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The History and Future of Longwall Mining in the United States

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	mg/m^3	milligram per cubic meter
ft/min	foot per minute	pct	percent
h	hour	psi	pound per square inch
in	inch	tpd	ton per day
lbf	pound (force)	tpwd	ton per worker-day
m	meter	tpy	ton per year

THE HISTORY AND FUTURE OF LONGWALL MINING IN THE UNITED STATES

By Thomas M. Barczak[1]

ABSTRACT

This U.S. Bureau of Mines report chronicles the historical development of longwall mining in the United States and speculates on future developments to the turn of the century. The involvement and contributions made by the Bureau during these developments are also discussed. Two major periods of history are analyzed: (1) from 1875 to 1950 when small advancing faces were operated manually, and (2) from 1950 to 1990 when mechanized extraction and powered roof supports provided a system to efficiently extract large coal panels. Five eras of technological development during the modern period are described and analyzed. These eras discuss the development of (1) mechanized extraction, (2) powered roof supports, (3) high-capacity roof supports, (4) shield supports, and (5) system automation. Current trends are analyzed in terms of longwall utilization, face production, support capacity, face widths, and new technological developments. From these analyses, the future of longwall mining to the year 2000 is speculated. It is concluded that longwall mining will continue to grow in importance during the next decade and that the next major technological milestone will be the realization of a fully automated longwall mining system.

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INTRODUCTION

The coal industry has been a significant factor in the development of the American economy. Since the recent oil embargoes, which began in the mid-1970's, the demand for coal has grown and coal is likely to be a major source of domestic energy well into the next century. The coal industry has responded to this increase in demand with unprecedented increases in productivity, largely because of the success of longwall mining. Longwall mining currently accounts for nearly one-third of the underground coal production and continues to set coal production and work-force productivity records for underground coal mining. But it was only through a long history of successes and failures that this technology has developed into the safest and most productive underground mining system employed in the United States.

This report describes the mining practice associated with the first longwall installations and chronicles five eras of technological development from 1950 to 1990 that contributed significantly to the advancement of longwall mining in the United States. Measures of longwall utilization, contribution of longwall mining to underground coal production, and face production and work-force productivity are analyzed and compared. These data were obtained primarily from the U.S. Department of Energy's Energy Information Association reports, National Coal Association reports, Bureau census (1976-79), and Coal Age and/or Coal Mining census (1980-90). Some data on early longwall developments prior to 1970 were estimated from available literature as referenced throughout the report and from verbal communications with several industry personnel.

As part of the Bureau's mission to ensure a reliable source of energy for the United States, this report provides a data base for analyzing past and current trends to forecast the future of longwall mining and to assess the technological needs of the longwall industry in the near future.

TECHNOLOGICAL ERAS IN LONGWALL MINING

The historical utilization of longwall mining in the United States is depicted in figure 1. As indicated in the introduction, two general periods of utilization are evident: (1) the period between 1875 and 1950, and (2) the period between 1950 and 1990.

EARLY PERIOD (1875-1950)

Longwall mining was introduced in the United States in 1875 by emigrating miners from Wales (*1*).[2] Longwall operations in the late 1800's and early 1900's were characterized as advancing faces developed radially from a central shaft with backfilling to provide ground control (*2-3*). A hoisting shaft and an air shaft were established from the surface to the coal seam. Two perpendicular entries were driven for a distance of 125 to 250 ft from these shafts, and a hexagon- or octagon-shaped (shaft) pillar was formed, as shown in figure 2, by establishing a pair of

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

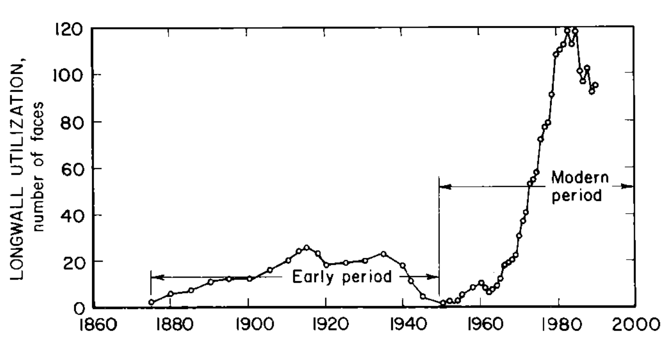

Figure 1.—Longwall mining utilization in the United States.

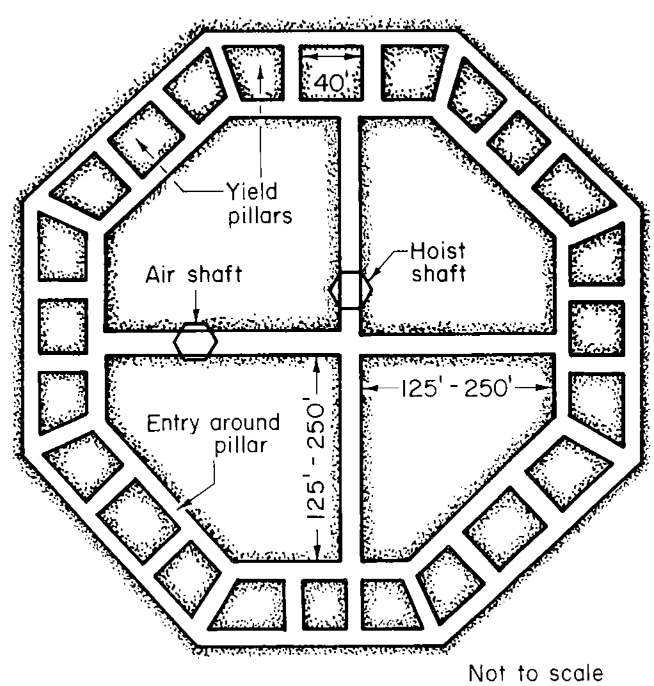

Figure 2.—Establishment of central shaft pillar for advancing longwall operations in the late 1800's and early 1900's.

circumferential entries. Since the roof often had a tendency to break close to the rib of the large shaft pillar, the pillars surrounding the shaft pillar were designed to be yielding-type pillars (typically 15 by 42 ft) to allow for controlled roof convergence that would not induce failure at the relatively stiff shaft pillar (*2-3*).

