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SHORT COMMUNICATION

Chimney subsidence over abandoned coal mines

Introduction

Chimney subsidence results from the intermittent, sequential collapse or unravelling of underground mine roofs in localized areas, whereby caving migrates through the overlying material to the surface to form a pit. Chimney subsidence occurs over underground mines with partial extraction systems. The expression on the surface is abrupt, usually in the form of conical depressions with the apex upward. In plan view, they are circular or oblong reflecting the geometry of the mine workings. In all reported studies on chimney subsidence, (Bruhn, *et al.*, 1980; Wildanger, *et al.*, 1980; Dunrad and Osterwald, 1980; Gray and Bruhn, 1984; Dunrad, 1984; Matheson and Pearson, 1985) chimney cavings occur in overburden of less than 61 m thick and in zones of rock weakness or areas of extensive vertical rock fracturing.

Chimney subsidence in the Hanna Mining District

Studies for the identification and characterization of chimney subsidences were conducted in the Hanna Mining District. The Hanna Mining District is located in the Hanna Basin, which is one of the major coal producing regions in Wyoming. Coal mining in the area began in 1868. Coal production was exclusively from underground mining until 1937 when the first strip mine was opened. At the present time, with the exception of a longwall mine, all production is from surface mines. Most of the chimney subsidence occurrences in the Hanna Mining District are located above the Hanna No. 2 and 3 mines (Fig. 1).

The Hanna Basin has a plains type topography and is characterized by numerous hogback ridges and strike valleys. The permanent and temporary streams are fed by intermittent drainages, referred to locally as ditches. The most prominent one is Big Ditch which flows westward, passing through the town of Hanna. The climate is semi-arid to arid, and the average annual precipitation is 38 cm.

The Hanna basin is one of the deepest intermontane basins in the Wyoming portion of the Rocky Mountain Foreland structural province. Coal occurs in the Upper Cretaceous Mesaverde Group and Medicine Bow Formation; Upper Cretaceous–Paleocene Ferris Formation; and the Paleocene–Eocene Hanna Formation (Glass and Roberts, 1980). The Hanna and Ferris Formations are the major coal-bearing units in the area. The mines studied are in the Hanna Formation.

The Hanna Formation in the Hanna Mining District is approximately 2450 m. The Hanna

