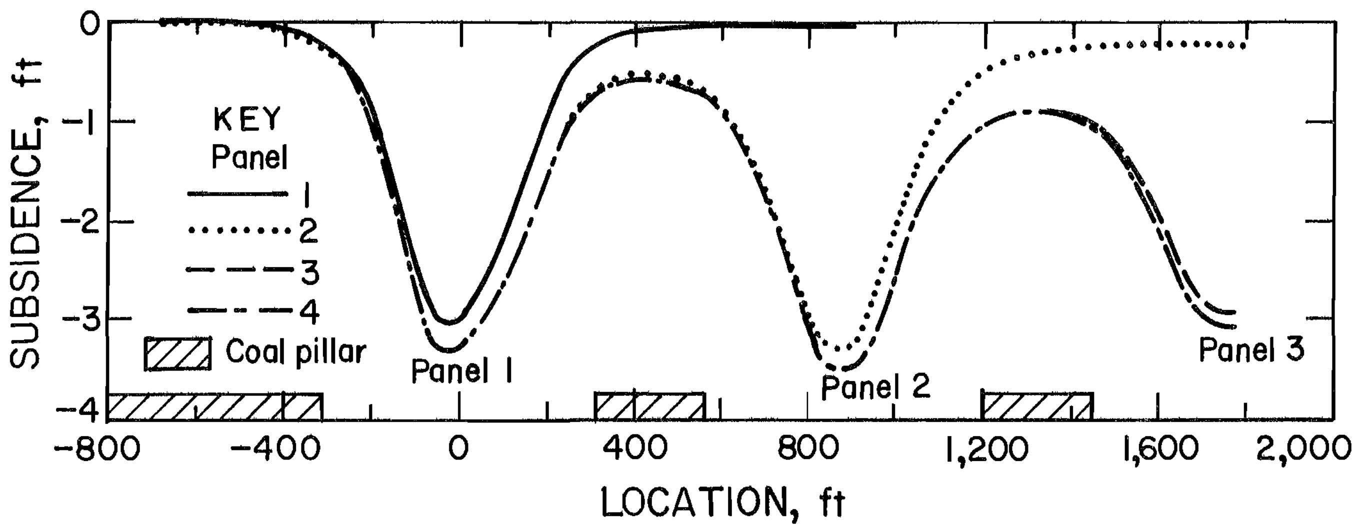

Figure 4.—Measured subsidence of profile during study.

