ISGS CONTRACT/GRANT REPORT 1983-7

USBM PO P3381514

Identification of mine subsidence on aerial photographs in central Illinois

Philip J. DeMaris
Robert A. Bauer

November 1983

Illinois Department of Energy and Natural Resources
STATE GEOLOGICAL SURVEY DIVISION
Champaign, Illinois

Prepared for the
U.S. BUREAU OF MINES
Twin City Mining Research Center
Minneapolis, MN

DeMaris, Philip J.
Identification of mine subsidence on aerial photographs in central Illinois / Philip J. DeMaris and Robert A. Bauer. — Champaign, IL : Illinois State Geological Survey Division, November 1983.

31 p. ; 28 cm. — (Illinois—Geological Survey. Contract/Grant report ; 1983-7)
Prepared for the U.S. Bureau of Mines, Twin City Mining Research Center.

1. Mine subsidences—Illinois—Sangamon County. Aerial photography in geology. I. Bauer, Robert A. II. Title. III. Series.

Printed by authority of the State of Illinois/1983/200

Identification of mine subsidence on aerial photographs in central Illinois

Philip J. DeMaris
Robert A. Bauer

Contract Report
Purchase Order P3381514
U.S. Bureau of Mines
Twin City Mining Research Center
Minneapolis, MN

ILLINOIS STATE GEOLOGICAL SURVEY
Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820

Table of Contents

List of Tables

Table		Page

List of Figures

Figures		Page

Abstract

This report evaluates the use of stereo pairs of aerial photography over and in the vicinity of a coal mine for the detection of subsidence due to underground coal mining in a glaciated area of central Illinois. The study area chosen was examined on 11 sets of imagery taken between 1939 and 1977. A number of sites where subsidence was previously documented in the study area are visible on the air photos and were used for comparison with other anomalies found on the photos.

The air photos were examined for anomalous topographic lows, unusual tonal and textural contrasts, and certain land use changes. The integration of the air photo anomalies and previously reported subsidence sites produced a set of 44 sites which were evaluated on all sets of photography. When the 44 sites were superimposed on the detailed mine map, sites fell either outside the limits of the mine or over areas of low or high extraction in the mine. Final judgements were made by comparing the configuration of coal extraction with the surface expression of the sites.

Aerial photography proved to be a useful tool for the identification of probable sites of subsidence in the study area. Fifty-nine percent (26 of 44) of the sites within the study area and seventy percent (26 of 37) of the sites within the boundary of the mine are probably due to mine subsidence. The remaining anomalies were judged to be unrelated to mine subsidence. Natural depressions which fall by chance over high extraction areas may have been attributed to mine subsidence.

Acknowledgements

The work for this report was performed for the U.S. Bureau of Mines, Minneapolis, Minnesota, under Purchase Order Number P3381514. The project officer was Mr. Larry Powell of the U.S. Bureau of Mines, Twin Cities Research Center.

We thank Stephen R. Hunt for initiating this project and Alan Goodfield of the Illinois Department of Transportation (IDOT) for providing access to IDOT air photography.

INTRODUCTION

The purpose of this study was to evaluate the effectiveness of using aerial stereo pair photographs to detect subsidence in a glaciated area of central Illinois and to try to identify indicators for recognition of subsidence versus natural glacial depressions. The Divernon area is located on the Illinoian groundmoraine. This area in central Illinois (fig. 1) was selected because both the subsurface geology and former mining practice are well known. In addition, the Divernon area had several well-documented cases of subsidence, which proved useful for reference. Five sets of air photos from the U.S. Department of Agriculture and 6 sets from the Illinois Department of Transportation, with coverage from 1939 to 1977, were used to evaluate the Divernon area (see Appendix A).

Aerial photos were examined on a "stand alone" basis and later in conjunction with other data. Because of variations in scale, quality, and percent of coverage among the sets of aerial photographs, a system of evaluation was developed in which any possible subsidence site (anomaly) discovered at any point in the investigation was evaluated on every set of photographs. In the final evaluation, evidence from the photos was matched against data from several sources to clarify the limits and advantages of the various types of data.

GEOLOGIC SETTING

The ground surface in the study area is Illinoian groundmoraine covered by loess, a deposit of wind blown silts. Loess ranges in thickness from 6.5 to 8 feet with an average of 7.2 feet and is the material in which our current soil is developed. The loess overlies till. The till has occasional lenses of sand or gravel, and averages about 19 feet thick and ranges from 4 to 33 feet thick in the study area. The till overlies bedrock. The average thickness of bedrock from the top of the coal which was mined in the area up to the base of the till is about 275 feet. This interval ranges from 268 to 294 feet thick in the study area. The bedrock consists of interbedded layers of shale, limestone, sandstone, and coal. The bedrock overburden over the coal mine consists of about 85 percent shale, 10 percent limestone and 5 percent sandstone. A coal mine in the area operated in the Herrin (No. 6) Coal seam which averages about 8.1 feet thick and ranges in thickness from 7.5 to 8.5 feet. This coal seam varies from 290 to 320 feet below the surface in the study area.

The Illinoian groundmoraine has many natural closed depressions located on the ground surface. These depressions were probably produced by melting ice chunks within the deposited groundmoraine material or by the melting of the glacial ice of uneven thicknesses producing variations in the thickness of the groundmoraine.

HISTORY AND NATURE OF SUBSIDENCE IN STUDY AREA

The Mine No. 6 (1900-1925) of Madison Coal Corporation underlies the Divernon area and practiced a room-and-pillar mining system. Parallel entries were driven to block out areas of coal. Then a series of entries was driven into these panel areas and interconnected to leave pillars of coal to support the mine roof (fig. 2).

The history of mine subsidence in the vicinity of Divernon can be assembled from various sources. Subsidence of the ground surface and damage to structures or land must be clearly distinguished. This report deals only with the lowering of the ground caused by subsidence, but not with any resulting damage.

Observations of previous investigators are a primary source for information on subsidence in Illinois, and this report relies heavily on them. A few published investigations include measurements of subsidence, in particular those by Andros (1914), Herbert and Rutledge (1927), Quade (1934), and Young (1916). Much of the information was recently summarized by Hunt (1980).

The most recent systematic study of subsidence occurrences in Sangamon County was part of an investigation conducted by John C. Quade in 1934 for the Federal Land Bank of St. Louis. This study was to provide a basis for assessment of loan applications in mining areas. He reported on 14 sites of subsidence above the No. 6 Mine. Quade found sag subsidences in Sangamon County that covered 3 to 20 acres and were 2 to 4 feet deep.

Additional studies in the Sangamon County area were performed by Herbert and Rutledge (1927) and Young (1916). Herbert and Rutledge placed bench marks over panels at a nearby mine and found 1.5 feet of surface subsidence where squeezes were taking place underground. Young compiled subsidence data for District VII, in which Sangamon County was located. Figure 3 shows the subsidence as a percentage of the height of coal mined compared to the depth of the coal mine.

