DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE APPALACHIAN REGIONAL COMMISSION

MISCELLANEOUS FIELD STUDIES
MAP MF-693 D

Table 1.--Comparison of mine-subsidence classifications used on this map with the earlier map of adjoining counties

1. Classification (after Bushnell, 1975b)	2. Map of Allegheny, Washington, and Westmoreland Counties (Bushnell, 1975b)		3. Present map; Armstrong, Beaver, and Butler Counties	
	Letter identifier	Description	Letter identifier	Description
Areas that correlate with high numbers of damaging mine-subsidence events	Ap	Pittsburgh coal bed mined underground before April 27, 1966, with 0 to 200 ft of overburden	A	One or more coal beds mined underground before April 27, 1966. Thickness of overburden is less than 500 feet in most places.
	Af	Upper Freeport coal bed mined underground before April 27, 1966, with 0 to 500 ft of overburden		
Areas that correlate with moderate numbers of damaging mine-subsidence events	Bp	Pittsburgh coal bed mined underground before April 27, 1966, with 200 to 500 ft of overburden		No equivalent mapped. Data generally are inadequate to allow correlation with areas of moderate numbers of damaging mine-subsidence events.
	Bf	Upper Freeport coal bed mined underground before April 27, 1966, with more than 500 ft of overburden		
Areas mined, but information on mining period and method inadequate for correlation		No equivalent	AC	One or more coal beds mined, but period and method of mining unknown (Sholes and Skema, 1974). If additional study shows mining was underground, reclassify to "A", or "Cm", depending on mining period. If mining was at the surface only, reclassify to "D", unless area is underlain by another mineable coal bed, in which case reclassify to "Cp".
Areas that correlate with minor numbers of damaging mine-subsidence events	Cp	Pittsburgh coal bed mined underground before April 27, 1966, with more than 500 ft of oberburden; mined underground between April 27, 1966, and June 30, 1974, with any thickness of overburden; or mineable underground after June 30, 1974, with any thickness of overburden	Cm	One or more coal beds mined underground between April 27, 1966, and June 30, 1975, with any thickness of overburden
	Cf	Upper Freeport coal bed mined underground between April 27, 1966, and June 30, 1974, with any thickness of overburden; or mineable underground after June 30, 1974, with any thickness of overburden	Cp	One or more coal beds potentially mineable underground after June 30, 1975, with any thickness of overburden
Areas that correlate with extremely rare damaging mine-subsidence events	D	Areas where coal is too thin for extensive underground mining in the foreseeable future or where coal has been removed by strip mining or natural erosion. Very restricted areas may have been undermined before 1910.	D	Areas where coal is too thin for extensive underground mining in the foreseeable future or where coal has been removed by surface mining, or no coal exists. Small areas may have been mined without known records.
	Dpw	Areas underlain by washouts in the Pittsburgh coal bed		

Figure 1.--Average rock thickness between the Vanport Limestone and individual coal beds of the Allegheny Group

EXPLANATION

A — Areas that correlate with high numbers of damaging mine-subsidence events

AC — Areas mined, but information on mining period and method inadequate for correlation

Cm / Cp — Areas that correlate with minor numbers of damaging mine-subsidence events