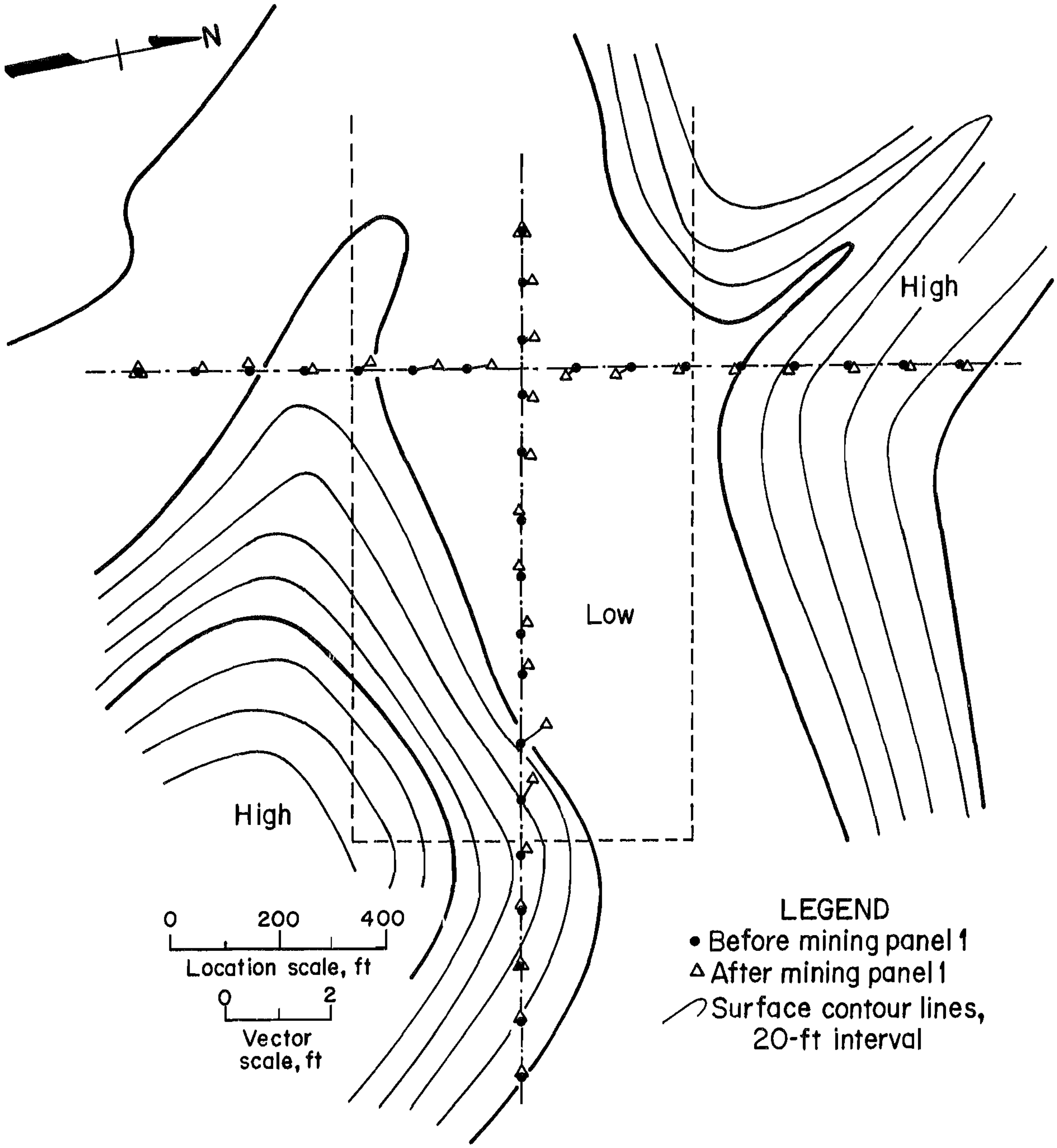

Figure 5.—Horizontal movements after completion of panel 1.