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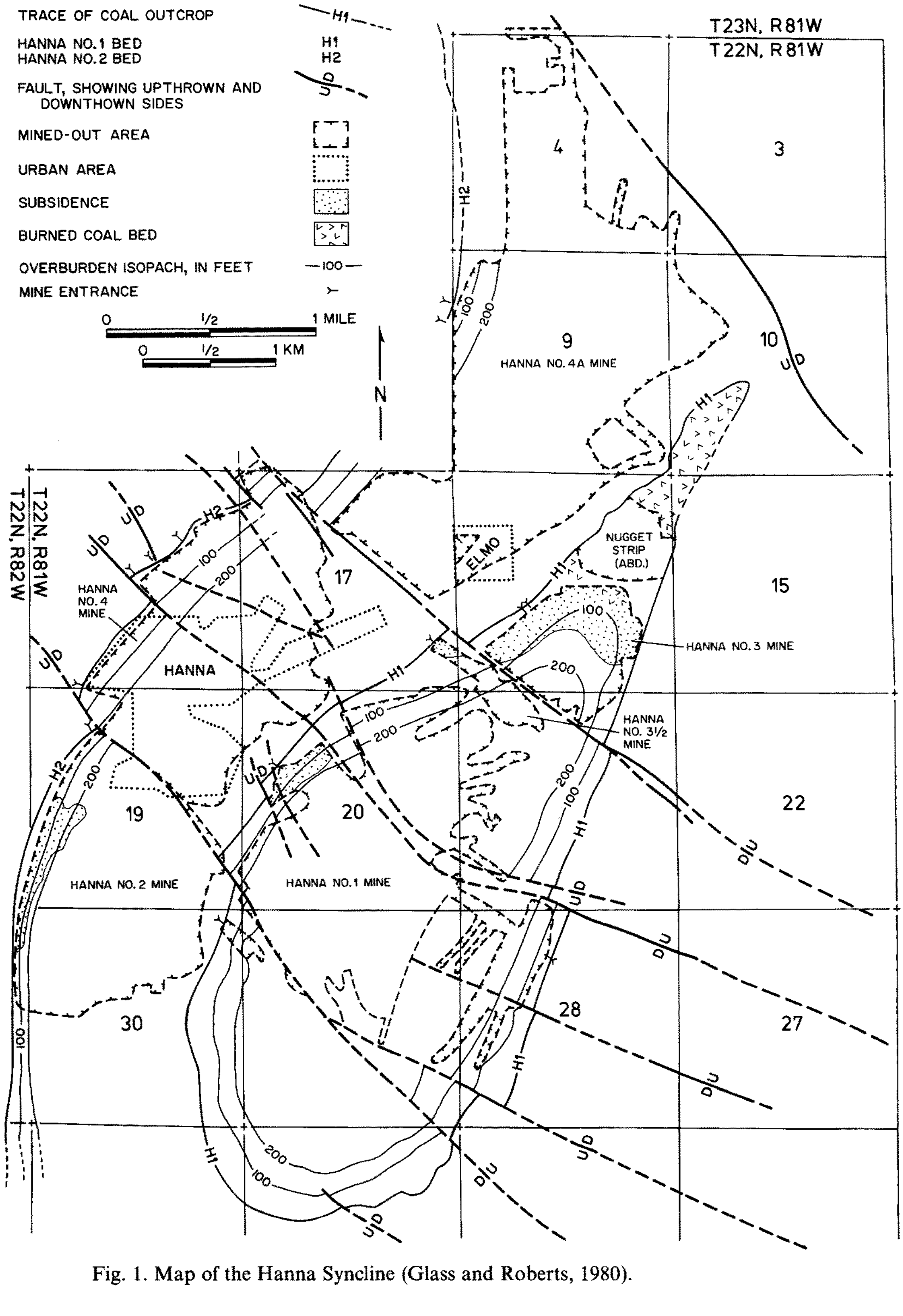

Fig. 1. Map of the Hanna Syncline (Glass and Roberts, 1980).

Formation contains at least 32 coal beds of more than 1.5 m thick. Most of the coal beds in the Hanna Formation are found in the Hanna Mining District.

The rocks associated with Hanna formation coals are perhaps the most variable in the coal field. The formation is composed of cross-bedded conglomeratic sandstones, siltstones, claystones and shales. Interbedded coal and shale often occur above the coal units. In the Hanna District, these rocks were deposited in a fluvial environment dominated by meandering streams (Glass and Roberts, 1980). Due to their fluvial origin, these rock formations are highly variable and change vertically and laterally over very short distances.

Structurally, the Hanna Mining District is located in the Hanna Syncline (Fig. 1). The syncline trends southwest to northeast. The dips vary from 23° SE on the west side to almost horizontal near the axis, and up to 45° NW on the east flank. The syncline is cut by NW to SE trending normal faults. Two major systematic, orthogonal joint sets are present in the Hanna Syncline (Glass and Roberts, 1980).

Mining methods in the Hanna District

Previous to 1940, the coal in the Hanna District, was mined using the room and pillar method (Fig. 2). The main entry headings were driven down the dip of the coal seam from the outcrop.