A series of entries or roadways were driven from the boundary of the shaft pillar, as shown in figure 3. These roadways were used for face ventilation and haulage and were maintained for operation through the caved area by building pack walls from roof, floor, and seam waste material along each side of the roadways. Temporary roadways, sometimes called stall roads, were made as the face advanced, as shown by the diagonal lines in figure 3. The stall roads were typically spaced 40 to 50 ft apart. They established a series of working "places" along the face. Typically one or two persons worked each of the places. The roof between the gob and the face was supported partly by wood props and partly by the stall-road pack walls as shown in figure 4. The distance between the gob and face coal was typically 10 to 12 ft.

The coal at the face was undercut, usually by hand, to a distance of 2 to 3 ft and supported by sprags set on 4- to 6-ft centers, as shown in figure 5. When undercutting was completed, the sprags were knocked out, allowing the immediate face coal to break free. Under ideal conditions, the face would break under the weight of the roof when the sprags were removed; however, the coal had to be frequently wedged and sometimes blasted free. The coal was then loaded and transported from the face, and an additional row of props was set near the new face prior to the next mining sequence. Excess waste material not used in the construction of the roadway pack walls was backfilled to support the immediate roof and to help establish a gob capable of carrying some of the overburden weight.

Technological improvements during this period were relatively few. The most significant improvement was the development of the steel (friction yielding) jack, which was first introduced in 1912 for roof control at the face (*4*). Prior to this, wood posts were used extensively to provide face support. The steel posts had significantly higher capacities than wood posts (100 tons[3] of resisting force

[3]In this report, "tons" refers to short tons unless otherwise indicated as "force" (2,000 lbf).

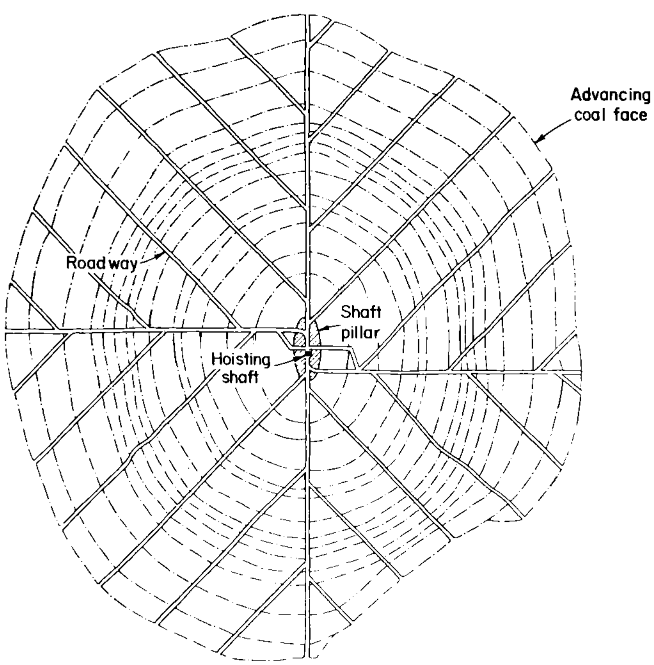

Figure 3.—Permanent haulage roadways driven from shaft pillar.

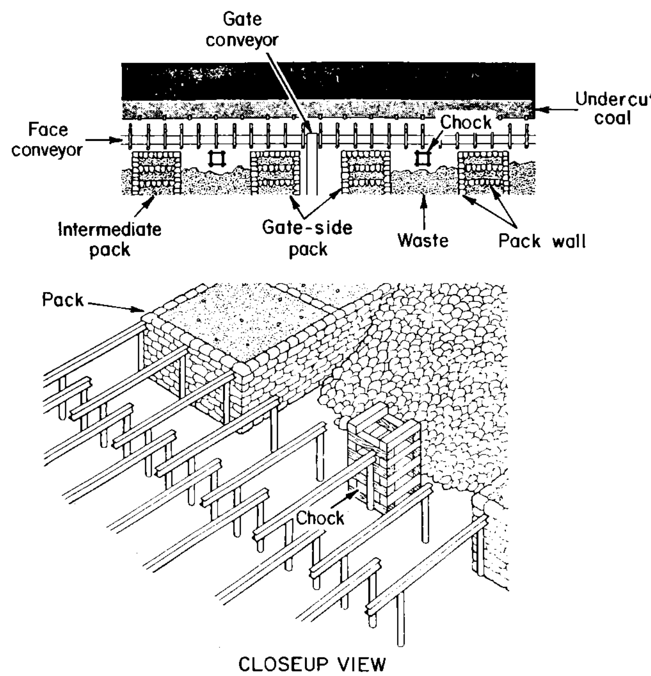

Figure 4.—Working places in early longwall operations.

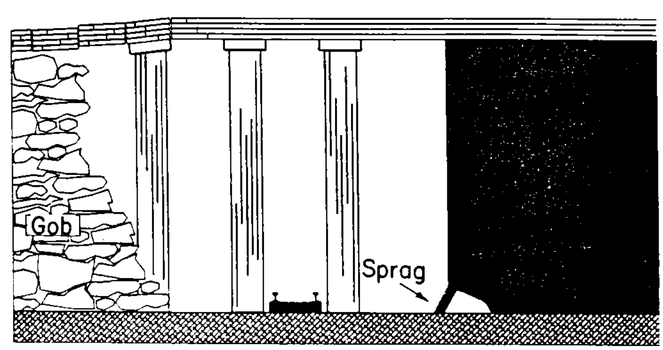

Figure 5.—Supporting of undercut face by wooden props or sprags.

compared with about 50 tons (force) for wood posts) and therefore provided better ground control in heavy roof conditions. But their most important attribute was that they could be recovered and reused. These steel jacks led to the development of the modified caving theory, wherein the immediate strata are allowed to cave behind the jacks (*5*). Another technological advancement made during this period was the utilization of scraper boxes and slushers to reduce the hand loading of coal. In 1924, a belt conveyor and partial chain conveyor superseded the low-capacity slushers and further improved the production potential and work-force productivity (*6*).