Cm - mined underground between April 27, 1966, and June 30, 1975

Cp - potentially mineable underground after June 30, 1975

D — Areas that correlate with extremely rare damaging mine-subsidence events

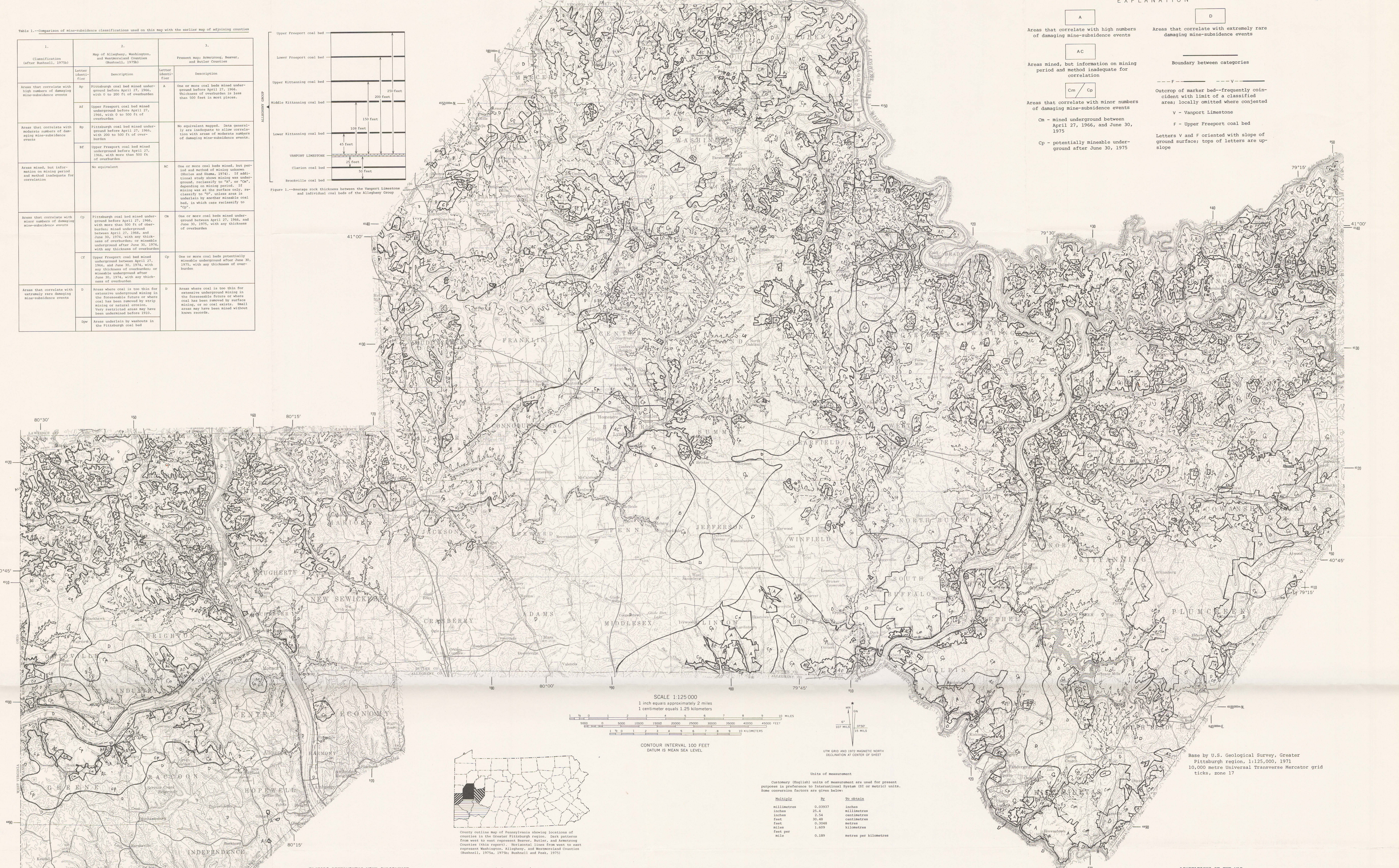
Boundary between categories

---F--- ---V--- Outcrop of marker bed--frequently coincident with limit of a classified area; locally omitted where conjested

V - Vanport Limestone

F - Upper Freeport coal bed

Letters V and F oriented with slope of ground surface; tops of letters are upslope



Base by U.S. Geological Survey, Greater Pittsburgh region, 1:125,000, 1971
10,000 metre Universal Transverse Mercator grid ticks, zone 17

SCALE 1:125 000
1 inch equals approximately 2 miles
1 centimeter equals 1.25 kilometers

