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Application of Remote Sensing to Subsidence Detection and Delineation

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The Mississippi Mineral Resources Institute
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Application of Remote Sensing

to

Subsidence Detection and Delineation

by

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ABSTRACT

Subsidence is defined as the lowering of a portion of the earth's crust in response _o man-made condisti o*- or natural geologic processes. Subsidence caused by ’hm extraction of groundwater or petroleum or by the collapse of underground mines is a problem in many of the world’s largest cities. One problem encountered in subsidence research and in preparing subsidence remediatior efforts is in identifying when subsidence began. Subsidence frequently occurs as a gradual lowering of a large area and may not be noticed until significant damage occurs. This research examined the feasibility of using remote-sensing imagery and image-processing techniques to detect and delineate subsidence zones. Conventional air photos were used to investigate an Illinois mine subsidence site. Digital image processing revealed a lineament corresponding to water and sewer-line ruptures which occurred during the subsidence event. Analysis of Landsat satellite imagery of the Richton area of Mississippi has thus far failed to indicate any strong lineaments known to be structurally controlled. More sophisticated image-processing may be required to detect subsidence on satellite imagery.

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INTRODUCTION

Subsidence is the lowering of a portion of the earth's surface in response to natural or man-made conditions and constitutes an environmental problem of considerable magnitude. Many of the world's largest cities, including New Orleans, London, Los Angeles, Bangkok, Tokyo, Houston, and Mexico City, are experiencing subsidence caused by the extraction of groundwater or petroleum from thick sequences of unconsolidated sediment (Dolan and Goodell, 1986). The harbor area which serves Los Angeles and Long Beach, California, has experienced vertical movements in excess of 9 metres, while Mexico City has documented subsidence misplacements up to 8 metres (Scott, 1978). Most of the cities experiencing major problems due to extraction of water or petroleum are located in low-lying coastal areas, where the economic damage being caused by subsidence is compounded by the world-wide eustatic rise in sea-level. The city of London, for example, has been forced to erect the $1 billion Thames Barrier to protect the city from flooding by storm surges from the English Channel and the North Sea. Houston, Texas, has experienced subsidence settlements in excess of two metres and has lost 80 square kilometres of land to inundation by the sea. Another 400 square kilometres are considered liable to periodic inundation. Subsidence damage in the Houston-Galveston area was estimated at $31.7 million per year, from 1969 to 1974.

In addition to subsurface fluid extraction, subsidence may be produced by underground mining of minerals and fossil fuels. Subsidence caused by the collapse of abandoned underground coal mines is a major enviromental problem in the Appalachian states and in Illinois. One major study (GAI Consultants, 1977), identified more than 300 subsidence incidents in the Pittsburgh Coal Field of Pennsylvania and

West Virginia. Mavrolas and Schechtmann (1981) indicated that 46 communities in Illinois had been adversely impacted by subsidence from abandoned mines. Van Besien and Rockaway (1985) collected case-histories of abandoned mine subsidence from 14 states, including Michigan, Oklahoma, Maryland, and Rhode Island, which are not usually thought of as coal-producing states.

Although there are other natural and man-made causes of subsidence, subsurface fluid extraction and mining are the most common causes of subsidence in the United States. The general mechanisms of these types of subsidence are well documented, but the causes of specific subsidence incidents are sometimes difficult to identify, making remedial measures more difficult. One of the problems with subsidence is establishing when it was initiated. Subsidence, particularly when it occurs as a broad trough-like depression, is likely to occur as a gradual almost imperceptible lowering of a large area. Such subsidence is frequently not detected until significant damage occurs in buildings or utilities. Uncertainty in the initiation date makes it difficult to identify which local events might have contributed to, or have been the occasion of, the subsidence.

The purpose of this research was to test the feasibility of using remote-sensing imagery and image processing techniques to detect subsidence in its early stages. If successful, periodic survellance of potential subsidence areas would assist the early identification of subsiding sites, making remedial measures easier, and perhaps less expensive, to implement. The research was funded by a grant from the (U.S.) Bureau of Mines, through the Mississippi Mineral Resources Institute. Funding was in the amount of $4,000 for the period from July 1, 1986 to June 30, 1987.

SUBSIDENCE

Subsidence is defined as the lowering of a portion of the earth's surface in response to man-made conditions or to natural geologic processes. Although a wide variety of processes may cause subsidence, two of the most important, and two which adequately represent the phenomenology of the other processes, are consolidation of thick sequences of sediment due to artificial withdrawal of groundwater or petroleum and the collapse of underground mine openings.

A. Mine Subsidence.

The surface manifestations of subsidence due to underground mining are frequently divided into two general categories: pit or sinkhole subsidence and sag or trough subsidence. Pit Subsidence (Figure 1) is produced by the progressive failure of the mine roof, a stoping process which migrates upward until it reaches the ground surface. The subsidence feature at the surface is a roughly circular hole in the ground, bounded by a distinct, sometimes overhanging, scarp which extends downward until it is masked by a pile of debris, or rubble, resting on the mine floor. Where the mine workings are very shallow, the subsidence pit may provide direct access to the mine, since the debris pile may not be high enough to mask the mine passageways.

With time, the initially steep walls of subsidence pits collapse to assume gentler slopes and to partially fill the original opening. As additional subsidence pits occur and weather to more stable contours, the land surface may be left with a series of conical depressions marking former mine entries and cross-cuts (Dunrud, 1984).

Where the soil portion of the mine overburden is thick and composed of saturated sands and gravels, pit subsidence