Although utilization of steel props and improved haulage provided by the slushers and face conveyors reduced work-force requirements from a typical face crew of 42 people to about 25 (*7*), longwall mining remained a labor-intensive effort with a productivity of only about 3 tpwd on most faces (*6*). The advancement of roof support and haulage equipment as mining progressed still required extensive manual effort and remained a significant production constraint. Maximum tonnages of 750 tpd were reported in 1915 at the height of the wood-prop longwall utilization. Production increased to about 850 tpd by 1935 when the steel jack and conveyor haulage technology reached full maturity (*7*).

A summary assessment of longwall performance during the 1875 to 1950 period is shown in table 1. Souder and Palowitch estimated that it took about 40 years for the early style longwalls, using wood props as the primary means of face support, to reach maturity (*7*). The adoption and diffusion of this longwall technology was inhibited by (1) the unwillingness of the operators to change from established room-and-pillar practices, (2) a work force unfamiliar with the longwall concept, and (3) several failures to provide adequate ground control. The introduction of steel jacks encouraged the adoption of the longwall practice, but the system remained labor intensive and productivity was generally below that of room-and-pillar systems.

As such, early longwall attempts were limited mainly to thin-seam operations where pack-wall construction and backfilling was minimized and where room-and-pillar technologies were ineffective. These early longwall technologies were best suited to strong, tough coal seams that could be undercut to a moderate depth without breaking prematurely. The seams also had to be largely free of rock inclusions and not disturbed by severe faulting. Reported advantages of successful early longwall operations compared with room-and-pillar workings were (1) complete removal of the coal at minimal expense, (2) large and more marketable coal size, (3) less timbering, (4) more controlled subsidence, and (5) better ventilation of the working face at less cost (*2-3*).

MODERN PERIOD (1950-90)

As mechanized longwall equipment became available, the profile of the panel changed from the circular geometries with a series of small faces to a single face developed across a large rectangular panel. Longwall mining, as it is familiar today (see figure 6), evolved through the implementation of several technological developments. These include (1) the introduction of mechanized extraction equipment (1950-60), (2) the introduction of self-advancing hydraulic roof supports (1960-66), (3) the utilization of high-capacity-powered roof supports (1966-75), (4) the introduction and development of the shield support (1975-85), and (5) the advent of system automation (1985-90).

1950-60 Era—Mechanized Extraction

The modern longwall mining period began in 1952 with a Bureau-sponsored trial at the Stotesbury Mine of Eastern Gas and Fuel Associates near Beckley, WV (*8*).[4] This marked the beginning of mechanized extraction of a relatively large coal panel using a German coal plane, as shown in figure 7. Roof control for the retreating longwall face was provided by wood cribs and mechanical friction props [capacity of 40 tons (force)] with I-beam caps, as shown in figure 8. A chain conveyor provided face haulage of the mined coal. Three panels were successfully mined between 1952 and 1958, producing an average of 530 tons per shift (*8*).

The most significant technological development during this period was the introduction of the plow. The plow provided mechanized extraction and replaced the labor-intensive method of undercutting practiced in the 1875 to

[4]A study of the role of the Bureau in the introduction of safe and efficient full extraction methods was done by E. A. Curth in 1986 at the Pittsburgh Research Center.

Table 1.—Summary assessment of longwall performance during 1875-1950 era

	1875	1950	Annual average
Utilization . . . . number of faces . .	0	4	15
Coal production . . . . . pct of underground mining . .	([1])	([1])	([1])
Average face production . . . . tpd . .	([1])	([1])	700-800
Average face labor productivity . . . . . tpwd . .	1	6	3

[1]Unknown.