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

County outline map of Pennsylvania showing locations of counties in the Greater Pittsburgh region. Dark patterns from west to east represent Beaver, Butler, and Armstrong Counties (this report). Horizontal lines from west to east represent Washington, Allegheny, and Westmoreland Counties (Bushnell, 1975a, 1975b; Bushnell and Peak, 1975)

Units of measurement

Customary (English) units of measurement are used for present purposes in preference to International System (SI) or metric units. Some conversion factors are given below:

Multiply	By	To obtain
millimetres	0.03937	inches
inches	25.4	millimetres
inches	2.54	centimetres
feet	30.48	centimetres
feet	0.3048	metres
miles	1.609	kilometres
feet per mile	0.189	metres per kilometres

INTRODUCTION

This map was prepared as part of a study of underground coal mining activity as it relates to surface subsidence, one element of a larger program of environmental analysis of the Greater Pittsburgh region. The premise of the study was that geologic and other mappable factors would correlate with known damaging subsidence events and thereby either increase the predictability of subsidence events or, at least, enable a general classification of land relative to its potential for subsidence. Other map products of the study concern Allegheny, Washington, and Westmoreland Counties (Bushnell, 1975a, 1975b; Bushnell and Peak, 1975), just south of the counties of the present map. For present purposes, these six counties comprise the Greater Pittsburgh region.

In this region, extensive underground coal mining has created a significant mine-subsidence problem. Mine subsidence is a term used to describe subsidence of the ground surface as a result of underground mining. This has been a source of concern to the residents of the bituminous coal fields and to the coal-mining industry for many years, but no general solution to the problem was found, in spite of some attempts by individual companies to protect surface structures from subsidence damage. Accordingly, a movement began to legislate subsidence regulations (Vandale, 1967). In 1961, the Legislature of the Commonwealth of Pennsylvania passed an act which provided for the establishment of an anthracite and bituminous subsidence fund. This "Mine Subsidence Insurance Act of 1961" became effective July 1, 1962, and under its provisions owners of a limited class of property can buy insurance from the Commonwealth. Information on this service is available from:

Division of Mine Subsidence Insurance
Pennsylvania Department of Environmental Resources
Kossman Building
Forbes and Stanwix Street
Pittsburgh, Pa. 15222

Later, the Commonwealth enacted the "Bituminous Mine Subsidence and Land Conservation Act of 1966," which went into effect on April 27, 1966. The 1966 Act requires that certain structures existing on the effective date be protected, that the owners of surface land or structures which have not been undermined have the right to support their property by purchase of underlying coal at a fair price, and that a notice of the status of mining and of coal ownership must be included in all deeds of property transfer to protect the buying public (Cortis, 1969). Details of the 1966 Act and standards and regulations are available from:

Division of Mine Subsidence Regulation
Pennsylvania Department of Environmental Resources
Donaldsons Crossroads
203 South Washington Road
McMurray, Pa. 15317

THE MAGNITUDE OF THE MINE-SUBSIDENCE PROBLEM

The classified areas of subsidence damage used in Allegheny, Washington, and Westmoreland Counties was based on 103 known and verified incidents. Accordingly, the record of damaging subsidence events doubtless is very incomplete. The high, moderate, and minor numbers of damaging mine-subsidence events referred to on the present map (table 1, column 1) therefore, are relative terms only. Nevertheless, mine subsidence is a significant problem, and the incomplete record shows that there has been an average of at least one damaging mine-subsidence event for about every 1,600 to 1,700 dwelling units that have been undermined in Allegheny, Washington, and Westmoreland Counties (Bushnell, 1975a, table 2; Bushnell and Peak, 1975, table 2). It is very likely that the true incidence is appreciably greater.

FACTORS DETERMINING MINE SUBSIDENCE

The underground mining of coal leaves a void or opening. Numerous factors then interact to determine whether or not surface collapse will occur.