The typical subsidence for the Sangamon County area is a gentle sag, one to four feet deep at its maximum. The average maximum change in ground slope is about 1 to 2 percent.* Figure 4 is an example of a large sag over a panel from the Madison Coal Corporation Mine No. 6. The company mined approximately 8 feet of Herrin (No. 6) Coal at

---

*Based on monument spacing of 100 feet or 33 percent of depth to the mines.

a depth of about 300 feet, with an extraction ratio of about 65 percent in the production panels. The data for the profiles are from the Quade report for Sangamon County and are 2 of the 14 profiles measured across the panel. This gentle settlement or sag of the surface is the only type of subsidence observed in the Divernon study area. The recognition of this type of subsidence by photo interpretation is one of the primary purposes of this study.

The Madison Coal Corporation Mine No. 6 was visited on several occasions by Survey geologists. In Illinois State Geological Survey mine notes of 1912, K. D. White noted that the underclay was quite thick, the top part consisting of a light gray portion (6 feet thick) grading downward into a greenish blue shale. He indicated that the underclay slaked badly and that heaving was a problem in the mine. Heaving or a squeeze of the mine floor is due to the inability of the underclay below the coal pillars to support the overburden weight. The larger the amount of coal removed, the higher the overburden pressures in the pillars and thus, below the pillars. When the concentrated pressures below the pillars become greater than the strength of the underclay, the underclay "squeezes" out from under the pillars up into the mined-out coal areas. The pillars and overburden will be lowered as the clay squeezes out from under the pillars. Subsidence is the end result of the overburden lowering.

A summary of production for the mine shows that although the mine was not abandoned until 1925, it did not operate after 1924. The mine map held by the Survey and the Illinois Department of Mines and Minerals states that the map was extended to May 4, 1925, and thus, represents the final map of the mine works.

EVALUATION OF AERIAL PHOTOGRAPHY FOR DETECTION OF SUBSIDENCE

General Principles

Multiple sets of aerial photos were analyzed to note change of relief, alteration of drainage, quality of drainage, and any subsequent land use changes to identify possible sites of past subsidence. The differences in quality, scale, etc. amongst the sets of aerial photos require that each be evaluated on its own merits.

All photos examined were black and white aerial photographs at scales from 1:3000 to 1:24,000. No photos were considered with scales smaller than 1:30,000 because of the small size of most of the subsidences. The ideal scale range to examine these discrete subsidences in central Illinois is about 1:5000 to 1:15,000 with acceptable ranges extending up to 1:3000 and down to 1:24,000. Larger scales than 1:3000 show good detail but fewer reference points for proper location of the feature. A similar study in England by Norman and Watson (1975) found subsidence detection best on 1:2000 to 1:10,000 scale photographs, and a study performed in Pennsylvania by Russell et al. (1979) used 1:10,000 to 1:30,000 scales for their work to detect pit-type subsidence.

A most crucial variable is seasonality of the photos, especially in this region of intensive cashcrop agriculture. Best seasons are March-May (post-snow and pre-crop) and late October-December (post-crop and pre-snow). Some of the best imagery is early spring photography, when the contrast in soil moisture is high, which emphasizes wetter drainage areas in contrast to the drier uplands. Although imagery in the June-September period is generally less useful because the crops tend to mask the topography, crop germination problems related to lows in the field (sometimes produced by subsidence) have proved valuable.

An anomaly was defined based on the following set of indicators:

1. topographic low (depression); especially if "out-of-place";
2. texture; especially locally "drowned" crops in spring photographs or poor crop cover in later photographs;
3. tone; a darker tone is associated with moist soil conditions or areas where the water table is closer to the ground surface; a light tone may indicate drier conditions; and
4. land use modification; change of crop, cropped area, or change in field use in response to drainage problems, weed problems, etc.

The interpretation of features on air photos primarily involves qualitative assessment, which is not well suited to quantification. In evaluating each set of aerial photographs, anomalies were rated as having a "weak" or "strong" positive indicator, or negative when an indicator was not present.

Evaluation Procedure

Background. Familiarity with the geologic setting and land use practices in the area are needed. The interpreter then scans the photographs to gain a knowledge of "normal" topography tone and texture variations, including reflections of subsurface structures, soil patterns, crop patterns and drainage. Then a search and identification of other irregularities (e.g., slope failure) that could be confused with subsidence is also performed. The area around suspected subsidence sites is scanned; it must be large enough to include all of the possible subsidence-affected area. Good quality photographs are desirable for these investigations.

Identification of Anomalies. Using the background knowledge gained from initial scanning of the aerial photos, the interpreter begins to identify anomalies in topography, tone, and texture. Depressions, apparent slope instability, different soil or crop texture patterns are noted. Human or animal adaptations such as changes in paths, land use changes (especially crop changes) or land abandonment are noted. Recognition of these anomalies depends both on the skill and experience of the interpreter and the quality of photographs; the interpreter may wish to check adjacent photographs to resolve questions of unusual land use. In this study, the photographs were initially investigated independently without other sources of subsidence or mine information. This procedure allowed the fullest use of the photos for evaluating the widest range of natural and coal mine subsidence features.

Comparison of Anomalies With Reported Subsidence. At this point all anomalies identified on aerial photos were compared with all reported subsidence sites for the area, including all known or probable subsidence due to natural or man-made causes. The unmatched reported subsidence sites were then inspected on all sets of aerial photographs. This examination of known subsidence sites may reveal that indicators were missed on some photos. It also reveals if some known subsidence sites are at or below the limits of resolution of the imagery; thus, indicators may be weak or absent.

Results

Site-Specific Evaluation. Forty-four sites in the Divernon area were studied on the sets of aerial photographs (fig. 5 and 6). All air photo anomalies and reported sites in or within about one-quarter mile of the general mapped boundary of the mine were considered for this study. Table 1 shows the disposition of the indicators for each site on the various sets of aerial photographs. Each site is categorized for each set of photographs as 1) "Positive" - the site showed some topographic, tonal or textural indication on a set of photos; 2) "Neutral" - the site was altered or obscured on a set of photos; or 3) "Negative" - the site was not found on a set of photos. The positive indicators were subdivided into "weak" and "strong" categories on the basis of how strong the visual contrast was between the site and the normal tonal, textural and topographic variations. Positive and negative indicators for each site were then compiled for use in the analysis (table 2). Also on table 2 are notes on each site concerning their persistence amongst sets of air photos, overall strength of indicator, and other observations.

Projection of Sites on Mine Map. The major downward movements of coal mine subsidence events are over and well within the boundaries of the production panels. The production panels are the highest extraction areas of the mine and are wide enough so that if overburden support is lost the event will reach the surface and cause subsidence. This is in contrast to the low extraction, narrow main entryways bound by barrier pillars. Even if all the pillars lost support in the main entryways in this mine, the collapsed width would be too small to reach and affect the ground surface. Only 28 of the 44 sites (63%) are positioned properly over production panels of the mine (table 3, fig. 7). Of these 28 sites, 13 are subsidence sites designated by J. C. Quade's report or areas marked on the mine map where squeezes had taken place in the mine (table 3).