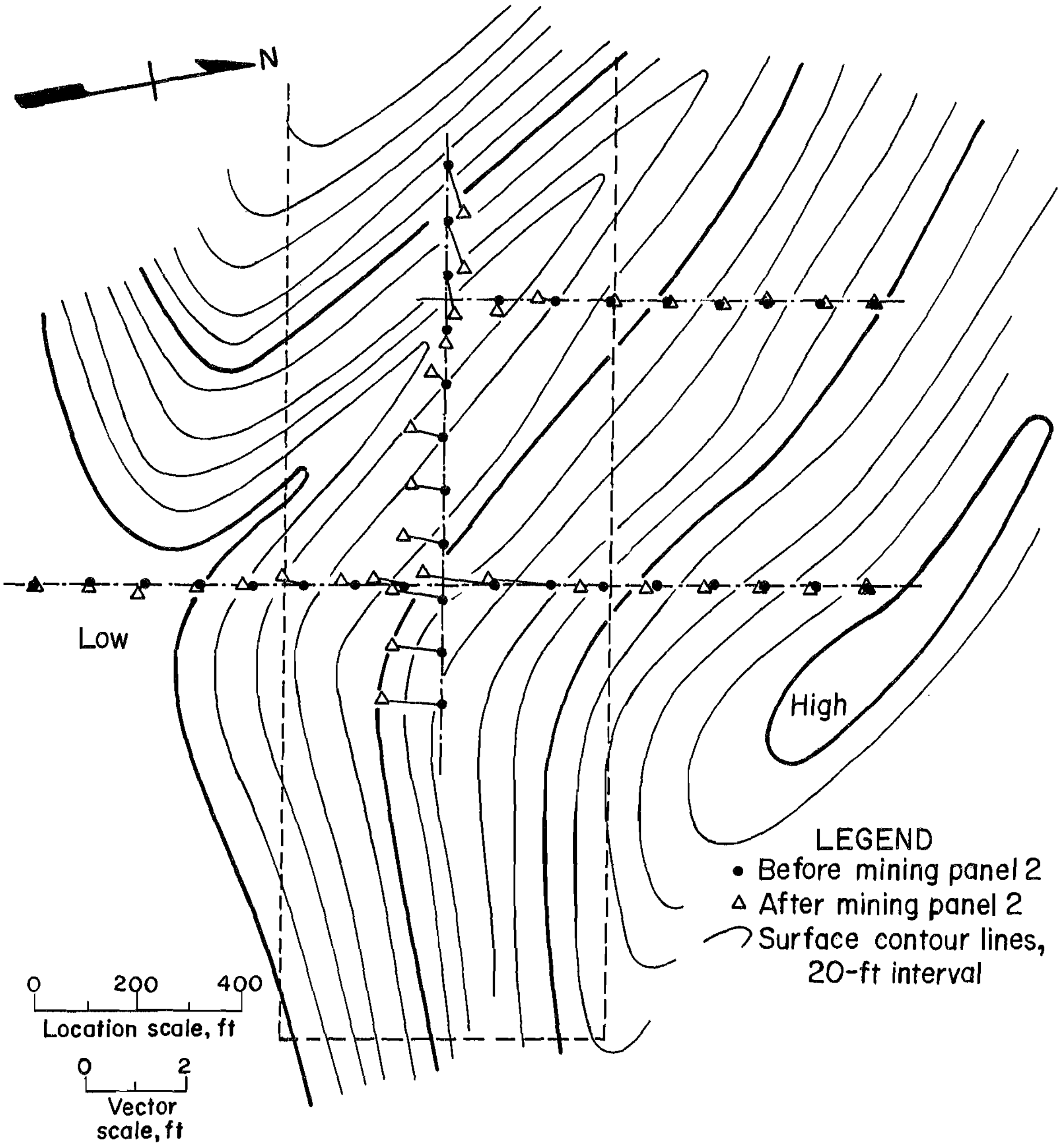

Figure 6.—Horizontal movements after completion of panel 2.