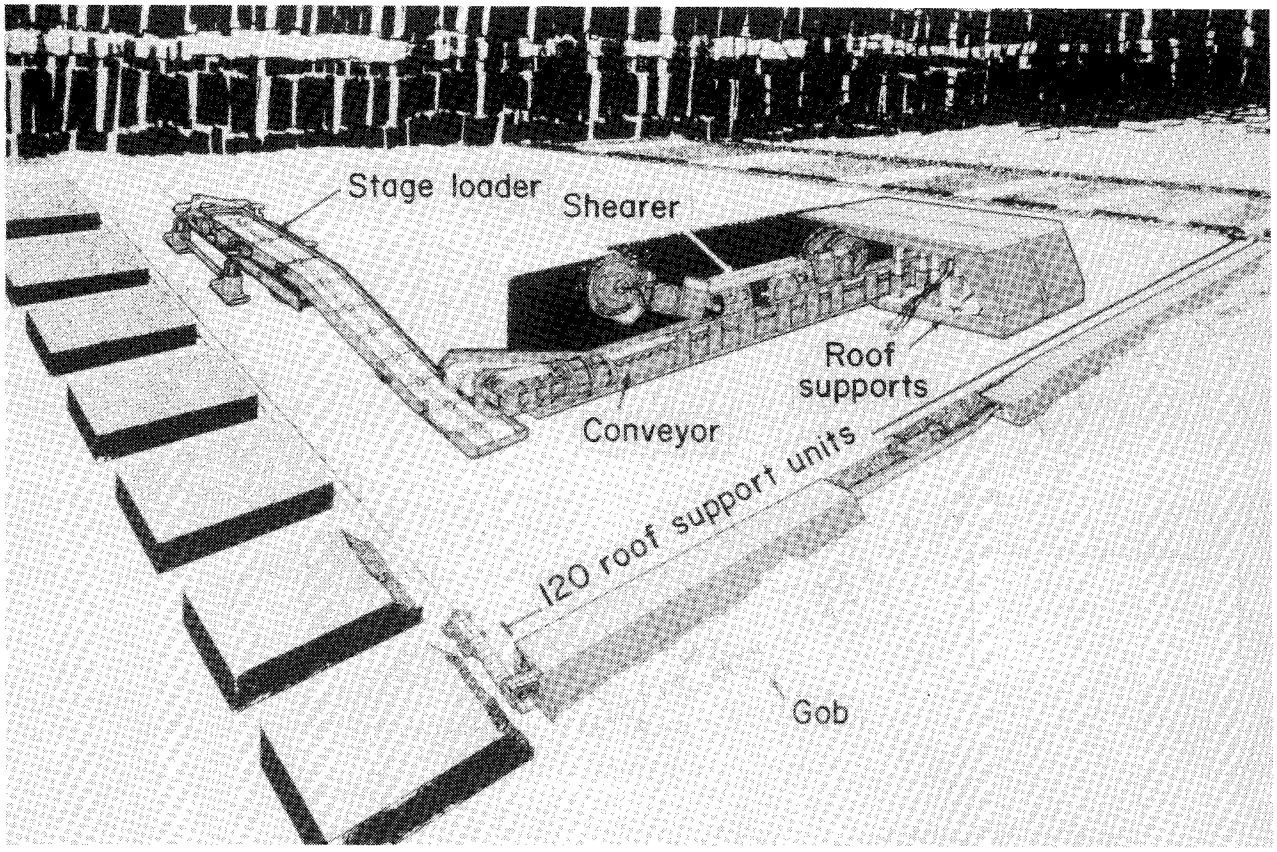

Figure 6.—Modern longwall mining system.

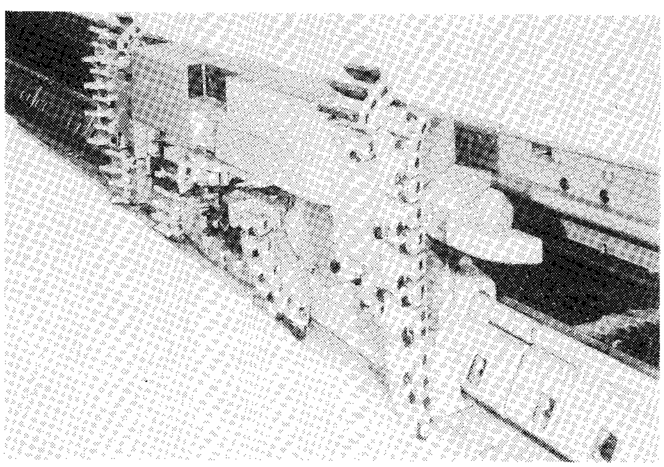

Figure 7.—German coal plane similar to one used in first mechanized longwall operation at Stotesbury Mine in West Virginia in 1952.

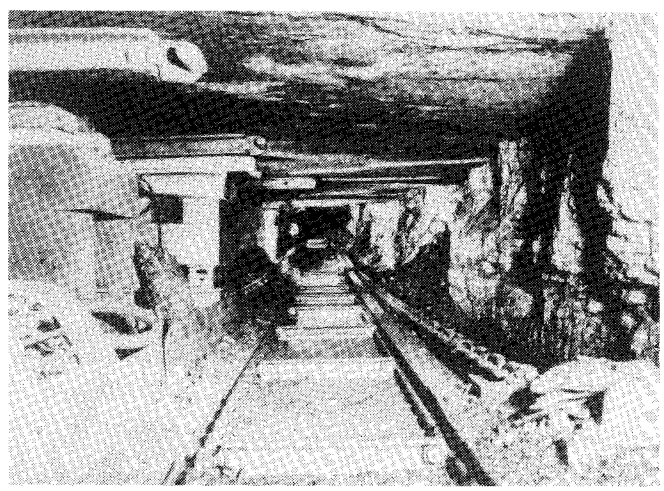

Figure 8.—Roof control using wood cribs and mechanical friction props.

1950 period. The plow had static cutting picks, which planed the coal from the face at depths of 2 to 4 in as it was pulled across the panel. The cutting head of the plow was mounted on an articulated base that slid under the conveyor (see figure 9). A haulage chain was attached to the base of the unit on the gob side of the conveyor. This arrangement created a drawbar leverage that caused penetration of the cutting picks into the coal, according to the principle of a billhook or ship's anchor. As a result, these plows were typically referred to as Hook plows. In hard