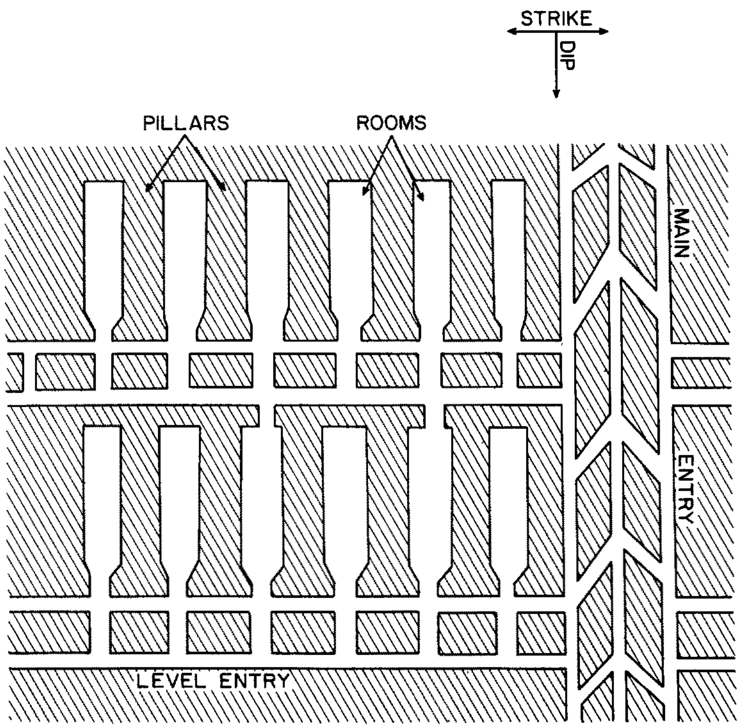

Fig. 2. Typical room and pillar mine plan in the Hanna District.

Level entries were driven off the main heading along the strike of the seam to facilitate the haulage of coal. Rectangular rooms were driven up-dip from the level entries to allow gravity to help pull the coal back down from the working face to the haulageway. When these mines began operating, the coal was mined by hand; therefore, it was expedient to orient the long dimensions of the rooms with the dominant joint direction in the coal.

The most severe chimney subsidences occur over Hanna No. 2 and No. 3 Mines. The No. 2 Mine is located on the west side of the town of Hanna. The mined coal seam is the Hanna No. 2 seam. The seam dips at 20° toward the SE and has a thickness of 9 m. The mine was opened in 1889 and closed in 1934. A total of 6 256 157 tons of coal were mined. The probable mined thickness was 3 to 6 m. The entries were 4.5 m wide; the rooms, 9 m wide and up to 76 m long; and the pillars, 9 to 15 m wide and 21 m long. The maximum depth of the mine was 305 m.

The No. 3 Mine is located southeast of the town of Elmo. The mined coal seam is the 6 m thick Hanna No. 1 seam dipping at 7° to the SE. The mine was opened in 1905, operated until 1920, and produced 2 153 234 tons of coal. Here, also, the probable mined thickness was 3 to 6 m; entries, 4.5 m wide; rooms, 9 m in width and 30 m or more in length; and pillars, 9 m wide and 30 to 40 m long. The maximum mining depth was 60 m. The mine descriptions are summarized in Table 1.

Table 1. Summary of mine description.

	Hanna No. 2	Hanna No. 3
Location	Sec. NW 19, T.22N., R.81 W.	Sec. SW 16, T22N., R.81 W
Dates of operation	1889–1934	1905–1920
Tonnage	6 256 157	2 153 234
Seam No.	Hanna No. 2	Hanna No. 1
Seam orientation	15°–20° SW, N 15°E to N 5°E	7° SW, N 40°E West Side 40° NE, N 20°E East Side
Seam thickness	7.3–11.0 m	5.8–7.3 m
Mining method	Room and Pillar	Room and Pillar
Mining dimension:		
Entries width	4.6 m	4.6 m
Room width	9.1 m	9.1 m
length	Up to 76.2 m	30.5 m
Pillar width	9.1–15.2 m	9.1 m
length	21.3 m	30.5–39.6 m
Mined thickness	3.0–6.1 m	3.0–6.1 m
Maximum depth	304.8 m	61 m

Chimney subsidence characterization

The chimney subsidence over the Hanna No. 2 Mine occurs in the bottom and east edge of a north–south trending draw that borders the south-west portion of Hanna (Fig. 1). Eighty–nine chimneys were located and surveyed. They extend over a mile along the draw, and the sinkhole pattern is parallel to the strike of No. 2 seam. The sinkholes are somewhat dish-shaped, probably because of erosion. Most of the surface subsidence occurs in a valley that leads into the Big Ditch drainage. This adversely affects the local hydrology in that all of the surface runoff that would normally flow into the Big Ditch drainage is either impounded in the sinkholes or flows into the underground workings through surface cracks. There is also evidence of underground mine fires. The formations exposed by the sinkholes consist of a highly fractured, very friable sandstone and unconsolidated alluvium.