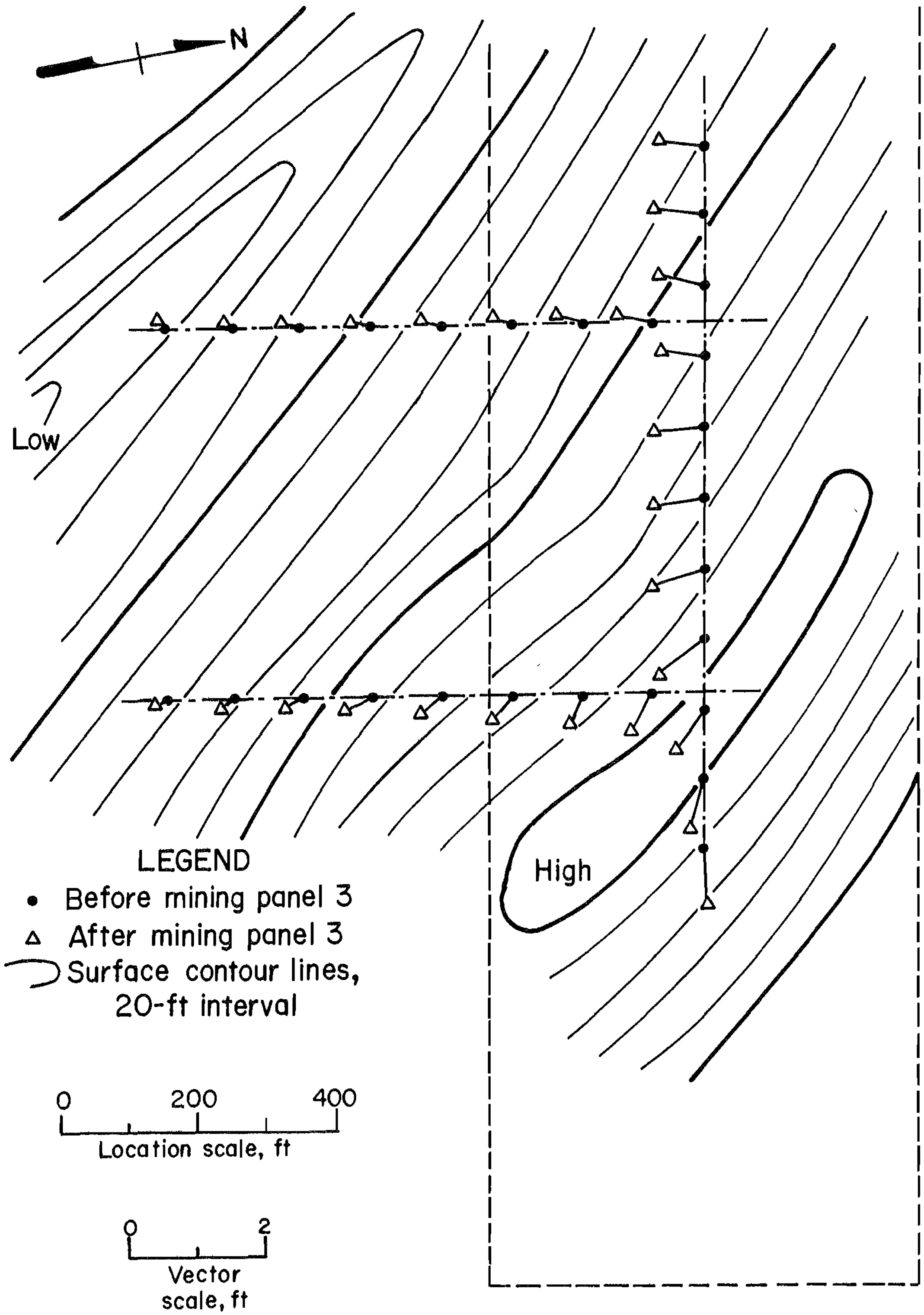

Figure 7.–Horizontal movements after completion of panel 3.

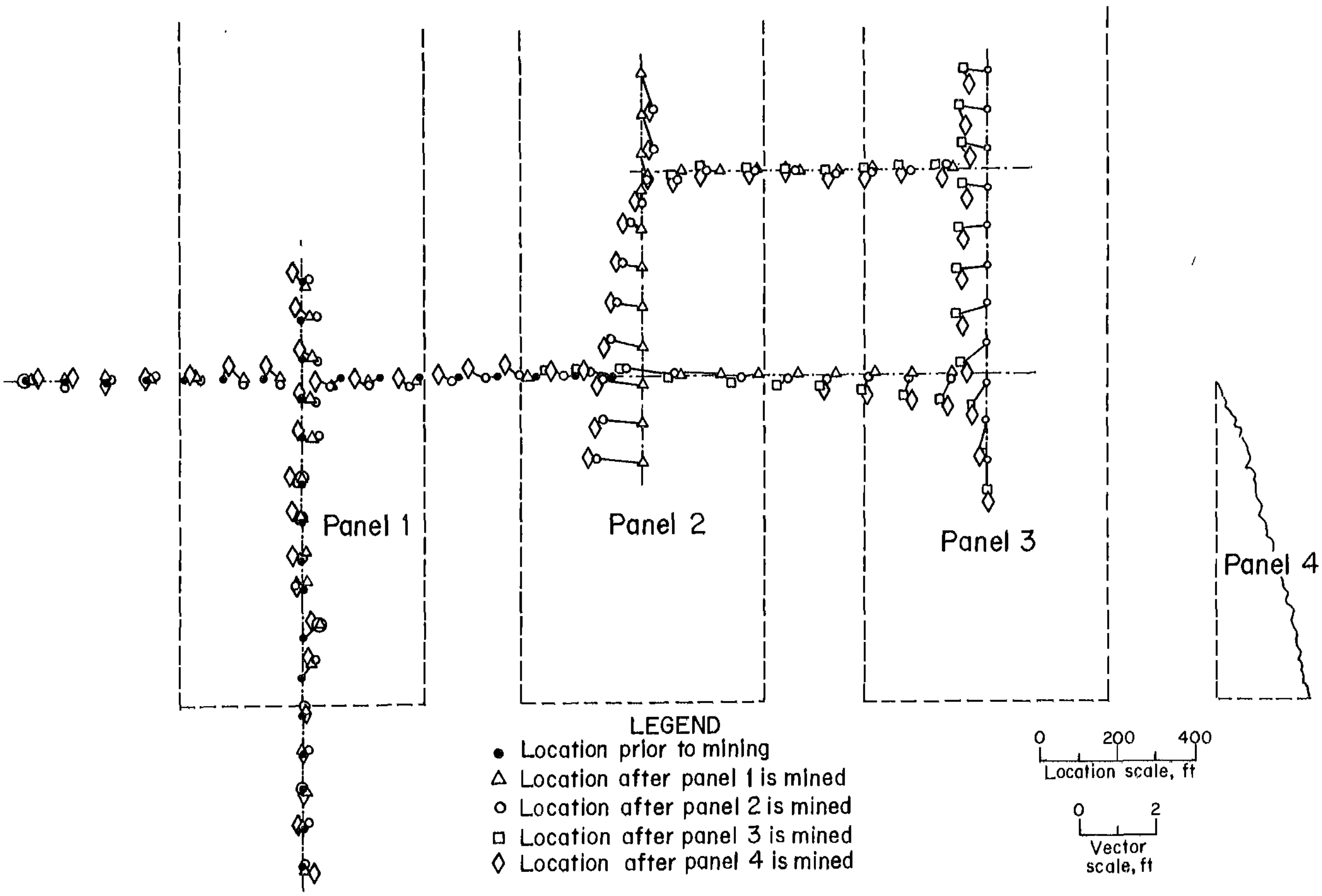

Figure 8.—Progressive horizontal movement during the study.