The semi-final evaluation using all available information is shown in the second to last column of table 3. Because field checks were not available for many sites in this study no judgements of "no subsidence" were made. In this case a decision was made between three categories:

1) Subsidence

2) Subsidence possible or probable, or

3) Subsidence unlikely.

The final evaluation was performed by using a detailed mine map showing all the mine's rooms and pillars along with the aerial photos. Three sites (25, 36, and 42) were upgraded to subsidence status based on how the mine plan (pillars) influenced the surface depressions. Sites 25 and 42 both show less subsidence over the east-west oriented chain pillars, which run down the center of the panels (see fig. 4). Since these pillars are larger than those in the production portions of the panel, less net subsidence results above them.

Site 20 was down-graded to a possible/probable status. It was only seen on one set of aerial photo coverage and had a weak, small indicator.

Two sites were down-graded to unlikely status. These were sites 13 and 29. Site 13 was over a section of the production panel where very short rooms were driven with only a few crosscuts present.

The coal extraction ratio was very low with few isolated coal pillars formed. Site 29 was part of a natural drainage way which runs through sites 29, 31 and 32. Aerial photos show an elongate one-half mile depression at a 45 degree angle to the mine plan.

The southeast portion of site 40 is located over very large chain pillars along the haulageways in the production panel. The production part of this panel is only the southern 2/3 of the outline shown in figure 7. The haulageways are the northern part of the panel.

This final evaluation shows that only 26 of 44 (59%) sites can be considered possible or probable subsidence events. Thirty-two percent (14 of 44) were evaluated as subsidence events based on other subsidence studies in the area and how the variation of the depth of the anomaly reacted to changes in the mine plan. This is shown by profile A-A' in figure 4 where less subsidence takes place over the large chain pillars along the haulageways through the center of the panel.

The final evaluation shows that 26 of 37 sites (70%) within the boundary of the mine could be considered possible or probable coal mine subsidence events.

It is interesting that the great majority of these 26 sites were undermined between 1918 and 1924 (table 4). Annual production rates and the number of miners surged beginning in 1917 due to American entry into World War I. Production may have been increased in part by raising the extraction rates, leading to more squeezes which resulted in subsidence.

Evaluation Problems. Once clear and effective criteria for classification were established, evaluation proceeded efficiently. Several of the sets of photos were found to be especially helpful for delimiting natural drainage features, and other photos (usually from June and July) showed clear evidence of localized crop problems. The tendency of corn seedlings to die in standing water helped to delimit the lowest areas within several sites, and the shape and position over the mine of these areas lent strong support to the case for subsidence. The tabulations capture only part of the relevant information, especially with regard to natural drainage. Some sites on or near drainage commonly exhibited "tone" and "topo" indicators but little evidence to substantiate that the anomalies were related to coal mine subsidence. This is why some sites may have several "weak positive" indicators, but were ultimately judged to be unlikely sites of subsidence.

Finally, resolution is often a problem, especially when only 1:20,000 or smaller scale imagery is available. Using such photography, subsidence sites of 1 1/2 to 2 acres or more can probably be consistently recognized, as well as subsidence sites down to 1 acre if they are sharply defined; subsidence sites smaller than a half acre are unlikely to be reliably discovered. This resolution problem is compounded by the small subsidence events which are not as deep as the large events, and thus give weak or imperceptible "tone" or "topo" indicators. However, the resolution problem may be largely a problem of graininess of the photos and not resolution of size since the subsidence events in the study area affect a minimum of an acre of the surface. Therefore, the resolution problem is largely solved by using imagery with scales of 1:10,000 or greater; a similar conclusion was reached for a study of mine-induced subsidence in England (Norman and Watson, 1975). Thus, given imagery in the 1:2000 to 1:10,000 scale range, sites of subsidence which alter drainage (and thus vegetation) can normally be identified in aerial photos. If the surface was only dropped slightly evidence of subsidence may be missed unless the local vegetation is very sensitive to such a change, as in river bottom areas and on plains of Pleistocene lakes in Illinois. Such areas were not studied.

This study also evaluated and verified subsidence data in J. C. Quade's 1934 report on Sangamon County. Our initial photo evaluation was done independently of this data source and only 7 of the 14 subsidence sites identified by Quade were picked up. The balance of the sites reported by Quade were rechecked on all sets of photographs during the comparison stage, and it was determined that 12 of the 14 sites had some positive indicators on at least 2 sets of coverage. Site 38 was an area designated by Quade as having subsidence, but no indicators were found for this site even though there were 8 sets of photographic coverage. Quade sites 10 and 16 were not undermined and are, therefore, not related to coal mine subsidence. Six of the Quade sites (23, 24, 33, 35, 39, and 43) had either surface surveys or were located over squeezes indicated on the mine map. The remaining Quade sites (6, 22, 28, and 41) were located over production panels and had positive indicators on 2, 6, 2, and 6 sets of photo coverage. These numbers of positive indicators were equal to or greater than the number of positive indicators for the confirmed subsidence anomalies 24 and 39. Therefore, Quade probably correctly identified subsidence at 10 of the 14 sites (71%).

The Quade report apparently reflects multiple sources of information, some of which could not be verified. These reports were produced rather rapidly which may explain why some information of lower reliability was included. However, the Quade reports are valuable because they contain data which, in part, are no longer available, even though they include a few errors.

Three subsidence sites (23, 24, and 39) involved in litigation in 1912 demonstrate problems related to limits of resolution and the limited impact on crop production after tiling. The sites became a drainage problem for the landowner and were tiled after being surveyed in 1912; the mining company apparently settled the damages out of court. The three sites had 2 to 3 feet of subsidence (Young, 1916). Sites 24 (4 acres) and 39 (2 3/4 acres) were each seen on only 2 sets of photographs, while site 23 (1 acre), was noted on 8 sets of photographs. Since all three areas were tiled, it may be that site 23 was the deeper of the three to begin with, or problems may have developed with the tile line of site 23, and it is not known whether these areas were also filled. For whatever reason, corrective measures may have reduced the visible signature of sites 24 and 39 more than that of site 23.

The largest and best documented anomaly (site 43) had repeated crop problems. Surveys of this area during and after subsidence showed a 2.1 feet drop at the lowest point, and a 1.5 feet drop covering a large area. The initial survey was probably performed after some movement had already taken place; the initial survey apparently followed recognition of some surface drop. Four sets of photographic coverage showed moderate to serious crop loss caused by spotty to total failure in germination within the lowest areas within site 43 (large area of subsidence at south end of study area, figs. 5, 6, and 7). Aerial photography during the 1970s indicates that the roughly 20 acre block around site 43 was no longer planted in corn. Field checks during the spring of 1980, 1981 and 1982 showed substantial ponding. We do not know if field tile was used or if an attempt was made to drain site 43.