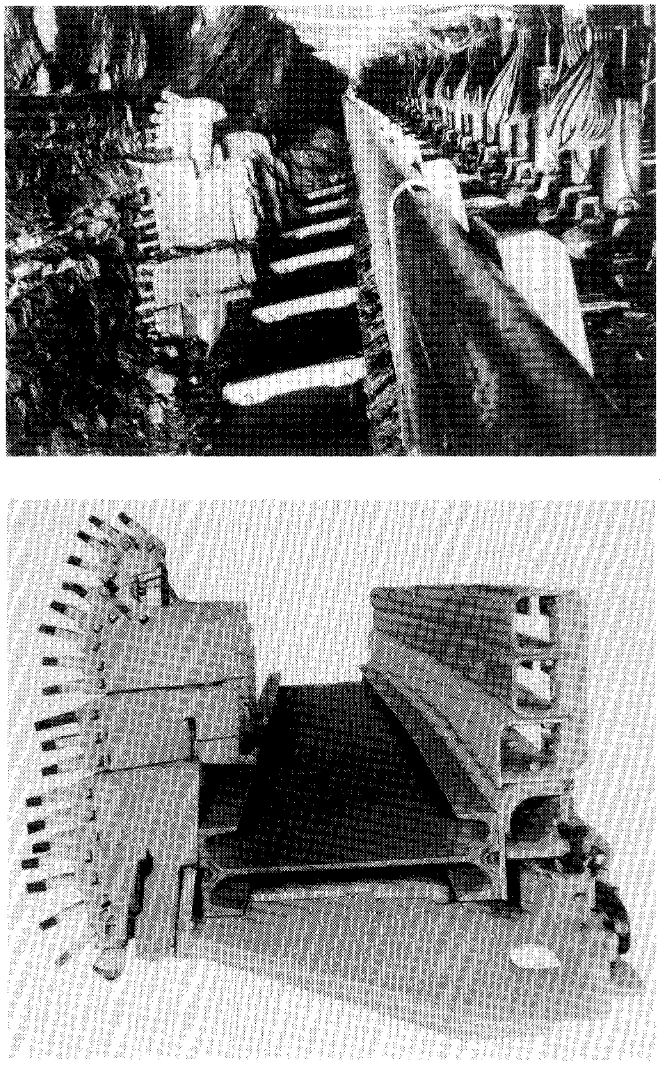

Figure 9.—Early plow design. Top, plow operating in a mine; bottom, closeup view of plow system.

coal, insufficient lateral force was generated to cause pick penetration into the coal; hence, early plow systems were limited to friable coals (Hardgrove grindability index between 70 and 80) (*9*). Because of this requirement, these plow installations were primarily in the Pocahontas Seam in southern West Virginia and northwestern Virginia.

The primary constraint to increased production from longwall operations during this era was roof-support advance. Mechanical friction props and wood cribs were the predominant support system. They had to be manually removed from roof contact, and in the case of the wood cribs, they were reconstructed as the face advanced. Figure 10 depicts a wood crib with a mechanical-release mechanism that permitted recovery of these passive support structures. The first hydraulic prop was also introduced toward the end of this era. These props also

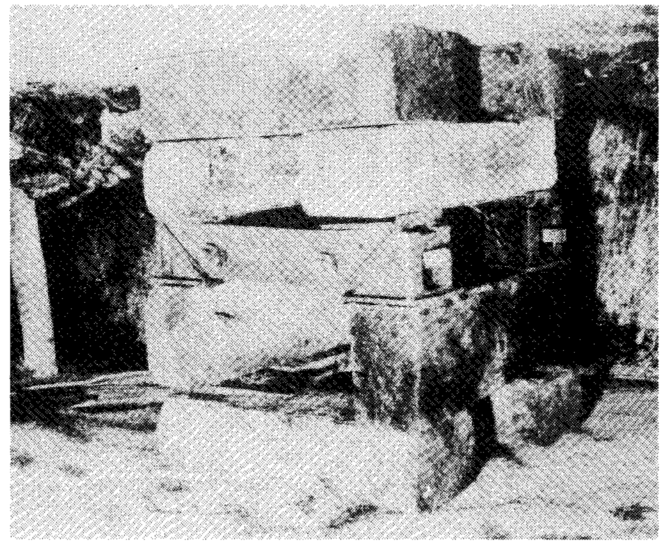

Figure 10.—Mechanical release for recovery of wood-crib supports.

required manual labor for recovery and resetting, and the labor-intensive wood cribs were still required to provide additional support.

Failure rate of longwall operations during the 1950-60 period was high (estimated at 75 pct). Only Eastern Associated Coal Co. was consistently successful. Operations of several other plow installations by other coal companies in West Virginia, Pennsylvania, and Arkansas were terminated because of either poor plowability of the coal, loss of strata control, or profitability lower than conventional mining methods.[5]

Support capacity during this era typically ranged from 25 to 75 tons (force) per jack, supplemented by wood cribs [capacity of 100 tons (force)]. The jacks were often damaged during the panel extraction and tended to be unstable in heavy strata conditions, which further reduced their effectiveness. Since the stiffness of the jacks was significantly greater than that of the wood cribs, the cribs provided relatively little support until the jacks approached their yield capacity. This combination was ineffective in many installations. The concern with ground-control problems, more than any other factor, led to a decline of longwall utilization by the end of this era.

A summary assessment of longwall performance during the 1950-60 era is shown in table 2. Average annual face production is estimated at 58,000 tons, with an estimated work-force productivity of 6 tpwd. Longwall utilization grew continually until the end of the era, averaging six faces over this time frame.

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[5]See footnote 4.

Table 2.—Summary assessment of longwall performance during 1950-60 era

	1950	1960	Annual average
Utilization . . . . number of faces . .	4	10	6
Coal production . . . . pct of underground mining . .	<0.1	0.15	0.1
Average face production . . . . tpy . .	20,000	70,000	58,000
Average face labor productivity . . . . tpwd . .	4	8	6

1960-66 Era—Powered Roof Supports

This era was characterized by the introduction of powered roof supports, which could be raised, lowered, and advanced hydraulically. Eastern Associated installed the first hydraulic, self-setting and self-advancing roof-support system in 1960 in the 52-in-thick Pocahontas coal seam at their Keystone Mine in southern West Virginia. This plow-operated face produced an average daily tonnage of 900 tons on two (8-h) production shifts.[6] By 1960, the poor production and low productivity of most previous longwall operations caused the prevailing attitude among coal operators that longwall mining was a "last-resort" method, used only for thin-seam mines where room-and-pillar methods failed. The introduction of self-advancing supports removed the productivity constraint caused by the labor-intensive support system, based on wood cribs and friction jacks, and revived interest in longwall mining. As shown in figure 11, the decline in longwall utilization ended in 1962 as the advantages of self-advancing supports were realized.

The first self-advancing roof supports were of frame-type constructions, wherein two hydraulic jacks were connected by a beam to form a frame construction, as shown in figure 12 (*10*). The units were operated in sets of two, with two frames linked together by a central shifting ram. As one frame remained set between the roof and floor, the other frame was lowered and advanced, thus creating a self-advancing support system. Hydraulic power was supplied to each support from a pump located in the headgate

[6]See footnote 4.