If the coal is completely removed from a large area, mine-roof collapse normally occurs immediately, and the ground surface may subside within days. If, however, the void is filled immediately with properly compacted mine, urban, or industrial waste, surface subsidence will not occur. If pillars of coal are left, with rooms of coal removed, then the possibility, time, and extent of collapse are uncertain. Where the pillars left after mining are large and strong and the rooms small, the pillars and the roof will support the overburden and collapse likely will not occur. Underground conditions, however, vary with time, and rock is commonly weakened after mining, thus resulting in delayed collapse. Locally, subsidence has occurred more than 30 years after cessation of mining.

If collapse into the mined-out void occurs: (a) the overburden may fall as a unit along more or less vertical fractures so that surface subsidence and, frequently, broken ground will occur, with the amount of subsidence approximately equal to the thickness of the mined-out coal bed; (b) the overburden may fragment as it collapses with an increase in volume owing to looser packing of the fragments, so that the void becomes filled without surface subsidence; or (c) as is commonly the case, both (a) and (b) occur in part so that the ground surface drops, but only for a portion of the thickness of the coal removed. Studies of many coal-mining areas show that regardless of the depth of mining, the amount of surface subsidence that occurs commonly is 50 percent of the thickness of the mined-out bed (S. E. Cortis, oral commun., 1974).

The following factors appear critical to an understanding of the cause, effect, and risk of mine collapse and surface subsidence: (a) rock character, (b) thickness of overburden, (c) mining operations, (d) ground-water regime, (e) loading and other surface activity, and (f) legislation.

Rock character.--The coal beds of western Pennsylvania are enclosed in a variety of rock types: limestone, mudstone, shale, siltstone, and sandstone. Each type reacts differently when an adjacent void is created. Although this reaction is a critical factor, a systematic study of rock variation has been made only in the Washington area of Pennsylvania (Berryhill and others, 1971). All else being equal, when a thicker coal bed is mined a bigger void results, with the potential for greater surface subsidence. Pillars of coal left in place, after mining is completed, that are sufficient in area (at least 50 percent of the area mined), and of appropriate dimensions and spacing will support the overburden. Bulging and spalling along free faces of the pillars are indications that the overburden weight is greater than the rock strength and that mine-roof collapse may eventually follow. Pillars can be forced downward into a weak floor rock that yields plastically under the weight of pillar and overburden. Thick massive sandstone layers usually are competent and support a wider span than, for example, shale. However, if a sandstone layer does fail, it may either subside as a unit with differential subsidence and possible ground breakage at its margins, or it may have a cantilever effect and tilt an adjacent surface upward with the result that structural damage caused by heaving can occur over areas not mined, as well as by subsidence in undermined areas (Cortis, 1969, p. 9).

A regional fracture system, approximately perpendicular to rock layering, cuts the rocks of the area, with shale generally containing more fractures than the sandstone. The fractures are planes of weakness that tend to orient lines of subsidence and also act as channel ways for fluids that lubricate and further weaken the rocks.

Thickness of overburden.--Surface subsidence can occur over mines that are greater than 600 feet deep (Cortis, 1969; Voight and Pariseau, 1970; Young, 1916), so there seems to be no safe depth of mining over which damage owing to surface subsidence can surely be avoided. Some workers however, agree that the greatest risks of damage are in areas with less than 100 feet of overburden (Bushnell, 1975b, table 1). The risk decreases somewhat as the thickness of overburden increases and is less for light residential structures and greater for larger, heavier commercial buildings. Apparently 150 to 200 feet of overburden is a critical depth, there being few known cases of subsidence damage in areas with more than 200 feet of overburden. Subsidence damage is very rare where overburden is thicker than 500 feet.