Evaluation of the effect of filling or partial filling on subsidence signatures was not possible because of a lack of "ground truth" information. But the elimination of drainage problems probably will not completely obscure soil moisture patterns associated with subsidence sites; they are commonly seen on imagery, particularly during dry seasons. For example, the outlines of nearly two thousand year old Roman camps in the United Kingdom can be mapped from air photography of plowed fields (St. Joseph, 1973). These alterations to the soil and subsoil appear to be long-term effects, and under the proper conditions allow for identification well after the event occurred. However, as noted above, efforts to correct the subsidence may weaken the visual indicators for subsidence to the point where detection becomes impossible on typical aerial photographs.

CONCLUSIONS

For best results it is desirable to have multiple coverage by high quality stereo pairs of aerial photography of the area of interest, ideally at scales between 1:2000 to 1:10,000, but not less than 1:24,000. Relief change (e.g., "out-of-place" topographic low), alteration of drainage, quality of drainage, and change in land use are the principal indicators used to identify possible sites of subsidence; subtle differences in texture and tone of photos provide important clues.

Forty-four investigated sites were found on aerial photos of the test area around and over the large No. 6 Mine of the Madison Coal Corporation. Twenty-six of the 44 sites could be considered possibly related to coal mine subsidence. Of these 26 possible subsidence sites, 13 were previously indicated as subsidence by J. C. Quade's report or were marked on the mine map as squeeze areas in the mine.

This study was performed in a glaciated area which has natural surface depressions and patterned ground features. Therefore, there are no simple visual indicators to look for on aerial photos to positively identify coal mine subsidence. The surface anomalies have to be superimposed over the mine plan. The anomalies over the production panels or other high extraction areas may be considered possible coal mine subsidence events.

Filling of lows created by subsidence and retiling may or may not obscure a subsidence site and affect crop production. Also, shallow subsidence may be too subtle to be detected on aerial photographs, unless high resolution photos were taken at an "ideal" time (e.g., after rain).

This study showed that if evaluations were made on the basis of photographic information alone, surface depressions caused by subsidence would be overlooked and natural glacial depressions would be counted as subsidence features. If the study area was enlarged more than one-quarter mile around the mine boundary, many more natural depressions would have been included in this study.

FUTURE RESEARCH

Efficiency in detection of subsidence sites on air photography could be improved in several ways. Custom photography with scales of 1:4000 to 1:10,000 is ideal. Infra-red imagery, which emphasizes natural drainage features, would assist in picking out subsidence sites which fall by chance along natural drainage. Also, infra-red or black and white imagery taken at the correct time after a heavy rain can enhance any subtle elevation changes related to subsidence.

Multiple sets of aerial photographs over more recently mined areas would give better time brackets for the subsidences and allow study of the timing and frequency of subsidence relative to mining method, extraction ratio, mine roof character, etc. Evaluation of remedial efforts to reclaim subsidence-affected acreage could also be pursued using this technique.

REFERENCES

Andros, S. O., 1914, Coal Mining Practice in District VII: Illinois Coal Mining Investigations Bulletin 4, Illinois State Geological Survey, 53 p.

Herbert, C. A. and J. J. Rutledge, 1927, Subsidence Due to Coal Mining in Illinois: U.S. Bureau of Mines Bulletin 238, 59 p.

Hunt, S. R., 1980,"Surface Subsidence Due to Coal Mining in Illinois," Ph.D. Thesis, Department of Geology, University of Illinois at Urbana-Champaign, 129 p.

Norman, J. W. and I. Watson, 1975, Detection of Subsidence Conditions by Photography: Engineering Geology, v. 9, no. 4, p. 359-381.

Quade, J. C., 1934, Preliminary Report of Subsidence Investigation, Sangamon County, Illinois: An investigation for the Federal Land Bank of St. Louis.

Russell, O. R., R. V. Amato, and T. V. Leshendok, 1979, Remote Sensing and Mine Subsidence in Pennsylvania: American Society of Civil Engineers, Transportation Engineering, v. 105, p. 185-198.

St. Joseph, J. K., 1973, Air Reconnaissance in Britain 1965-68: Journal of Roman Studies, v. 63, p. 214-246.

Young, L. E., 1916, Surface Subsidence in Illinois Resulting from Coal Mining: Illinois State Geological Survey, Mining Investigation Bulletin 17, Urbana, Illinois, 112 p.

Table 1. Summary of Nature of Indicators for Each Site for All Sets of Photo Coverage

Site Number	Sets of Air Photo Coverage	Positive Indicators: Strong Topo.	Positive Indicators: Strong Tone/Text.	Positive Indicators: Weak Topo.	Positive Indicators: Weak Tone/Text.	Neutral (Altered or Obscured)	Negative (Not Seen)
1	7	-	-	2	2	-	3
2	7	-	-	1	1	-	5
3	7	-	-	1	2	-	4
4	7	-	-	1	2	-	4
5	7	-	-	1	1	1	4
6	11	-	-	-	2	2	7
7	11	-	1	4	3	2	1
8	11	-	-	5	3	-	3
9	11	-	-	10	1	-	-
10	11	-	-	5	-	2	4
11	10	-	-	1	1	1	7
12	7	-	-	-	5	-	2
13	7	-	-	-	5	-	2
14	7	-	-	3	1	-	3
15	9	-	-	1	1	-	7
16	10	-	-	1	1	-	8
17	10	-	-	-	7	-	3
18	11	-	1	-	6	2	2
19	11	1	3	-	3	2	2
20	11	-	-	1	-	1	9
21	11	-	4	4	-	1	2
22	8	-	-	2	4	-	2
23	9	-	2	1	5	-	1
24	11	-	-	2	-	-	9
25	11	1	2	-	7	-	1
26	11	-	1	3	2	2	3
27	9	-	-	-	6	-	3
28	11	-	-	-	2	-	9
29	8	-	-	1	2	-	5
30	7	-	-	1	5	-	1
31	8	-	-	1	6	-	1
32	10	-	-	1	5	-	4
33	11	-	-	2	7	-	2
34	9	-	-	5	3	-	1
35	9	-	-	1	4	-	4
36	8	-	1	1	4	-	2
37	7	-	-	2	1	1	3
38	8	-	-	-	-	-	8
39	9	-	-	1	1	1	6
40	8	1	-	1	2	-	4
41	11	-	2	2	2	-	5
42	8	1	2	1	2	-	2
43	11	-	3	3	4	-	1
44	10	-	-	1	6	-	3