The average depth of the sinkholes was found to be 3 m, and 70% of them were less than 4 m in depth (Fig. 3). Most sinkholes are elongated or rectangular in plan view. The average mean diameter (average of long and short axes) was about 20 m with 70% of them having a mean diameter of less than 21 m (Fig. 4). The average long and short axes were 24 and 15 m, respectively, which compare fairly well with the mining dimensions.

The subsidence over Hanna No. 3 is confined to the Big Ditch drainage, except for the northern part of the mine area (Fig. 1). Approximately 404 700 m^2 are severely disturbed. Two hundred twenty-five chimney subsidence occurrences were located and surveyed. Most of the pits have vertical sides, but some of them are cone-shaped cavities that widen with depth. The cone-shaped cavities are probably indicative of collapse that has recently reached the surface, and the overhanging material has not yet been eroded into the pit. The overburden exposed in most of the sinkholes is alluvium. In the north part of the subsidence area, some of the sinkholes, in addition to alluvium, also expose a highly fractured sandstone. Due to the close proximity of Big Ditch Creek, many sinkholes contain water; and the mine is probably inundated.

The average depth of the chimney over Hanna No. 3 Mine is approximately 3.5 m, with 70% of it less than 4 m deep (Fig. 3). The average mean diameter is 14 m, with an average for long and short axes of about 18 and 10 m (Fig. 4).

In addition to the depth and diameter of the chimney sinkholes, the overburden thickness at the caving site was also determined. The following section analyses the data and determines the sinkhole development and overburden thickness relationship. The summary of chimney subsidence statistics is given in Table 2.

Analysis of the data

The chimney subsidence sinkholes over Hanna No. 2 Mine have a larger average mean diameter than the sinkholes over No. 3 Mine, even if the workings at both mines are similar in size. Since No. 2 Mine is older, the larger diameter may be due to greater erosion. When the caving reaches the surface, the contact is abrupt, and the sides of the pit are vertical or overhang. As erosion takes effect, the sinkholes increase in diameter and assume a dish-like shape. Consequently, the diameter becomes larger.

The shallower depth of pits at the No. 2 Mine may be the consequence of slumping of the sides

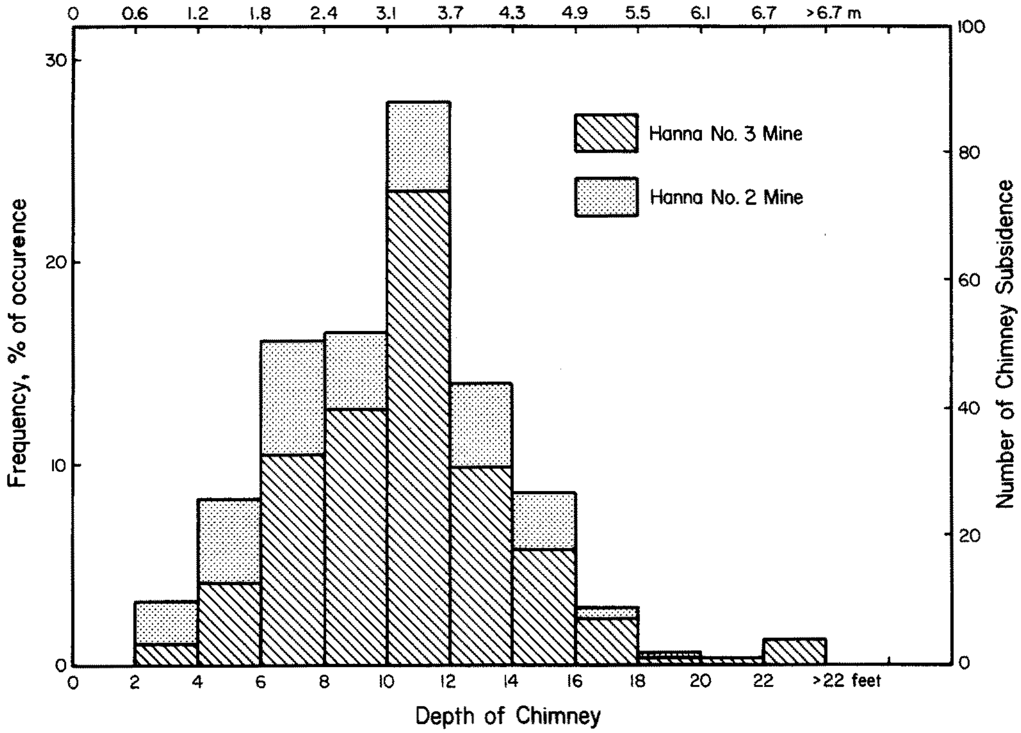

Fig. 3. Frequency of chimney subsidence for intervals of chimney depth at the Hanna Mine District.