Mining operations.--It is emphasized that mining is a dynamic process and that active mining results in enlargement of undermined zones. The ideal mining operation removes as much coal as possible, leaving only enough coal to support the mine roof while the mine is being worked. Older mining methods left up to 75 percent of the coal in place; modern miners strive for 100 percent recovery. Two methods widely used in the Greater Pittsburgh region are continuous long-wall mining, and, more commonly, "full retreat" room and pillar mining. In full-retreat mining the pillars are drawn or removed in the last stage of mining. In both methods, the operation retreats from the farthest part of the mine to the portals, and the roof collapses behind the operation. Surface subsidence occurs almost immediately after retreat with possible damage to surface structures, but the surface thereafter is relatively safe from further subsidence.

Within any mine, two areas of risk are significant. The risk of mine-roof collapse and surface subsidence is greatest over the active or working face and mined-out rooms. The risk of subsidence generally is less over the entries, headings, haulage ways, and air tunnels, which commonly have a lesser span and are usually reinforced by timber, steel, or reinforced-concrete supports.

Operations in the older mines left much valuable coal underground. Many of these mines are being reopened, either by stripping along the edges of the outcrop or, underground, by scavenging all or as much as possible from the pillars. Stripping, of course, effectively removes any risk of mine subsidence, but scavenging increases the risk by further weakening or removing the pillars.

Ground-water regime.--This is another factor that influences subsidence but for which there is no systematic data. Water has the effect of a lubricant, and many tests show that the presence of water in rock lowers its strength and allows it to deform plastically rather than rupture. The deformation of some clay floors under the weight of pillars and overburden probably is a result of water saturation.

In some cases, not only natural waters but discharge from sewers and industrial operations flood abandoned mines and produce chemical reactions that cause a faster-than-normal weathering of coal pillars, overburden, and mine-floor rocks.

Loading and other surface activity.--Logically any extra weight on the ground surface, such as a large building on narrow footings, could cause collapse of the undermined strata. However, only where overburden is relatively thin does this loading appear significant in practice, for the weight of such structures is generally very small compared to the weight of rock overburden. Moreover, it is difficult to separate effects of surface loading from ground water effects.

Other surface activity that may affect the potential for subsidence includes "armoring" of the surface with impervious roads, parking areas, and buildings. Although data are lacking, it appears reasonable to suggest that, at least locally, armoring may be beneficial by restricting infiltration and thereby reducing possible deleterious ground-water effects. Conversely, removal of natural vegetation may enhance infiltration, thereby accelerating weathering processes in overburden and mines.

Legislation.--The Act of 1966 vastly decreased the risk of subsidence damage from underground mining in the bituminous coal fields of Pennsylvania. In addition to structures or areas that now are protected automatically or are protected by purchase of underlying coal, some structures otherwise unprotected receive some protection simply from being located adjacent to protected structures. Very few structures have been damaged as a result of underground mining done since 1966 (Cortis, 1969).

COAL GEOLOGY AND MINING ACTIVITY IN ARMSTRONG, BEAVER, AND BUTLER COUNTIES

Outcropping bedrock units in the area of the present map are, from oldest to youngest, the Pocono Sandstone of Devonian and Mississippian age and the Pottsville, Allegheny, Conemaugh, and Monongahela Groups of Pennsylvanian age (Wagner and others, 1975a). Only the last three units are important to the problem of subsidence. The Allegheny Group, about 300 feet in thickness, is exposed at the surface in most of the northern part of the area, and the Conemaugh Group, 600 to 650 feet in thickness, predominates in the southern part. Rocks of the lower part of the Monongahela Group are found only along the extreme southeastern boundary of Armstrong County and in a few hilltops in southern Beaver County. Regionally, the rock layers dip gently southward, but in the eastern part of the map area northeast-trending rock folds complicate the structure to a degree (Wagner and others, 1975b).

Available records show that coal has been mined underground from eight coal beds in these three counties. Seven beds are in the Allegheny Group; in ascending order they are the Brookville, Clarion, Lower Kittanning, Middle Kittanning, Upper Kittanning, Lower Freeport, and Upper Freeport coal beds. Figure 1 shows the thickness of rock between individual Allegheny Group coal beds and the Vanport Limestone (Poth, 1973a, b, c), a readily traceable stratigraphic unit in the Counties.