Table 2. Results of Investigation

Site Number	Anomaly Present on Air Photos		Comments
	Pos.	Neg.	
1	4	3	Fair persistence of anomaly throughout air photo coverage
2	2	5	Poor persistence
3	3	4	Poor persistence
4	3	4	Poor persistence
5	2	4	Poor persistence
6	2	7	Poor persistence; Quade site
7	8	1	Strong persistence, lies on natural drainage
8	8	3	Good persistence, lies on natural drainage
9	10	0	Identified as a man-made pond along a stream
10	5	4	Fair persistence, lies on natural drainage; Quade site
11	2	7	Poor persistence
12	5	2	Wide area of patterned soil, believed unrelated to subsidence
13	5	2	Fair persistence of weak indicators
14	4	3	Poor persistence; appears to be natural relief
15	2	7	Poor persistence
16	2	8	Poor persistence; Quade site
17	7	3	Good persistence; lies by natural drainage
18	7	2	Strong persistence; small area
19	7	2	Strong persistence; strong indicators
20	1	9	One indicator seen on one coverage; Quade site
21	8	2	Strong persistence; strong indicators
22	6	2	Good persistence; Quade site
23	8	1	Strong persistence; strong indicators, field survey; Quade site
24	2	9	Poor persistence, field survey; Quade site
25	10	1	Strong persistence; strong indicators
26	6	3	Good persistence
27	6	3	Fair persistence
28	2	9	Poor persistence; Quade site
29	3	5	Fair persistence on early cover, lies on natural drainage
30	6	1	Good persistence of odd tone/texture
31	7	1	Good persistence; lies on natural drainage
32	6	4	Fair persistence of weak indicators
33	9	2	Strong persistence; Quade site
34	8	1	Strong persistence
35	5	4	Fair persistence
36	6	2	Good persistence; probably Quade site
37	3	3	Fair persistence
38	0	8	No indicators seen on any coverage; Quade site

Table 2. Continued

Site Number	Anomaly Present on Air Photos Pos.	Neg.	Comments
39	2	6	Poor persistence, field survey; Quade site
40	4	4	Fair persistence, lies on natural drainage
41	6	5	Fair persistence; Quade site
42	6	2	Fair persistence of strong indicators
43	10	1	Strong persistence, strong indicators, field survey; Quade site
44	7	3	Good persistence

Table 3. Summary of Information on Each Site

Site Number*	Anomalies* Pos.	Anomalies* Neg.	Not Undermined, Not Over Panel	Quade, Surveys, Or Mine-Map Squeeze Subsidence	Semi-Final Judgement	Final Judgement
1	4	3			P/P	P/P
2	2	5	N		U	U
3	3	4			P/P	P/P
4	3	4	N		U	U
5	2	4			P/P	P/P
6	2	7		Q	S	S
7	8	1			P/P	P/P
8	8	3	N		U	U
9	10	0	N		U	U
10	5	4	N	Q	U	U
11	2	7	N		U	U
12	5	2	N		U	U
13	5	2			P/P	U
14	4	3			P/P	P/P
15	2	7	N		U	U
16	2	8	N	Q	U	U
17	7	3	N		U	U
18	7	2			P/P	P/P
19	7	2			P/P	P/P
20	1	9		Q	S	P/P
21	8	2			P/P	P/P
22	6	2		Q	S	S
23	8	1		Q,Su,M	S	S
24	2	9		Q,Su,M	S	S
25	10	1			P/P	S
26	6	3			P/P	P/P
27	6	3			P/P	P/P
28	2	9		Q	S	S
29	3	5			P/P	U
30	6	1	N		U	U
31	7	1	N		U	U
32	6	4	N		U	U
33	9	2		Q,M	S	S
34	8	1		M	S	S
35	5	4		Q,M	S	S
36	6	2			P/P	S
37	3	3			P/P	P/P
38	0	8		Q	U	U
39	2	6		Q,Su,M	S	S

Table 3. Continued

Site Number*	Anomalies* Pos.	Neg.	Not Undermined, Not Over Panel	Quade, Surveys, Or Mine-Map Squeeze Subsidence	Semi-Final Judgement	Final Judgement
40	4	4	N		U	U
41	6	5		Q	S	S
42	6	2			P/P	S
43	10	1		Q,Su	S	S
44	7	3	N		U	U

*From Table 2
N = Not Undermined
Q = Quade Subsidence Site
Su = Surface Survey of Subsidence
M = Subsidence Shown on Mine Map
S = Subsidence
P/P = Subsidence Possible or Probable
U = Subsidence Unlikely

Table 4. Year Panels Were Mined Under Possible/Probable Subsidence Sites

	Year Mining Completed or Period of Mining	Dating Information on Subsidence Event
1	1922	
3	1920	
5	1918	
6	1922	
7	1921	
14	1918*	
18	1920	
19	1920	
20	1919	
21	1919	
22	1900-1918*	
23	1903-1918*	Surface trough surveyed in 1912
24	1903-1918*	Surface trough surveyed in 1912
25	1908-1918*	
26	1924	
27	1920	
28	1918	
33	1918	On 1925 map
34	1921	On 1925 map
35	1918-1919	On 1925 map
36	1920	
37	1918	
39	1905-1918*	Surface trough surveyed in 1912
41	1919	
42	1918	
43	1919	Surface trough surveyed in 1929

*Panels before 1918 were not dated on mine map.