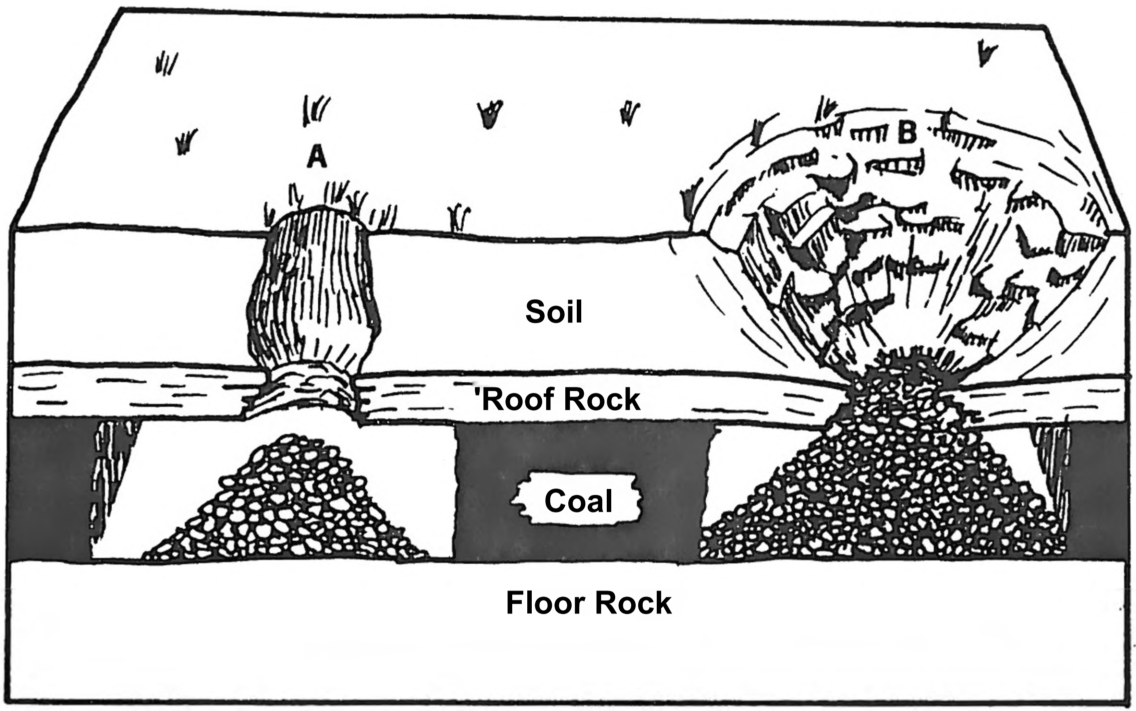

Figure 1. Pit subsidence. Pit at A has formed recently, while pit at B has weathered and slumped to a conical depression.

can produce much more dramatic results. The saturated overburden materials flow into the relatively small openings in the rock of the mine roof. If the mined seam dips, or if water is flowing in the mine, tremendous volumes of soil can be washed into the mine, leaving great craters in the ground surface. This condition was particularly common in the Anthracite Districts of Pennsylvania, where many seams, some up to 15 metres thick, subcropped below Pleistocene outwash channels (Bunting, 1915).

Sag or trough subsidence is produced by the complete removal of coal, or any other mineral value, from a large area of the mine, or by the failure of the mine pillars, or of the mine floor beneath the pillars (Figure 2). The immediate roof of the mine may fall and collect on the mine floor as debris, but eventually the pillar fails by crushing under the weight of the overburden, or the mine floor experiences a bearing-capacity failure, allowing the pillars to deflect downward. Deprived of the support of the pillars, the still-intact roof-rock sags downward until it rests on the debris, producing a gentle sag or trough in the ground surface. Tension fractures may occur along the outer margin of the trough, while low pressure-ridges may occur near the center of the trough (Young, 1916). Tension fractures and pressure-ridges are less common where soils overlying the bedrock are thick.

Sag subsidence features are generally relatively broad, extending over several rooms and pillars, or even over an entire panel of the mine. The magnitude of the downward deflection of the ground surface at the center of the trough depends upon the thickness of the seam removed, the depth of the mine below the surface, and other variables of mining and geology (Aughenbaugh and Elifrits, 1983). The deeper the seam is, the less deflection is produced at the surface.

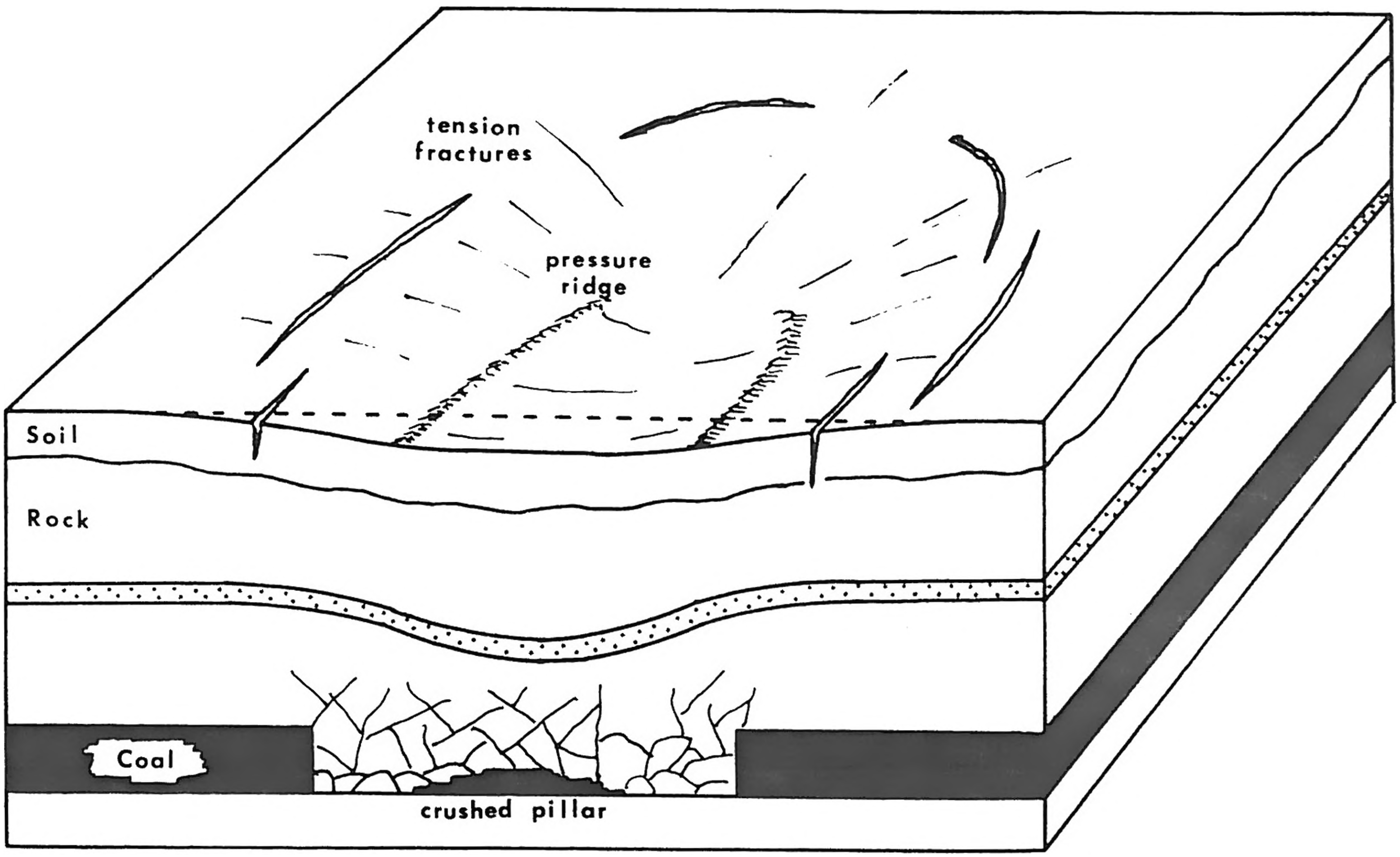

Figure 2. Block Diagram of a Sag, or Trough, Subsidence Feature.