The eighth coal bed mined in the three counties is the Pittsburgh, which forms the base of the Monongahela Group. The Pittsburgh bed is separated from the Upper Freeport bed by the full thickness of the Conemaugh Group and thus is at least 600 feet higher in the rock section. South of the map area, the Pittsburgh coal bed is widely mined underground, but owing to its limited outcrop in these three counties, the Allegheny Group coal beds are more important here.

For reference, the outcrops of the Vanport Limestone and Upper Freeport coal bed are shown on the map. This selection was made because: (1) the Brookville and Clarion coal beds, beneath the Vanport Limestone (figure 1), have been little mined underground in the three counties in the past and have limited potential for additional underground mining in the future; and (2) the rocks above the Upper Freeport are essentially barren of coal, except for the Pittsburgh, which is only locally present. The 250-foot-thick rock interval above the Vanport Limestone and below the top of the Upper Freeport (figure 1) therefore, is the "coal zone" that includes the coal beds accounting for most of the extensive underground mining in the three counties. The most productive coal bed in the map area is the Upper Freeport; about twice as many mines have been opened in it as in all other coal beds combined. The Lower Freeport and Lower Kittanning coals are the next most productive beds.

Generally, 28 inches is accepted as the lower limiting thickness for underground mining of bituminous coal, and this thickness was used to define mineable coal on the present map, (Kohl and Briggs, 1976, after Sholes and Skema, 1974). However, this limit cannot be considered precise because thinner beds have been mined underground locally, and Allegheny Group coal beds in the area are close to 28 inches thick in many places. For example, 43 of 122 Lower Kittanning coal-bed sections reported from the three counties by Sisler (1926, p. 39-40, 62, and 86) range in thickness from 24 to 32 inches.

Mineable coal in individual coal beds is distributed irregularly in Armstrong, Beaver, and Butler Counties. Some parts of the map area are underlain by more than one mineable coal bed, whereas other parts are lacking mineable coal.

In the three-county area, underground coal mining has been most widespread in Armstrong County, and most mines active in 1975 are located there. Although Beaver County has the fewest underground coal mines of the three, one of the few recently recorded incidents of damaging mine subsidence took place there. Apparently, this event occurred over one of the numerous abandoned clay mines of the area. Records of outline and extent of clay mines are sparse so they were not included in the present investigation. At a number of places in the three counties, clay and coal have been extracted from the same mine.

Limestone and, locally, sandstone also have been mined underground but these mines also are not included on the present map. Some such mines have found subsequent use for underground storage and mushroom farming, evidence that limestone and sandstone mines largely are not significant to the subsidence problem.

The chief sources of information on extent and periods of underground mining were individual mine maps from files maintained by the U.S. Bureau of Mines and agencies of the Commonwealth of Pennsylvania. Access to these maps and other information was kindly provided by S. E. Cortis and T. B. Alexander of the Pennsylvania Division of Mine Subsidence Regulation.

Because systematic collection and preservation of mine maps is a relatively recent governmental function, maps of many areas mined in the first half of the 20th century and earlier are not available. Additional sources of mine information are the maps of individual western Pennsylvania coal beds prepared by Sholes and Skema, (1974).

THE BASIS FOR CLASSIFICATION OF SURFACE-SUBSIDENCE AREAS IN ARMSTRONG, BEAVER, AND BUTLER COUNTIES

Consideration of the preceding factors suggests that overburden thickness, mining operations, and the legislative factor are at present sufficiently well known for meaningful map presentation. Data are inadequate for regional analysis of the nature and distribution of overburden and the ground-water regime.

Work in Allegheny, Washington, and Westmoreland Counties (Bushnell, 1975b) was made viable by the availability of the lengthy, though incomplete, record of damaging subsidence events, and the recorded events were related chiefly to mining of the Pittsburgh coal bed. In contrast, in predominantly rural Armstrong, Beaver, and Butler Counties the record of subsidence damage is sparse. The classification shown on the present map therefore is based on the assumption that the correlation of subsidence events with mappable factors made in Allegheny, Washington, and Westmoreland Counties can be extrapolated with general validity to Armstrong, Beaver, and Butler Counties.