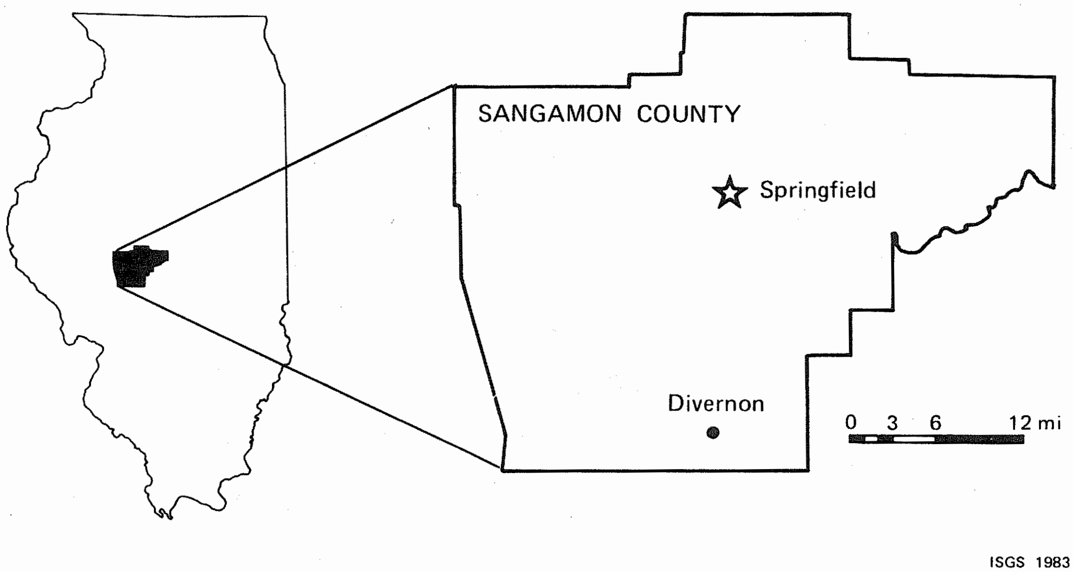
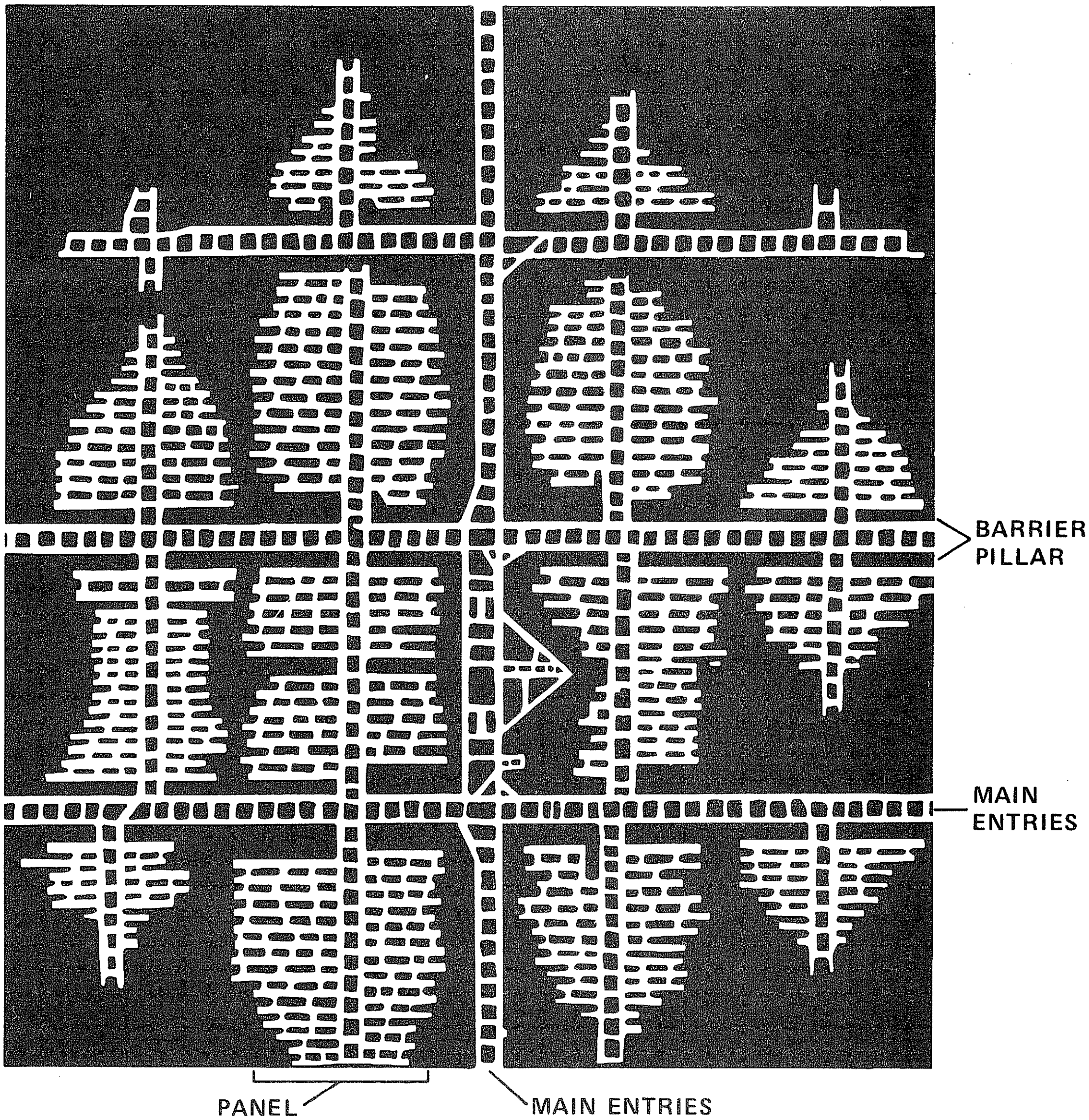


Figure 1. Location of Divernon study area.



PANEL EXTRACTION: UP TO 80 PERCENT (IF PILLARS ARE PULLED)
ROOM WIDTH: 15-30 FEET
ROOM LENGTH: 200-300 FEET
ROOM PILLAR WIDTH: 10-30 FEET
BARRIER PILLAR WIDTH: 50-150 FEET

500 ft (152 m)

ISGS 1979

Figure 2. Mine plan typical of No. 6 Mine of Madison Coal Corporation.

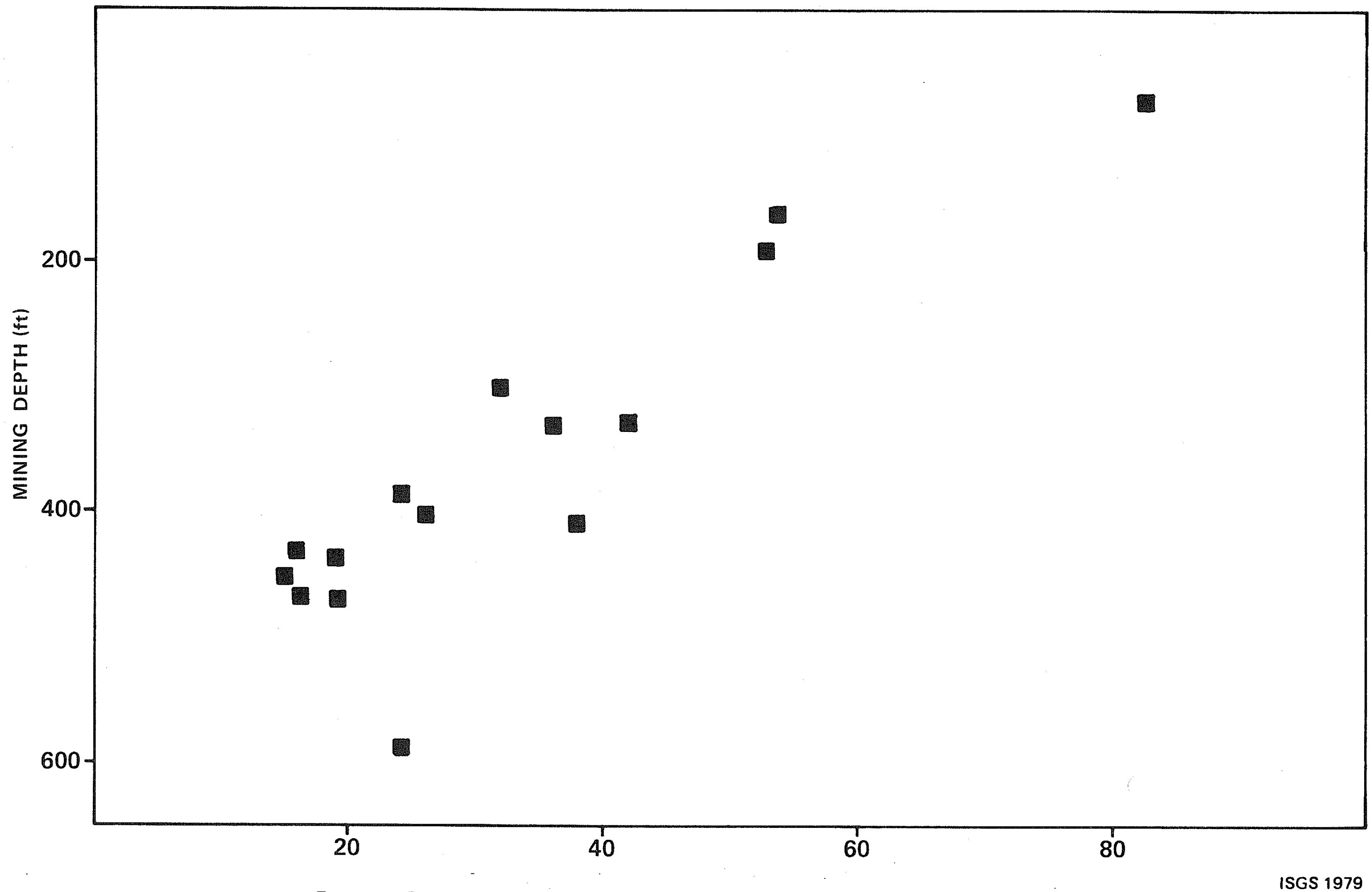


Figure 3. Percentage of subsidence versus depth of mining for District VII (Young, 1916).