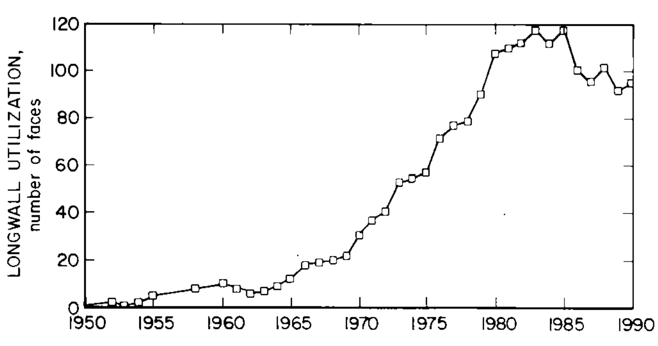


Figure 11.—Longwall utilization during modern period (1950-90).

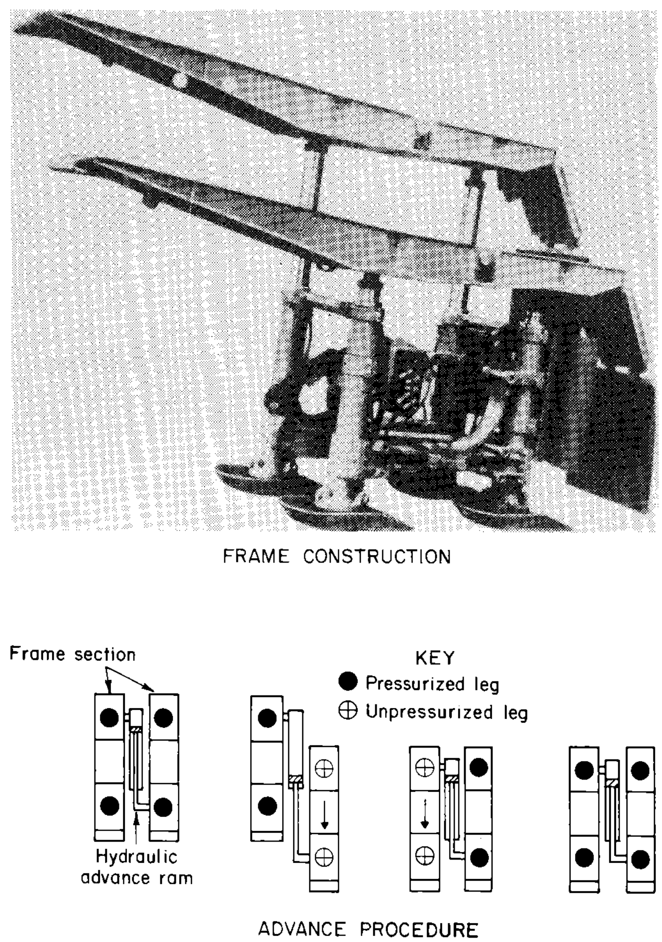


Figure 12.—Self-advancing frame-type roof support.

entry. Leg capacities ranged from 33 to 44 tons (force), providing a frame support capacity at yield of 66 to 88 tons (force) for two-leg designs and 132 to 176 tons (force) for four-leg designs. Typical setting pressures were 50 pct of the yield pressure. Yield capability on each leg cylinder was provided by hydraulic relief of internal leg pressure through a mechanical valve.

Longwall installations using self-advancing frame supports were successful in strata conditions where the roof caved easily behind the advancing supports. There were serious failures when coal companies attempted to install these supports under more competent roof strata, such as massive sandstone and limestone. The inadequacy of these low-capacity support systems to control competent roof was best illustrated by several failures at the Old Ben Coal Co. installations in Illinois, where between 1962 and 1971, six failures were experienced with low-capacity support systems at their No. 21 Mine. Similar failures were experienced at nearby Freeman Coal Co., and longwall installations were discontinued in these regions (*11*).[7] As a result of these and other failures, the enthusiasm for expansion of longwall utilization was again stifled and the number of installations increased from 10 in 1960 to only 12 in 1965.

Another significant technological development that occurred during the 1960-66 era was the introduction of the shearing machine. Kaiser Steel Coal Corp. installed the first shearer in the United States in their Sunnyside Mine in Utah in 1961 (*12*). The shearing machine, as shown in figure 13, provides active cutting of the face coal from an electrically powered rotating drum. The capability of active coal cutting alleviated the soft coal constraint of plow installations and hence expanded the application of longwall mining to other coal seams. In addition to being able to cut hard coal and rock inclusions, the shearer extracted a 24- to 28-in-deep web, which provided increased production potential if sufficient cutting speeds were maintained relative to the thin web (2- to 4-in) plow extractions.

Some disadvantages and problems associated with early shearer installations were as follows:

1. Initial installations were used in conjunction with frame-type roof supports. These supports tended to be difficult to steer and advance uniformly, which sometimes made it difficult to maintain good face alignment—a factor critical to wide web extractions.

2. The shearer weighed about fivefold more than the plow and hence required more robust face conveyor designs. Maintenance of face conveyors was a considerable problem with early shearer installations, not only because of the shearer's weight, but also because of the larger snakeover distance required by the wider web extraction. Failure of the connections between conveyor pan sections was a common problem on many early shearer installations.

3. Shearers produced finer sized coal than plows. This was a disadvantage for marketing since a coarse coal product was preferred for heating and electric power generation. The fine coal size also was disadvantageous for face conveyor operation. The fines tended to jam the face conveyors since the early conveyor designs incorporated closed bottoms that trapped material within the conveyor return. This contributed to additional downtime for the conveyor systems, which reduced the productive mining time.

4. Early shearer designs had to be operated in seams greater than 4 ft high since the shearer traveled on the face conveyor and clearance had to be designed beneath the shearing machine's undercarriage to accommodate hauling of the coal by the face conveyor.

5. Dust generation was considerably greater on shearer-operated faces because of the finer product produced from active pick penetrations and secondary breakage of the coal. The installation of dust suppression devices also tended to be more difficult on shearing machines because of the dynamic nature of the drum compared with the static plow.