At depths of a few hundred metres, the downward displacement may be scarcely noticeable, even with instrumentation, although the characteristic tension fractures may still occur.

The magnitude of surface displacements is also affected by the width of collapsing mine openings or by the width of the area in which the pillars have failed. In general, surface displacements increase with increasing widths of opening. Surface displacements reach a maximum, for a given depth and seem thickness, at the "critical width", which is usually estimated at 1.4 times the seam depth, based on British experience (National Coal Board, 1975) . Subsidence displacements do not increase as opening widths exceed the critical width.

As with most features which are heavily affected by the geologic conditions, subsidence features do not always fit cleanly into either the pit or sag classifications. Stoping failing of the mine roof, which usually produces a pit failure of the surface, may not always reach the ground surface. As roof material falls to the mine floor, bulking occurs and the pile of debris has a greater volume than the original intact rock. The pile of roof material may eventually fill almost the entire cavity. In such cases, the last few feet of overburden being tightly bound together with plant roots may simply sag downward leaving a shallow sag-like depression in the surface. Several pit subsidence features may coalesce, and with weathering, combine to produce a broad sag-like depression of the surface. In other sag subsidence cases, the mine pillars may not be completely crushed, preventing the mine roof from deflecting downward to meet the debris-covered mine floor. In such circumstances, pit subsidence features may develop later within the larger subsidence trough, marking only partiallycollapsed mine entries and cross-cuts.

B. Fluid-Withdrawal Subsidence.

Subsidence produced by the extraction of subsurface fluids typically resembles mine sag subsidence, although involving much larger areas. One of the largest areas affected by the extraction of groundwater is the San Joaquin Valley of southern California where vertical settlements of several metres have been observed. Although these displacements are considerable, their distribution over such large geographic areas makes the formation of surface fractures less probable. Where the unconsolidated materials are confined to small basins, or where the detailed stratigraphy of the sediments serves to concentrate the subsidence strains, large fractures may be observed. The "Pixley Fissure" was a large tension fracture in the San Joaquin Valley, first observed in 1969. The fracture was 800 metres long, 2.4 metres wide and open to a depth of 1.8 metres. Surface subsidence in the Pixley area was estimated as 3.6 metres. Aseismic faulting, faulting associated with non-tectonic stresses, has also accompanied groundwater withdrawal. The Picacho fault, 7 kilometres east of Picacho, Arizona, was traceable for 15.8 kilometres and had an apparent displacement of 0.1 metres (Holzer and Thatcher, 1977).

Lister and Secrest (1985) investigated surface fractures on the floor of the arid Hualapai Valley near Kingman, Arizona. Large desiccation polygons (up to 300 metres in diameter) were attributed to long-term drying of the fine alluvial sediments in the basin, while more recent fissures up to 3 kilometres in length were attributed to a single aquifer pump test in deep sands. A series of arcuate fractures was attributed to subsidence caused by dissolution of salt beds occurring approximately 400 metres below the surface.

Pit subsidence features are occasionally produced by groundwater withdrawal. Lusk (1962) reported subsidence pits or sinks at Clarksdale, Mississippi. The pits were circular features up to six metres in diameter and from 0.3 to 1.0 metres deep. The pits were believed to form because of the drying of a clay layer induced by prolonged pumping of an underlying sand aquifer. As the clay layer dried, desiccation cracks formed and coarse material overlying the clay was washed into the cracks. The voids in the overlying coarse materials eventually created a sink-like depression in the ground surface.

PREVIOUS RESEARCH

Little research has been performed on the development of remote sensing technology for specific application to detection of subsidence. Available publications stress the application of conventional remote sensing technology, especially air photo interpretation, in the solution of problems involving tectonics, salt dome solution, and subsidence.

Earth Satellite Corporation (1975) applied remote sensing techniques to the problem of identifying mine subsidence features in the Antracite Districts of eastern Pennsylvania. ERTS-1 (Landsat 1) satellite imagery and both conventional and infra-red air photos were evaluated for application to the detection of subsidence features. More than 1000 subsidence features were identified on the basis of air photo interpretation. Recognition criteria were usually tonal contrast and the presence of open fractures, either radial or annular to the suspected subsidence feature. Satellite imagery was evaluated as useful only for delineation of regional structural trends and large lineaments. No image-processing techniques were applied to either satellite imagery or air photos. Matheson (1986) applied conventional air photo interpretation to detect mine subsidence features along the Colorado Front Range, in the Colorado Springs and Boulder-Weld Coal Fields. No image-processing techniques were applied.

In their investigation of desiccation and subsidence fractures near Red Lake Playa in the Hualapai Valley of Arizona, Lister and Secrest (1985) utilized air photos ranging in scale from 1:6,000 to 1:60,000. At the smaller scales, they found it impossible to delineate fracture zones or lineaments unless these were emphasized by vegetation growth. No application of image-processing techniques was reported. In a completely unrelated study of the same area, Deister, Stevens, and Van Besien (1983) had employed digital image-processing techniques to satellite imagery of the Hualapai Valley and the adjacent Cerbat Mountains. Directional filtering of Band 7 (reflected Infra-red) data from Landsat 1 yielded a number of lineaments in the vicinity of Red Lake Playa which paralleled the subsidence fissures identified by Lister and Secrest. These fissures, in turn, were sub-parallel to the major Neal Ranch Fault, which forms the eastern boundary of the Cerbat Mountains.