Table 2. Summary of chimney subsidence statistics.

	Hanna No. 2	Hanna No. 3
Number of chimneys	89	225
Average depth of chimneys	3.0 m	3.4 m
Average mean diameter of chimney	19.4 m	13.8 m
Average overburden thickness	30.8 m	14.3 m
Maximum overburden thickness	79.2 m	47.8 m
% Chimney in <30 m overburden	43.2%	96.10%
% Chimney in >30 m overburden	56.8%	3.9%

into the pit over a longer period of time. Furthermore, since the overburden thickness above the voids at the No. 2 Mine is greater, this would allow more material to bulk, and would occupy a larger volume. The greater depth of sinkholes at the No. 3 Mine may be due to the packing and/or flushing of the caved materials by percolating surface water from the Big Ditch Creek.

An attempt was made to correlate sinkhole diameter and depth with overburden thickness. No direct relationship was found to exist. Gray and Bruhn (1984) found that most of the chimney subsidences over the Pittsburgh seam develop where the overburden is less than 15 m

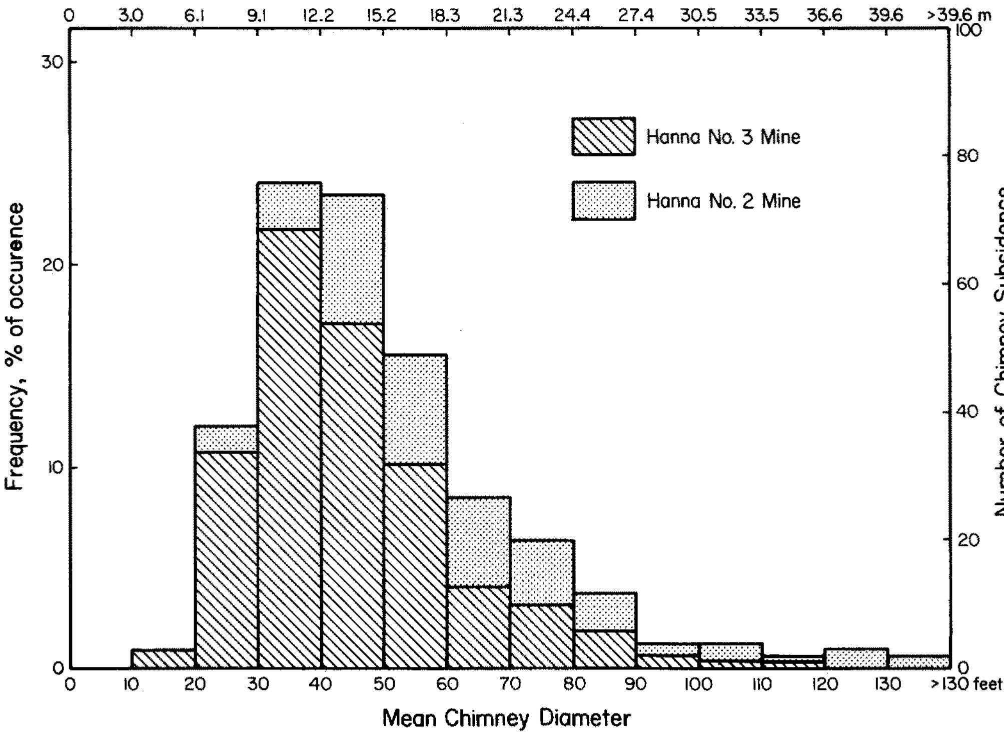

Fig. 4. Frequency of chimney subsidence for intervals of mean chimney diameter at the Hanna Mine District.

thick. Dunrad and Osterwald (1980) state that over abandoned mines in northern Wyoming and North Dakota, the most severe subsidence occurs in overburden of less than 61 m thickness. Matheson and Pearson (1985) report that chimney subsidence in the Colorado Springs coal fields occurs at an overburden thickness of less than 46 m. In this study, all of the sinkholes developed at overburden thicknesses of less then 73 m. Fig. 5 shows the frequency of sinkholes over Hanna No. 2 and No. 3 Mines.