Despite these problems, shearer extraction was adopted fairly quickly. Figure 14 shows the percentage utilization of plows and shearers. From its inception in 1961, shearer utilization increased to account for 42 pct of the longwall operations by 1966.

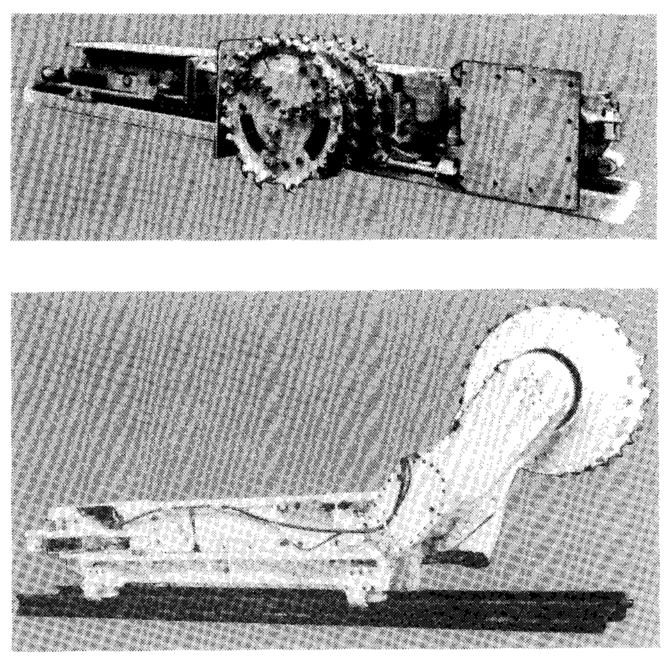


Figure 13.—Fixed (top) and ranging-arm (bottom) longwall shearing machines.

[7]See footnote 4.

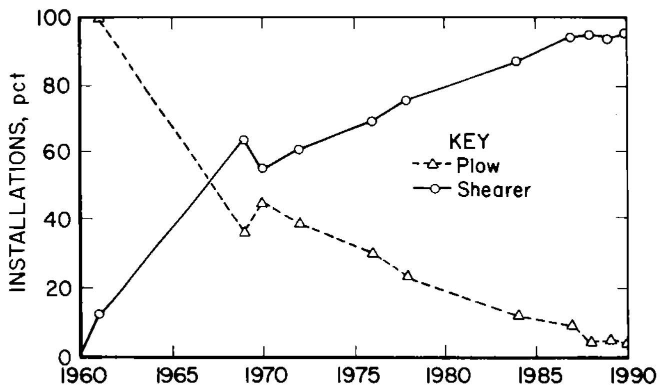


Figure 14.—Comparison of utilization of plows and shearers.

Performance during the 1960-66 era is summarized in table 3. Utilization fell during the beginning of the period and then rose as the powered-roof-support technology was implemented. On average, the number of installations grew by 50 pct over the previous era (1950-60). However, longwall mining was still limited in application and reports of failures in the Illinois coal basin stifled utilization. The number of faces reached only 18 by 1966. Successful installations demonstrated improved production capability over the previous era. Annual face production increased by 72 pct and the work-force productivity jumped 183 pct as the support advance constraint was removed by the self-advancing-roof-support technology. Longwall mining accounted for about 0.4 pct of the total underground production by the end of this period. Bureau involvement during the 1960-66 era was minimal because of budget constraints. Efforts were limited primarily to ground-control studies conducted by the Bureau's Denver Research Center.

1966-75 Era—High-Capacity Roof Supports

Support capacities increased dramatically during the 1966-75 era, as shown in figure 15, as a result of failures experienced with the low-capacity support systems of the previous era. Support capacity increased by a factor of 2 to 4, with four-leg supports providing resistances as high as 700 tons (force). Average support capacity was approximately 475 tons (force).

The first high-capacity support system was installed in Island Creek Coal Co.'s Beatrice mine in western Virginia in 1966. This system featured 560-ton (force) supports that provided excellent control of the competent sandstone roof and operated for a period of 10 years without failure while producing a respectable 1,000 tons per shift of raw coal (*9*). In 1966, other installations by Eastern Associated at their Kopperston No. 1 and Wharton No. 2 Mines in southern West Virginia proved the success of high-capacity support systems under sandstone roof conditions where previous installations using low-capacity supports had failed.

A significant advancement in support design was achieved with development of the chock support, an example of which is shown in figure 16. The chock support can be thought of as a mobile crib. This design essentially tied two frame supports together with a rigid canopy and semi-rigid base. This design improved structural stability and increased roof contact area over the previous frame-type systems. The increased roof cover helped reduce accidents caused by material falling from the immediate roof, especially during support advance. The chock support was advanced as a single unit by a hydraulic ram attached to the face conveyor. Early designs employed six legs, as shown in figure 17, but four-leg designs provided an improved travel way for the face personnel and equipment and were the dominant designs by the end of this era (*10*). Chocks were the preferred roof supports for shearer installations because they could be advanced more quickly and provided better control of face alignment since each unit was connected directly to the face conveyor. For this reason, chock supports also provided more active control of plow pressure against the face, which also contributed to the installation of plows in harder coal seams.

Table 3.—Summary assessment of longwall performance during 1960-66 era

	1960	1966	Annual average
Utilization .... number of faces ..	10	18	9
Coal production .... pct of underground mining ..	0.15	0.7	0.4
Average face production .... tpy ..	70,000	125,000	100,000
Average face labor productivity .... tpwd ..	8	20	17

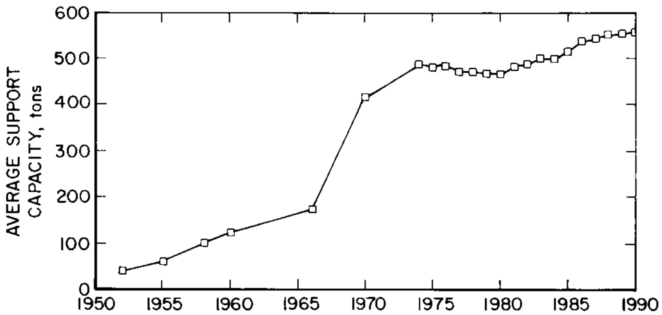


Figure 15.—Historical development of roof support capacities showing significant increase between 1966 and 1975.