Elifrits (1980) applied remote sensing image-processing and data-base management techniques in a study of subsidence over an operating coal mine in Jefferson County, Illinois. Although satellite imagery was available, high-altitude infra-red aerial photography was the primary source of lineaments in the study. Satellite imagery from Landsats 2 and 3 was used primarily for land-cover classification. Subsidence features, except for large fractures and lineaments, were located by ground observation.

SCOPE OF WORK

The objective of this research was to test the feasibility of using remote-sensing image-processing techniques to detect subsidence. The preceding discussion on subsidence and the uses of remote sensing in subsidence studies indicated that the two more reliable indicators of subsidence were the fractures associated with most subsidence events, and the changes in ground tone, or albedo, caused by changes in soil-moisture and subsidence-induced alterations of the drainage pattern. Both phenomena could reasonably be expected to be observable on large-scale air photographs, particularly if image enhancement techniques were applied. The presence of such features in smaller-scale air photographs and in satellite imagery would have to be demonstrated on imagery of areas where subsidence was known to have occurred. Multi-temporal imagery (before and after) is essential to the study, since it is otherwise impossible to determine whether or not featuers observed in post-subsidence imagery were actually caused by subsidence or pre-existed the subsidence.

While the multi-temporal satellite imagery of Mississippi, on which the proposal was based, proved to be unavailable, before-and-after air photos were available for a mine subsidence event in Illinois. These served to establish the feasibility of using image-processing techniques to detect subsidence features. In addition, image-processing techniques were applied to an area near Richton, Mississippi, where dissolution of deeply buried salt deposits is suspected, and where subsidence-related deformation might be observable.

ILLINOIS SUBSIDENCE INVESTIGATIONS

A. Location

Johnston City, site of the mine subsidence incident, is a community with a population of approximately 4,000, located about 85 miles southeast of St. Louis, Missouri The town is situated on the northern edge of Williamson County, and near the southern boundary of the Illinois Coal Basin (Figure 3). The primary industries of this southern portion of Illinois are coal mining and agriculture. The area is studded with abandoned coal mine tipples and surface mine spoil banks. The area immediately around Johnston City was once known as the "Quality Circle" because of the thickness and purity of the coal seams in this area.

B. Geology

Johnston City lies in the Till Plains Section of the Central Lowlands Physiographic Province (Figure 4), near the southern limit of Pleistocene glaciation. The immediate area is known as the Mount Vernon Hill Country, and consists of gently rolling topography interrupted by occasional flat areas which were once peri-glacial lake beds. The till deposits, which are of Illinoian age, are thin (less than three metres thick) and discontinuous.

Underlying the Pleistocene deposits are Lower Pennsylvanian coal-bearing formations. At Johnston City, these strata consist of interbedded shales, sandstones, limestones, and coal of the Carbondale Formation. Shale is the most abundant rock type. The Herrin (Illinois No. 6) coal seam is 2.5 to 3.0 metres thick and lies at a depth of 80 to 90 metres below the ground surface.