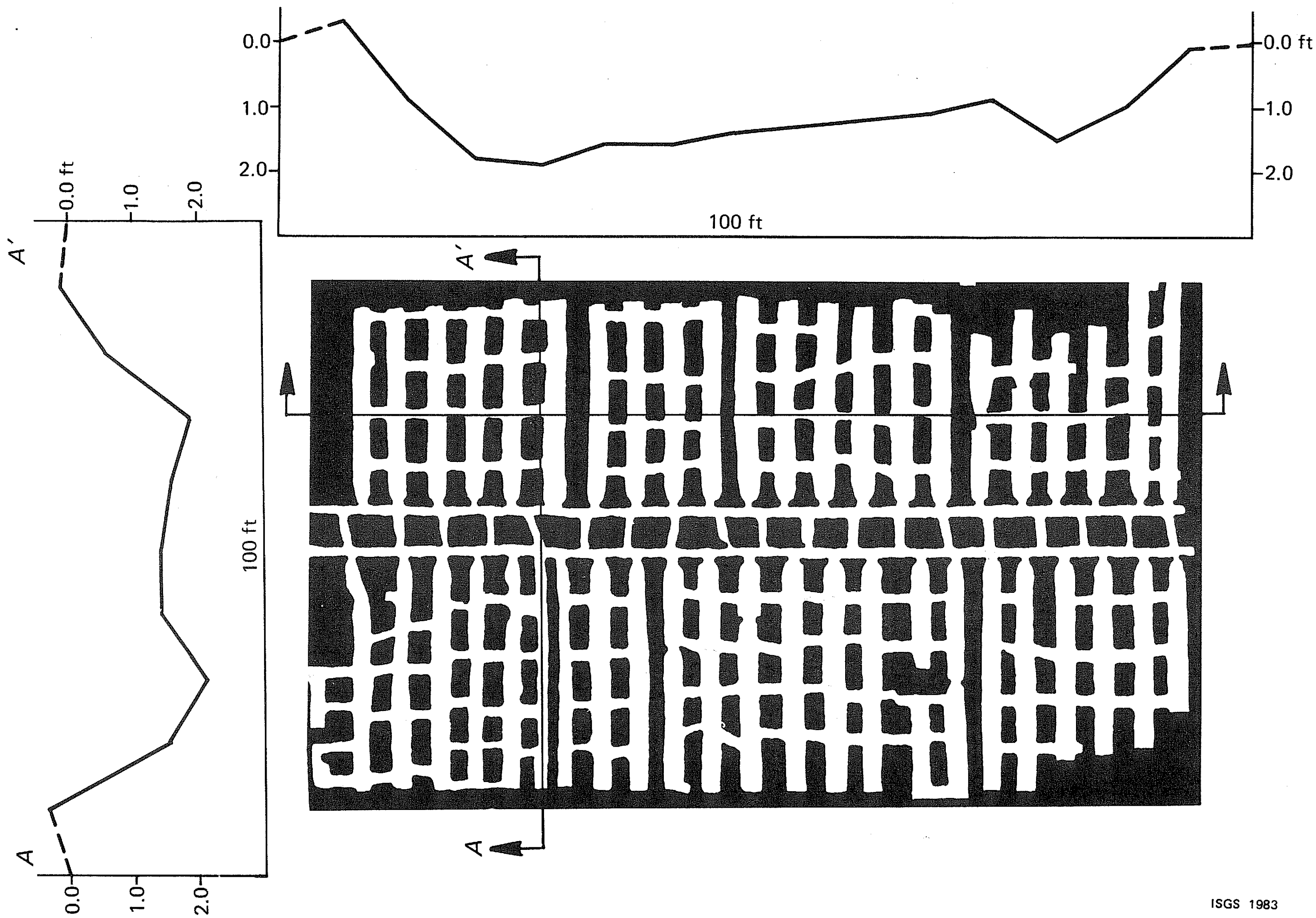


Figure 4. Map and subsidence profiles of production panel in No. 6 Mine of Madison Coal Corporation, site 43 (based on survey by Quade, 1934).