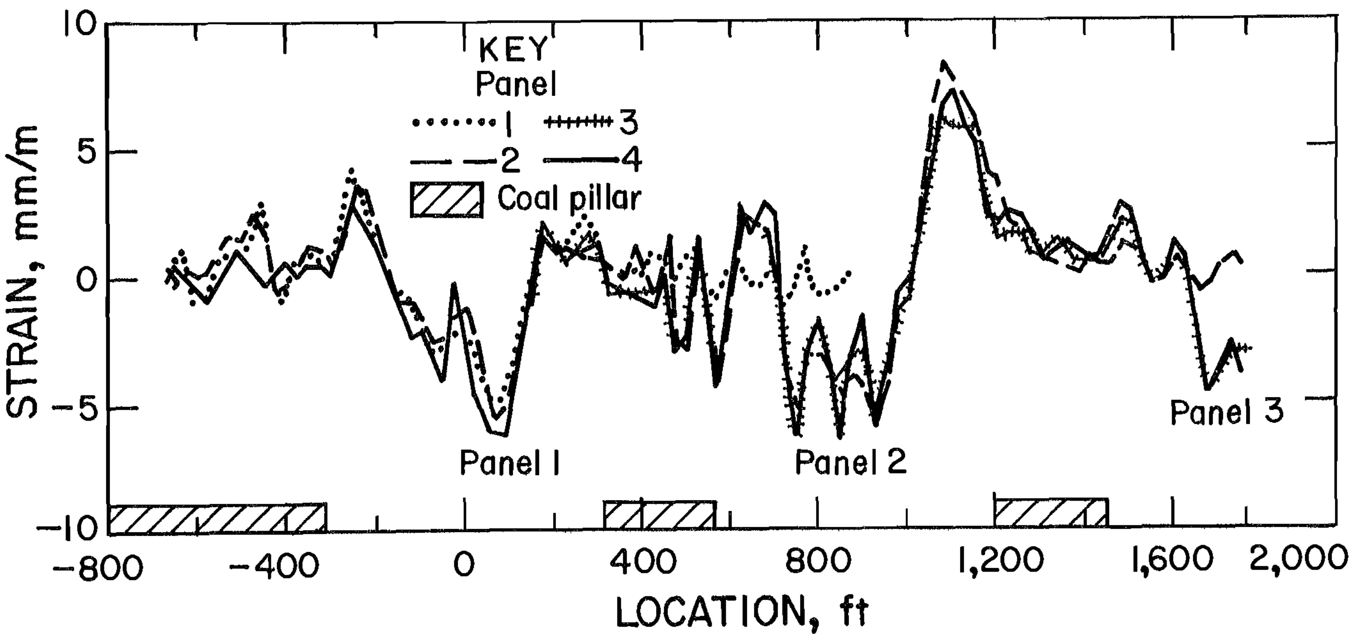

Figure 9.—Distribution of horizontal strains during study.

SUMMARY AND CONCLUSIONS

A monitoring array was installed over a series of longwall panels in southwestern Pennsylvania. The measured vertical subsidence is in agreement with the Bureau of Mines subsidence prediction model and verifies its applicability to moderately sloping terrain. Additional small vertical movements occurred within the trough of each panel with the mining of the following panel. No further vertical movements were observed with additional mining. The vertical component of the subsidence process was completed with the mining of the adjacent panel.

Horizontal movements due to subsidence are typically thought to be toward the center of the subsidence trough. At this site, this is only true for level or near level terrain. Moderately sloping terrain dramatically alters the direction and magnitude of horizontal movement. Small horizontal adjustments observed after the cessation of vertical movement may represent the adjustment of the surface to the changes in slope induced by subsidence.

The magnitude of horizontal strains was materially affected by the local slope, however, not the general distribution. The zones of tension and compression were similarly distributed with respect to the panel geometry irrespective of local slope. The pattern of strains imposed by the mining of each panel did not change with subsequent mining, indicating that differential horizontal movement ceases with vertical subsidence. At this site, any future changes in the distribution of strain that deviate from those developed by mining should not be attributed to subsidence.

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