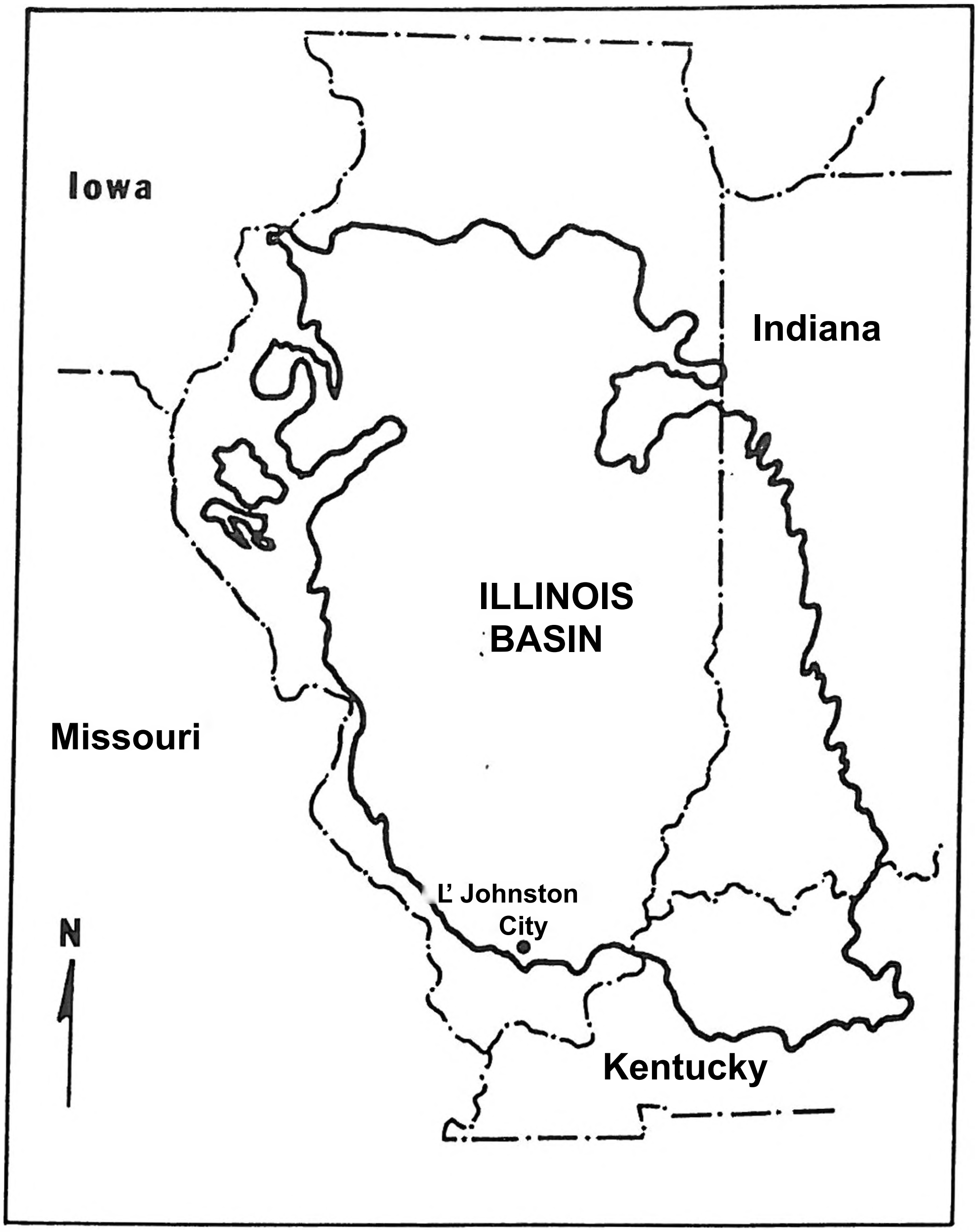

Figure 3 Location of Johnston City, Illinois

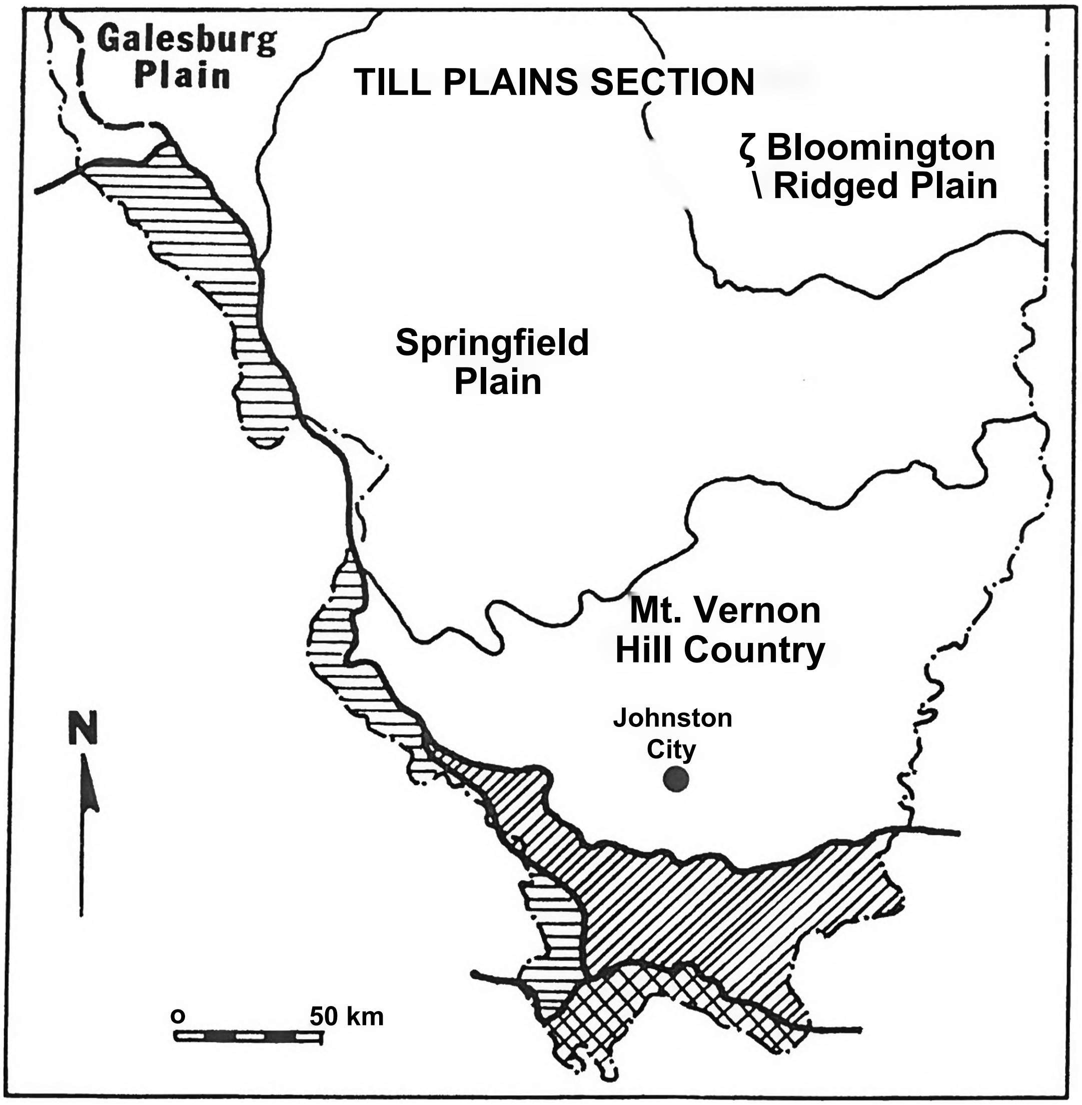

Figure 4 Physiographic map of southern Illinois.

The principal structural features of the immediate area are the Rend Lake Fault System, which trends roughly north-south and the Collage Grove Fault System which strikes east-west (Figure 5). Both systems are discontinuous and made up of numerous minor faults and displacements. The Rend Lake Fault System may be characterized as a normal fault with the eastern block being the downthrown side. The Collage Grove system is more variable; normal, reverse, and strike-slip displacements have been observed within this fault system which runs through Johnston City. The area is subject to occasional seismic activity. Lawrenceville, epicenter of the Richter Magnitude 5 earthquake of June 10, 1987, is approximately 160 kilometres northeast of Johnston City.

C. Mining History.

Coal mining in this area is among the oldest in Illinois and the Midwest. The first shipping mine opened in 1870, and mines are still active in the area. Johnston City was undermined by the Lake Creek Coal Mine which operated from 1890 to 1930. All mining was done by the room and pillar method, where pillars were left to support the mine roof for some indefinite, but hopefully lengthy, period of time. Like most mines in the area, the Lake Creek Mine was wet. An unusually large pillar, 45 metres square, was left beneath the town's Washington Elementary School, to provide permanent protection against subsidence. In 1928, the mine encountered a fault with 20 metres of displacement, along the northeast boundary of the mine. This fault is part of the Cottage Grove Fault System and trends northwest to southeast. In 1930 the Lake Creek mine was closed.