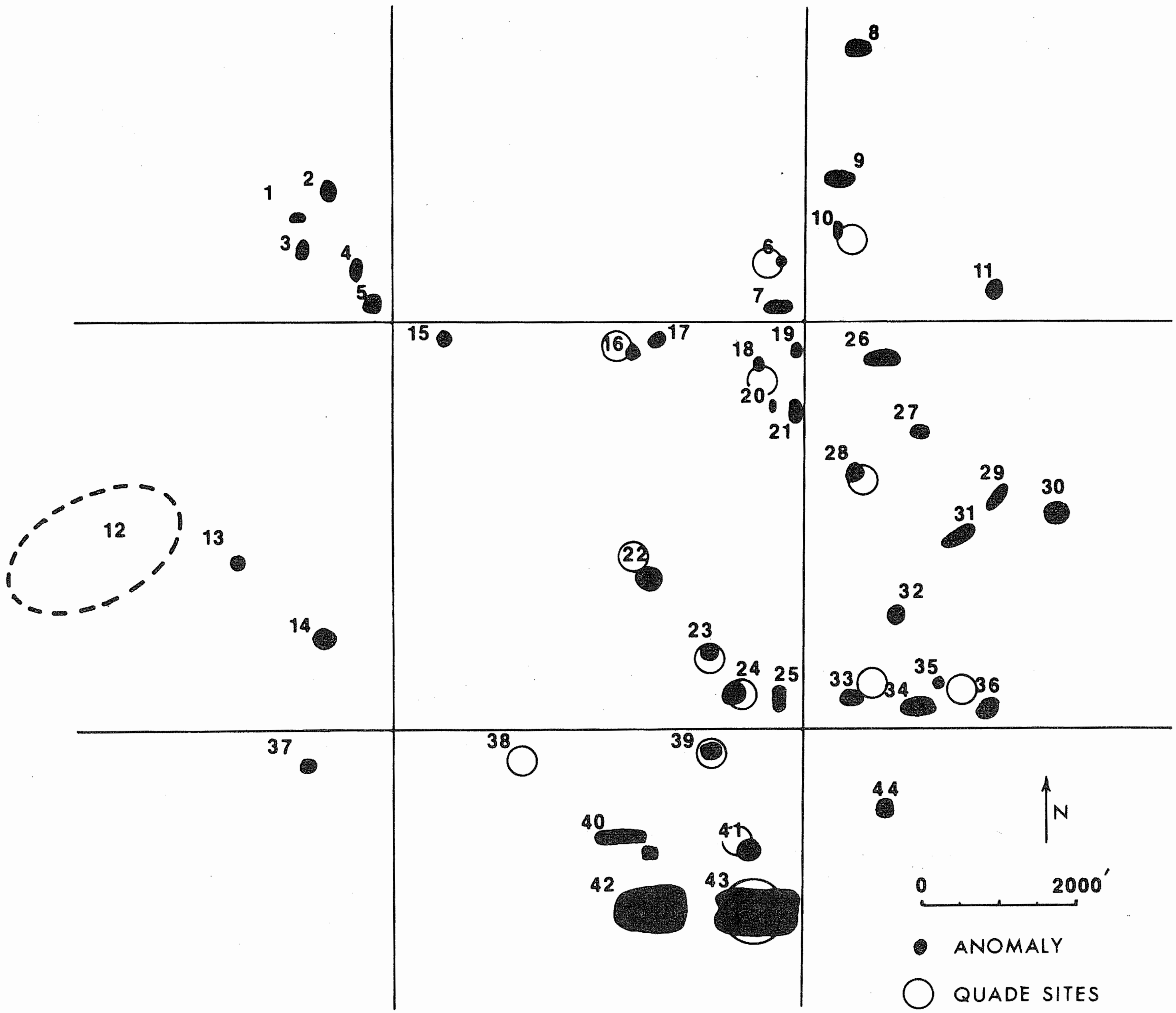


Figure 5. Location and number for sites located on stereo pair aerial photographs of the Divernon area.

Figure 6. Mosaic of aerial photos showing location of anomalies.

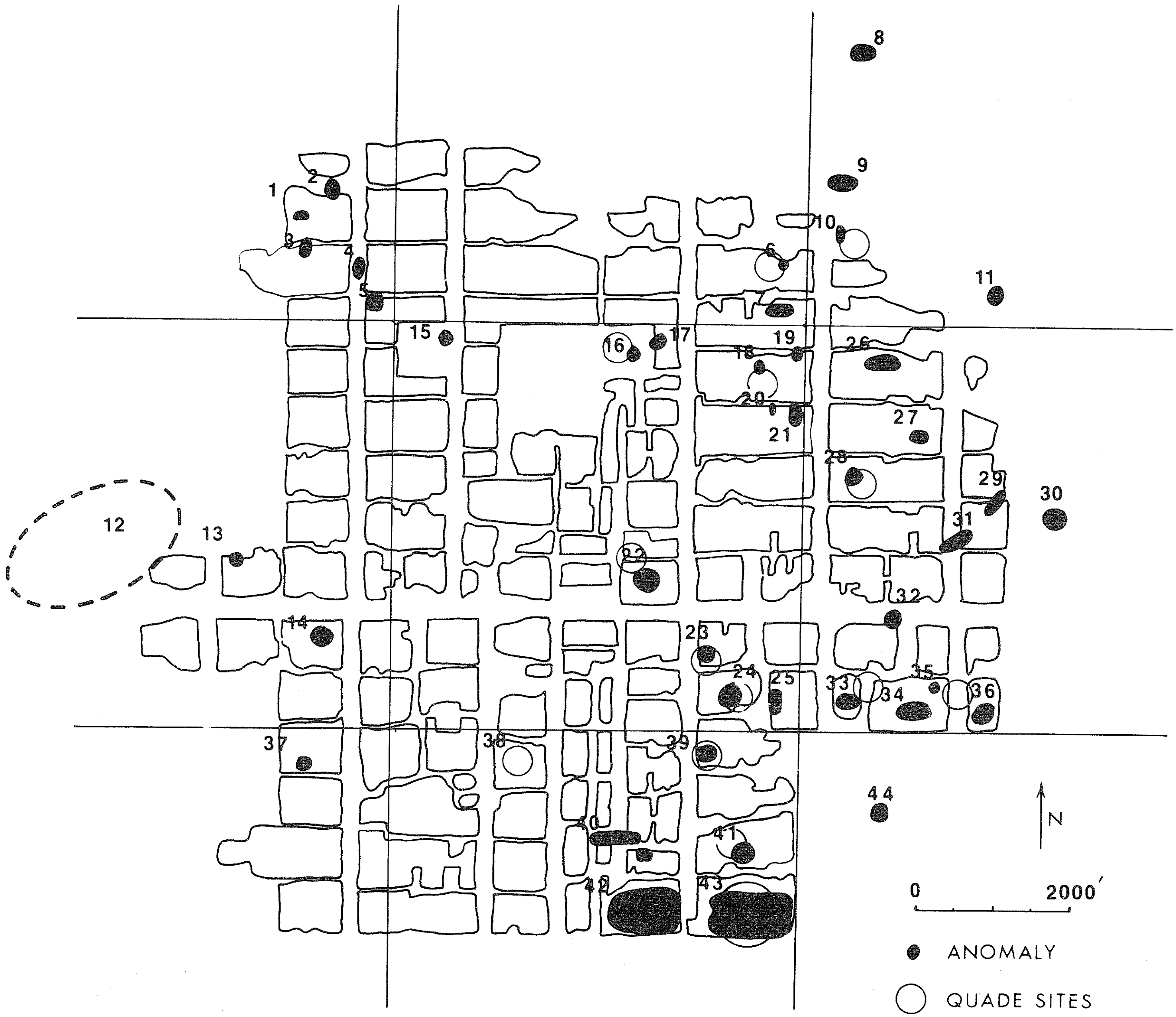


Figure 7. Anomalies and Quade subsidence sites superimposed over outlines of mine production panels.

Appendix A

Air Photography Used in Study

	Date	Flight(s)	Source	Coverage	Scale
1	August 1939	BHD-1 and-4	A.S.C.S.	Full	1:22,000
2	June 1950	BHD-3G	A.S.C.S.	Full	1:20,000
3	June 1956	PR-115	I.D.O.T.	Partial	1:9,600
4	July 1956	BHD-1R	A.S.C.S.	Full	1:20,000
5	March 1962	X-200	I.D.O.T.	Full	1:22,000
6	August 1962	BHD-3CC and-4CC	A.S.C.S.	Full	1:20,000
7	January 1965	X-330	I.D.O.T.	Partial	1:3,000
8	July 1965	PR-1097	I.D.O.T.	Partial	1:3,800
9	September 1968	BHD-1JJ and-3JJ	A.S.C.S.	Full	1:20,000
10	February 1972	R-2016	I.D.O.T.	Partial	1:3,000
11	November 1977	R-2660	I.D.O.T.	Full	1:24,000