Over Hanna No. 2, almost 24% of the sinkholes occurred between 18 and 24 m. There was no subsidence at overburden thicknesses of less than 12 m, since the minimum overburden over Hanna No. 2 is 12 m. All subsidences occurred at thicknesses of less than 73 m, with 43% at less than 30 m. Over Hanna No. 3, the largest percentage of sinkholes occurred in the 12–18 m interval of overburden, and all occurred at an overburden thickness of less than 42 m, with 96% occurring at less than 30 m.

Fig. 6 shows the cumulative frequency of chimney subsidence for overburden thickness intervals at the Hanna Mine District. It was determined that the histogram follows a log-normal distribution, with a median thickness of 17 m and a covariance of 56%. Based on this distribution, a cumulative probability curve of chimney subsidence for overburden thickness can be developed for the Hanna Mining District (Fig. 7). The cumulative probability plot can

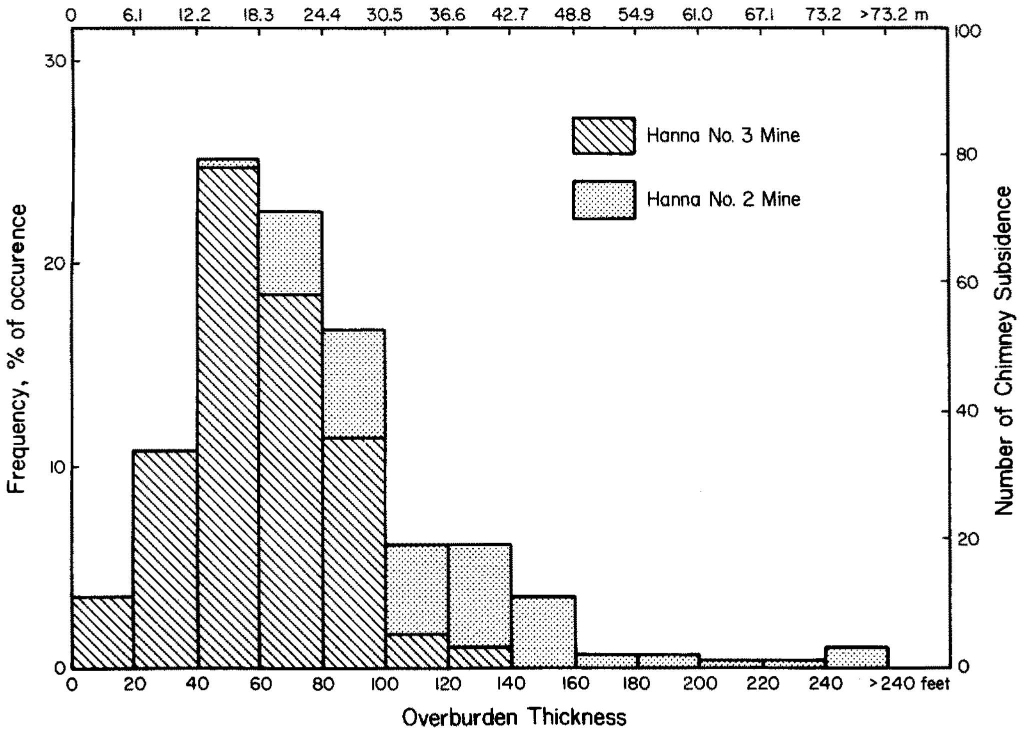

Fig. 5. Frequency of chimney subsidence for intervals overburden thickness at the Hanna Mine District.

be used to determine the probability of chimney occurrence for a given overburden depth range. From the curve, it can be seen that the probability of a chimney occurrence at overburden depth of more then 49 m is 2%, and the probability for the range of 15 to 24 m is 62%. The cumulative probability curve can give a measure of risk of sinkhole development within a given overburden depth interval.