D. Subsidence History.

Sporadic incidents of sag-type mine subsidence have occurred in Johnston City ever since the Lake Creek Mine

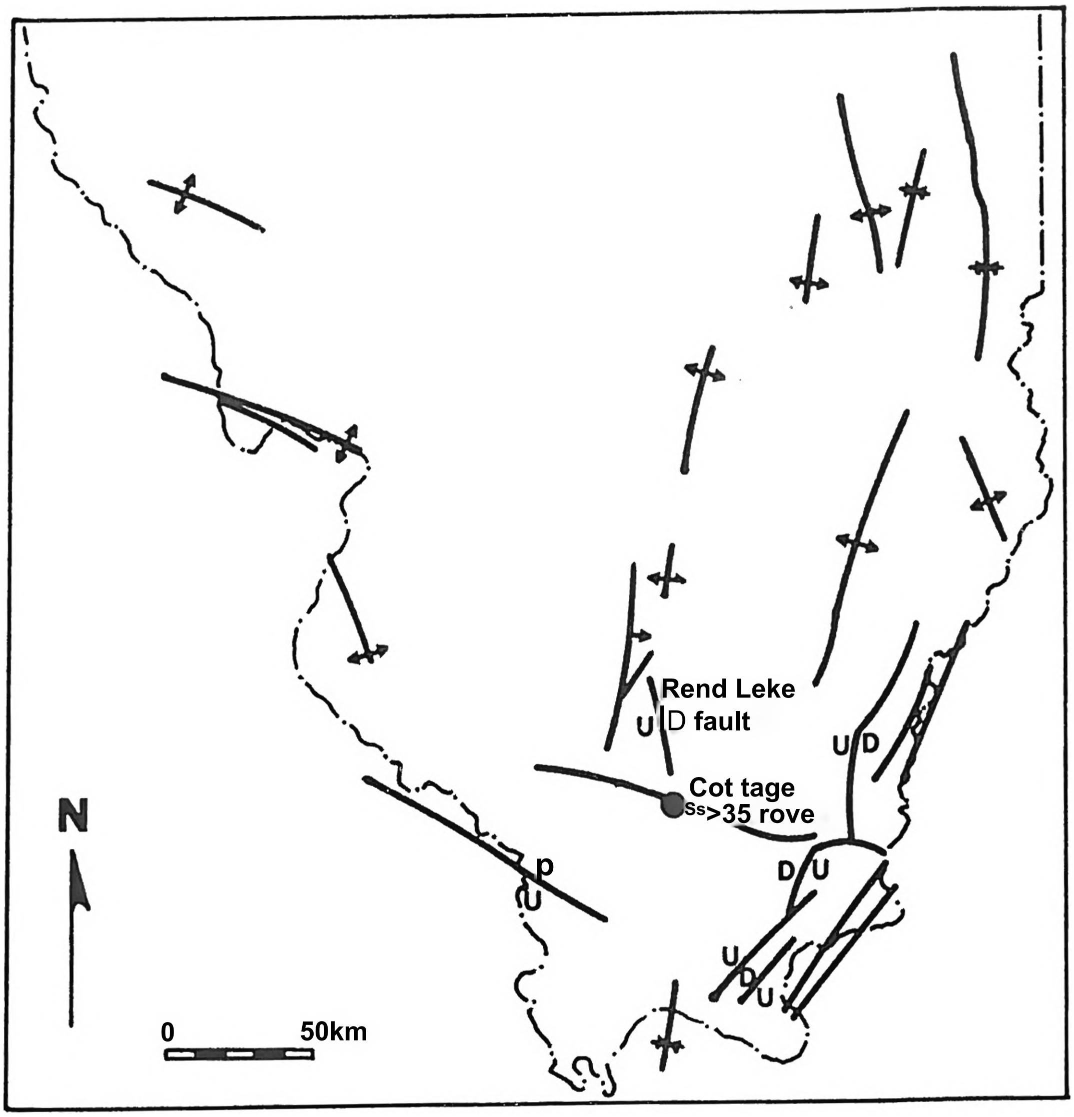

Figure 5 Structures map of Southern Illinois

dosed in 1930. Until 1971, however, it appeared that the block of coal left under the elementary school was serving its intended function and protecting the school from subsidence. In 1971, subsidence damage was noted in the elementary school building; the building was declared unsafe, and the building was razed later that same year. In the light of current subsidence technology it was recognized that the protective block of coal left under the school was too small to prevent damage to the structure by subsidence in adjacent mine workings.

In the belief that subsidence was then complete, construction of a new school building was initiated on the same site during the summer of 1974. In October of that same year, while the new building was still under construction, additional subsidence occurred. Significant damage was inflicted upon the new school building, and rupturing of utility lines was reported in the vicinity of the school (Aughenbaugh and Stephenson, 1974) . Completion of the new elementary school building was postponed indefinitely.

E. Remote Sensing Investigations.

Conventional air photos of the Johnston City area were available; one set (Figure 6) was taken in May, 1960, at a scale of 1:21,000 while the second set, at a scale of 1:9,600, was taken in December, 1974, approximately two months after subsidence damaged the partially completed replacement school. No evidence of subsidence was visible on either set of photos.

A portion of the 1974 air photo coverage was loaded into the MMRI remote sensing image-processing system using a video-digitizer (digitizing TV camera). The resulting image

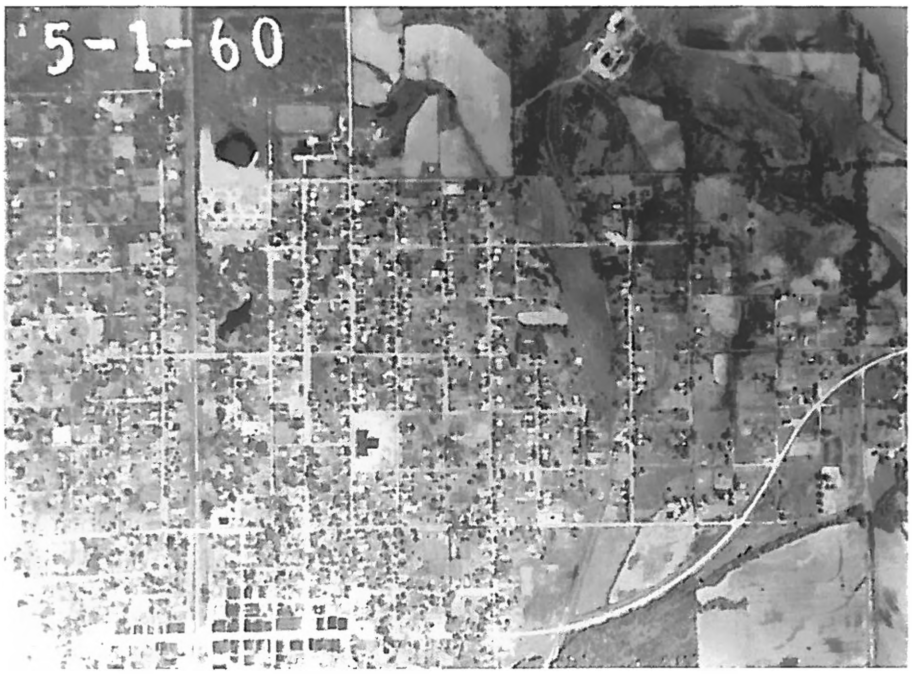

Figure 6 Airphoto of Johnston City in 1960.
The T-shaped structure in the center is the elementary school approximately 11 years before it was destroyed by subsidence.