Table 1 compares the classification used in Allegheny, Washington, and Westmoreland Counties with that applied to the three counties of the present map.

The broad classification is the same on both maps; areas labeled A correlate with areas that have high numbers of recorded damaging subsidence events, areas labeled C with minor numbers, and areas labeled D with extremely rare events. However, no areas are labeled B on the present map for the following reason.

In Allegheny, Washington, and Westmoreland Counties, most underground coal mining has been restricted to only two beds, the Pittsburgh (Bushnell, 1975a) and the Upper Freeport (Bushnell and Peak, 1975), and the history of mining of these beds is moderately well documented, so the data allowed the intermediate classification B on that map. In comparison, in Armstrong, Beaver, and Butler Counties, a greater number of coal beds have been involved in underground mining, and a less complete documentation of mining activity exists there. With these conditions, the authors believe that a B (moderate numbers) classification cannot be justified here, particularly in view of the uncertainties inherent in extrapolating the subsidence-damage record from an adjacent area. Rather, the very general AC label has been applied to some areas, indicating that the basis for classifying these areas was inferior.

Another difference between previous and present classifications in table 1 is in application of the overburden factor, but this difference is more apparent than real. In Allegheny, Washington, and Westmoreland Counties, the data indicated that 200 feet and 500 feet of overburden are significant, if general, indicators of degree of risk of subsidence damage (Bushnell, 1975a; Bushnell and Peak, 1975).

In compiling the present map, overburden was also considered, but inclusion of this data on the map has been omitted for clarity. Most areas labeled A on the map were in fact mined under less than 200 feet of overburden, so the 200-foot subdivision largely is unnecessary. Moreover, essentially all coal mines in areas labeled A were less than 500 feet below ground surface, and most coal mines and mineable coal in areas labeled Cm and Cp also are under less than 500 feet of overburden.

Where compilation revealed overlap of one mined or mineable coal bed with another, the map classification shown is that of the higher risk. On the present map, for example, where a coal bed mined underground prior to April 27, 1966, (A in our classification) coincided geographically with another coal bed mined after that date, (Cm) that part of the map is classified A.

In both classifications in table 1, lower-case suffixes to the capital-letter identifiers relate to details of the classification; they do not necessarily reflect different correlations with numbers of damaging events. For example, the distinction between Cm and Cp on the present map is made because information on extent of underground mining between 1966 and 1975 appears on no other map of this area, and this information may be useful to some readers.

The legislative factor is the same in both classifications in table 1, reflecting conditions before and after passage of the Act of 1966.

LIMITATIONS OF THE MAP

Chief map limitations result from:
(a) Incomplete documentation of mining activity and differences in the usefulness of source documents. For example, most mine maps examined appeared complete and accurate, but on some maps, statements of location were lacking or were inadequate for precise compilation.
(b) The sparse record of damaging mine-subsidence events that necessitated extrapolation of correlations from adjacent areas.
(c) Lack of detailed information on thicknesses of unmined coal in parts of the map area.

Moderate effort in the field and an additional document search probably would reduce significantly the limiting effects of the first factor. Only extensive field studies and coal-exploration effort would enhance knowledge of subsidence events and coal thickness throughout the three counties.

Because of these limiting factors, this map is intended chiefly as a guide to expectable conditions. Detailed studies of specific sites are required to determine whether the expectable conditions are present and how they will affect planned activities.

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MAP SHOWING AREAS THAT CORRELATE WITH SUBSIDENCE EVENTS DUE TO UNDERGROUND MINING IN ARMSTRONG, BEAVER, AND BUTLER COUNTIES, PENNSYLVANIA

By
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1976

Interior—Geological Survey, Reston, Va.—1976
For sale by Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202