Conclusion

In some respects, this study is incomplete. There is no information on the historical sequence of chimney subsidence development. Furthermore, data on the rainfall–subsidence occurrence relationship is non-existent. Historical sequence and rainfall relationship could be invaluable in predicting future chimney subsidence development.

Based on the above study, for the Hanna Mine District, it can be said that the overall weakness of the overburden rock, coupled with the coincidence of mine workings with major joint orientations, may have contributed to the initiation of chimney subsidence. Also, during periods of excessive precipitation, the proximity of a major drainage probably increased the rate

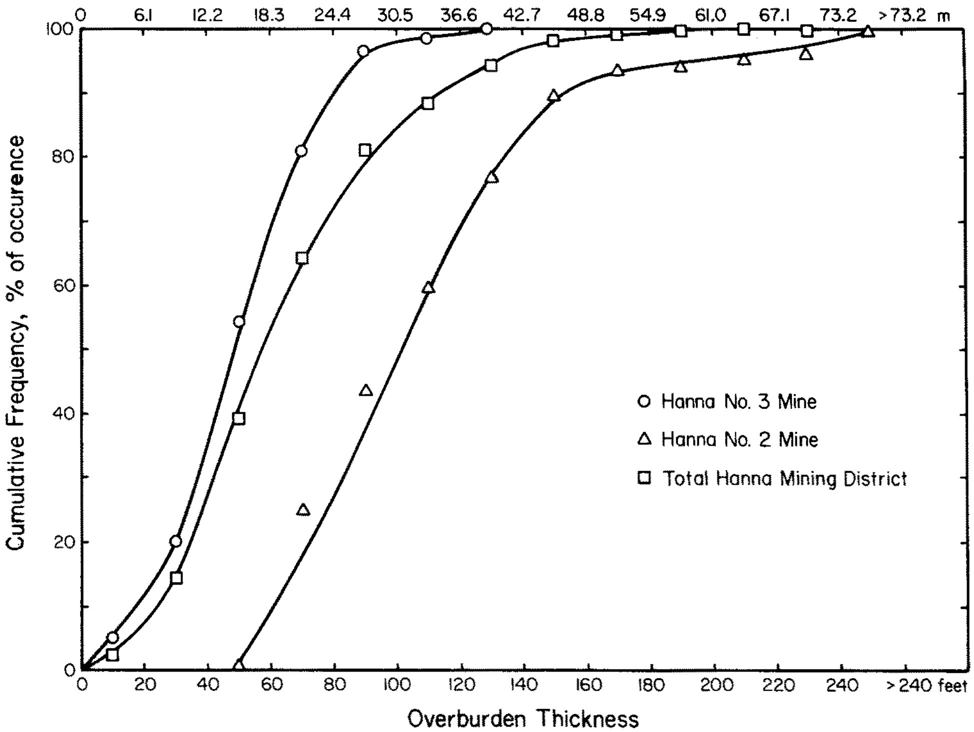

Fig. 6. Cumulative frequency distribution for intervals of overburden thickness.