was smoothed with and low-pass filter and contrast-stretched to utilize the maximum brightness range of the output display device (See Appendix for details of the MMRI processing system and image-processing techniques). A pronounced bright lineament is observable on the resulting image (Figure 7). Directional filtering with a 3 x 3 matrix produced the same lineament (Figure 8), but failed to produce any other lineations. The lineament, which coincides with water and sewer-line ruptures which occurred during the October, 1974 subsidence incident (Figure 9), is interpreted as a zone of drier soils caused by the loss of soil moisture into bedrock fractures produced by the subsidence. The fracture is not observable in the 1960 air photos. No other subsidence features were observable on the 1974 air photos, although ground surveys indicated that surface displacements of considerable magnitude occurred during the subsidence.

MISSISSIPPI INVESTIGATIONS

Landsat multi-spectral imagery of the Richton Dome area, near Hattiesburg, Mississippi, was also examined for lineaments. Emplacement of the salt dome or subsequent dissolution of the salt may have resulted in the formation of fractures visible on satellite imagery. Directional filtering of Band 7 (Reflected Infra-red) data revealed strong lineaments only in the NNW-SSE alignment.
These lineaments are coincident with stream drainage patterns and may not be indicative of anything other than regional slope. At this time, only Band 7 data have been analyzed. Additional investigations are planned with other bands of the Landsat imagery and with high-altitude air photos.

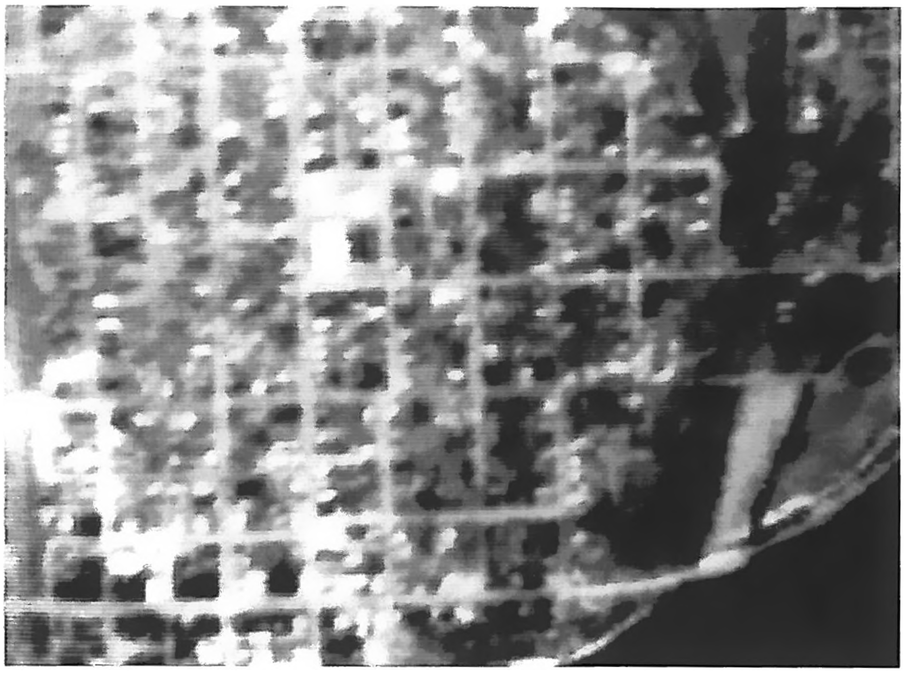

Figure 7 Processed image of Johnston City in 1974. Lineament trends ENE - WSW and lies just south of school.

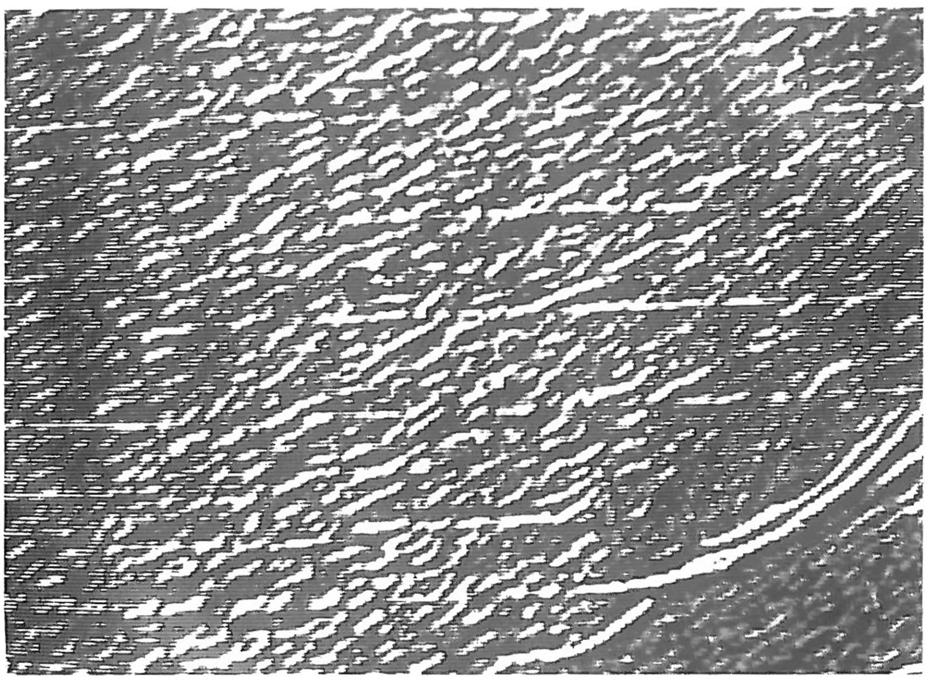

Figure B Results of ENE - WSW directional filtering of 1974 air photo of Johnston City.

Figure 9 Location of lineaments with respect to breaks in utility lines.

CONCLUSIONS

Investigations to date have not been sufficient to establish the feasibility of detecting subsidence features through the use of image-processing techniques applied to air photos and satellite imagery. Previous investigations indicated that many subsidence features can be detected through conventional photo-interpretation techniques applied to low-altitude air photos. That digital image-processing can be advantageously applied to conventional low-altitude air photos was demonstrated by analysis of before and after photos of Johnston City. Relatively simple enhancement techniques such as low-pass filtering and contrast-stretching were sufficient to reveal a previously undetected lineament corresponding to reported breaks in water and sewer lines.

The lack of multi-temporal Landsat imagery of known subsidence areas has thus far prevented the evaluation of satellite imagery for detecting subsidence features. That such imagery may have application is demonstrated by the fortuitous detection of lineations parallel to the reported subsidence fissures in the Hualapai Valley of Arizona. The analysis of Landsat imagery of the Richton area of Mississippi has so far indicated limited applicability for such small scale imagery. However, utilization of multi-spectral and multi-temporal imagery may permit detection of at least larger fissures with satellite imagery.

REFERENCES

Aughenbaugh, N. B. , and Elifrits, C. Dale, 1983, Subsidence and Time, American Institute of Mining and Metallurgical Engineers, Preprint 83-388, 8 p..

Aughenbaugh, N. B., and Stephenson, R. W. , 1974, Appraisal of Subsidence at Washington Elementary School, Johnston City, Illinois, 28 p..

Bunting, Douglas, 1915, The Limits of Mining Under Heavy Wash, American Institute of Mining and Metallurgical Engineers, Bulletin 97, pp. 1-21.

Deister, R., Stevens, M. M., and Van Besien, A.C., 1983, A Study of the Wallapai Mining District, Northwestern Arizona, unpublished student report, Univ, of Missouri-Rolla , 38 p..

Dolan, Robert, and Goodell, H. Grant, 1986, Sinking Cities, American Scientist, Vol. 74, No. 1, pp. 38-47.

Dunrud, C. Richard, 1984, Coal Mine Subsidence - Western United States, in: Man-Induced Land Subsidence, Geological Society of America, Reviews in Engineering Geology, Vol. 6, pp. 151-192.

Earth Satellite Corporation, 1975, Use of Photo Interpretation and Geological Data in the Identification of Surface Damage and Subsidence, Appalachian Regional Commission, ARC-73-111-2554, 113 p..

Elifrits, C. Dale, 1980, A Subsidence Study Over a Room and Pillar Coal Mine, Unpublished Dissertation, Univ, of Missouri - Rolla, 118 p..

GAI Consultants, Inc., 1977, Study and Analysis of Surface Subsidence over the Mined Pittsburgh Coal Bed, Bureau of Mines Contract J0366047, 155 p..

Guacci, Gary, 1977, The Pixley Fissure, San Joaquin Valley, California, in: Evaluation and Prediction of Subsidence, American Society of Civil Engineers, pp. 303-319.

Holzer, Thomas L., and Thatcher, Wayne, 1977, Modeling Deformation Due to Subsidence Faulting, in Evaluation and Prediction of Subsidence, American Society of Civil Engineers, pp. 349-357.

Hunt, Stephen R., 1978, Characterization of Subsidence Profiles over Room-and-Pillar Coal Mines, in: Proceedings, Illinois Mining Institute, pp. 50-66.

Lusk, Tracy W., 1963, Problem of Desiccation Sinking at Clarksdale, Mississippi, in: Geologic Research Papers - 1962, Mississippi Geological, Economic, and Topographical Survey, pp. 60-75.

Mavrolas, P., and Schechtmann, M., 1981, Coal Mine Subsidence, Proceedings from a Citizens' Conference, Illinois South Project, Herrin, Illinois, 45 p..

National Coal Board, 1975, Subsidence Engineers Handboook, London, ill p..

Scott, Ronald F., 1978, Subsidence - A Review, in: Evaluation and Prediction of Subsidence, American Society of Civil Engineers, pp. 1-25.

Van Besien, A. C., and Rockaway, J. D., 1985, Statistical Analysis of Subsidence over Room-and-Pillar Coal Mines, in: Proceedings, Second Conference on Ground Control Problems in the Illinois Coal Basin, Southern Illinois University, pp. 183-145.

Young, L. E., 1916, Surface Subsidence in Illinois Resulting from Coal Mining, Illinois State Geological Survey Cooperative Coal Mining Investigations Series, Bulletin 17, 205 p.

APPENDIX

IMAGE PROCESSING EQUIPMENT AND TECHNIQUES

A. General.

The remote-sensing image-processing and display system at the Mississippi Mineral Resources Institute is the Spectral Data VIP system, and is based on the IBM-PC computer. Image processing techniques referred to in this report are from the VIP-RIPs Program Package by Spectral Data. RIPS Processing techniques were originally developed at the EROS Data Center and were adapted by Spectral Data Corporation for use on the IBM-PC.

B. Low-Pass Filters.

The RIPS low-pass filter routine is called "SMOOTH". The module passes a sub-array of variable size over each pixel in the image. The mean value of all pixels covered by the sub-array is then substituted for the pixel at the upper left corner of the sub-array. The effect is to smooth out abrupt (high-frequency) changes in pixel brightness. The larger the sub-array being used, the more effective is the filter in suppressing abrupt changes in brightness, but the longer is the required processing time. For this investigation, a sub-array of 2 x 2 pixels was used to reduce processing time.

C. Contrast Stretching.

The RIPS contrast-stretching module is called "SCALE". The contrast of an image can be improved, or stretched, by applying input values for Bias and Gain:

$$\text{Output Pixel} = (\text{Input Pixel} + \text{Bias}) * \text{Gain}.$$

A gain of 1.6 was used on the Johnston City investigations. No bias correction was used.

D. Directional Filtering.

The RIPS routine for directional filtering and for ege enhancement is called "CONVOLVE". In this module, a 3 x 3 sub-array of nine number is passed over the image. Each pixel covered by the sub-array is multiplied by the corresponding number in the sub-array. The sum of the nine products is then substituted for the pixel value at the center of the sub-array. Depending on the values inserted in the sub-array, the image can be filtered to enhance lineaments in any specified direction or can be used to visually enhance the edges of changes in image tones or brightness values. A sub-array used to enhance north-south lineaments is:

$$\begin{matrix} -1 & +2 & -1 \\ -2 & +4 & -2 \\ -1 & +2 & -1 \end{matrix}$$