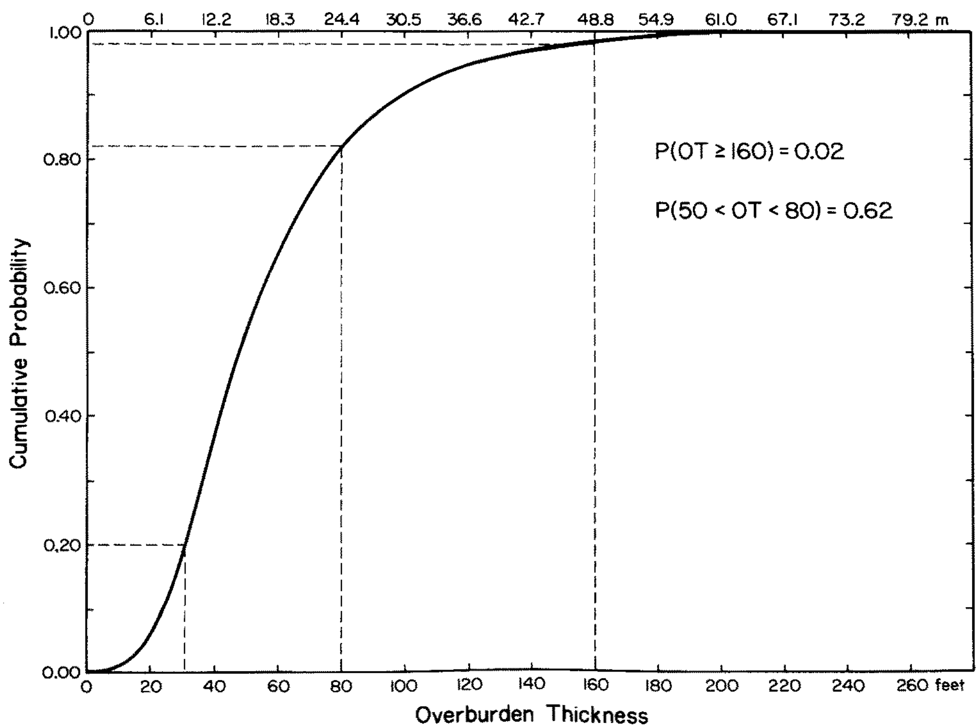

Fig. 7. Cumulative probability of chimney subsidence for overburden thickness.

of subsidence, if water was diverted into the mine workings. Introduction of water into the mine would cause the deterioration of the roof material and the flushing of caved debris. The result of flushing of caved material is the acceleration of caving into voids that have not yet reached the surface. Furthermore, the burning of the coal seam would provide additional void and weaken the roof rock, initiating and/or causing caving.

The overburden thickness appears to be the major controlling factor. Most of the subsidence has occurred where the thickness of overburden is less then 73 m. Bulking of the caved material may limit development of chimney subsidence in thicknesses of overburden greater than 73 m. However, complete burning of the coal seam and flushing of caved material may allow caving to migrate into higher than expected levels of overburden. Nevertheless, based on the available data on the frequency of occurrence for given depth intervals, probabilistic predictions can be made.

If chimney subsidence occurrences at different mining districts are studied similarly, with the compiled data it may be possible to quantify the controlling factors and provide probabilistic predictions for the development of chimney subsidence under various conditions.

Acknowledgement

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References

Berg, W.R. (1980) *Subsidence Due to Underground Mining in the Hanna Coal Field*, unpublished Master's thesis, University of Wyoming, Laramie, Wyoming.

Bruhn, R.W. *et al.* (1980) Subsidence Over Abandoned Mines in the Pittsburgh Coalbed, *Proceeding, 2nd International Conference on Ground Movements and Structures*, Cardiff, Geddes, J.D., ed., John Wiley, New York, pp. 142–56.

Dunrad, C.R. (1984) Coal Mine Subsidence–Western United States, in *Man-Induced Land Subsidence, Reviews in Engineering Geology*, Vol. 6, The Geological Society of America, pp. 151–94.

Dunrad, C.R. and Osterwald, F.W. (1980) Effects of Coal Mine Subsidence in the Sheridan, Wyoming, Area, *Geological Survey Professional Paper 1164.*

Glass, G.B. and Roberts, J.T. (1980) Coal and Coal Bearing Rocks of the Hanna Coal Field, *Wyoming Geological Survey, Report of Investigations*, No. 22, Laramie, Wyoming.

Gray, R.E. and Bruhn, R.W. (1984) Coal Mine Subsidence – Eastern United States, in *Man-Induced Land Subsidence, Reviews in Engineering Geology*, Vol. 6, The Geological Society of America, pp. 123–49.

Matheson, G.M. and Pearson, M.L. (1985) *Chimney Subsidence Development in the Colorado Springs Coal Field, Colorado*, SME-AIME Fall Meeting, Albuquerque, New Mexico, October 16–18, Preprint No. 85–329.

Wildanger, E.D. *et al.* (1980) *Sinkhole-Type Subsidence over Abandoned Coal Mines in St. David, Illinois,* Abandoned Mined Lands Reclamation Council, Springfield, Illinois.

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