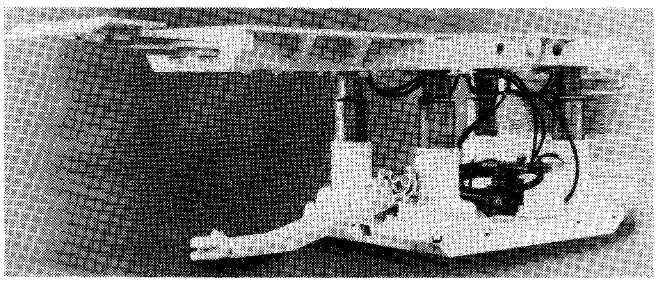


Figure 16.—Four-leg chock-type roof support.

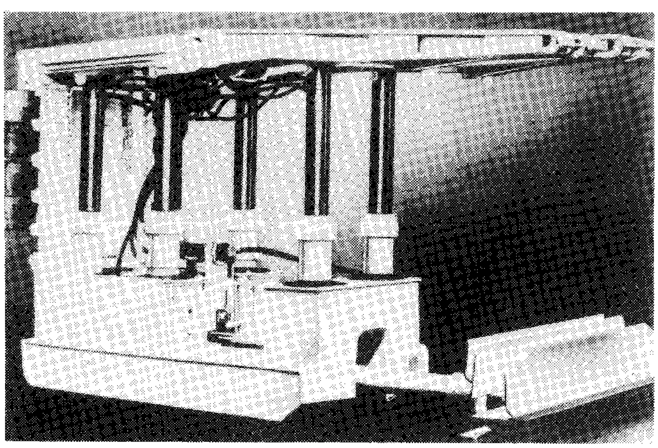


Figure 17.—Six-leg chock-type roof support.

In addition to improvements in support capacity and design, technological improvements were also made in extraction systems. The Gleithobel plow (shown in figure 18) eliminated the troublesome guidance problems (*9-10*).[8] In this design, the plow is trapped on a ramp plate on the face side and a stabilizing arm reaches across the conveyor to a gob-side guidance tube. This provided a more stable arrangement than the plate which slid under

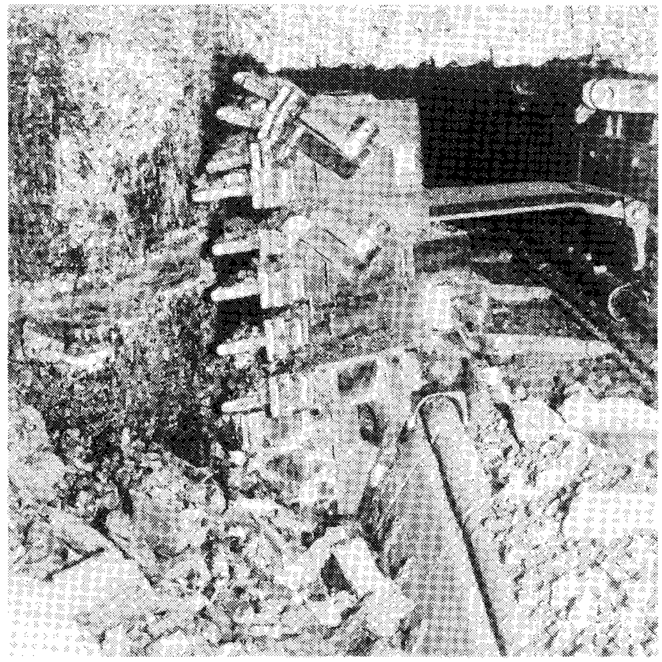


Figure 18.—Gleithobel plow used to mine hard coal seams.

the face conveyor on previous systems. This arrangement also reduced haulage power requirements since considerable haulage energy was wasted in previous designs by friction developed by the stabilizing plate that ran underneath the face conveyor. Face-side haulage (location of the haulage chain at the face-side base of the plow) also provided more efficient utilization of haulage power to coal cutting, which allowed their application in harder coal seams. The Gleithobel plow was first placed in service in the Moss No. 2 Mine of Clinchfield Coal Co. near Dante, VA, in 1974 and successfully mined the hard Tiller Seam for the first time (*9*). Prior to this, the Tiller Seam, with a Hardgrove grindability index of 40 compared with 100 for the Pocahontas No. 3 Seam, was not considered amenable to longwall mining since it was too hard to plow and too thin to employ shearing machines.

Improvements in the Hook plow design of the previous era included height adjustments for operation in undulating coal seams and add-on sections for operating in thicker coal seams. The improved Hook plow, with greater depth of cut capability than the Gleithobel plow, remained the most productive cutting system. Hook plows were consistently producing 2,000 tpd of clean coal from several installations (*10*).

Despite these improvements in plow technology to broaden their application, the trend favored the use of shearing machines, as indicated in figure 14. By 1968, the number of shearer installations exceeded that of plow installations, and by 1975, about 68 pct of the longwall

[8]See footnote 4.

faces employed shearing machines for coal extraction (*13*). A significant development in shearer technology that helped spur the application of shearing machines was the introduction of the double-drum and ranging-arm design shown in figure 19. The primary advantage of the double-drum machine was its quick capability in cutting height adjustment. This was most advantageous in undulating coal seams and in conditions where cutting height had to be routinely adjusted to leave top coal to provide control of unstable immediate roof.

The first double-drum ranging shearers were installed in the Pittsburgh No. 8 Seam in the northern Appalachian coalfields in the late 1960's. A production record high of 6,000 tpd was established at Eastern Associated's Federal No. 1 Mine in April 1969 with a double-drum shearer (*13*). Other advantages of the double-drum designs included more efficient cutting of the panel corners and bidirectional cutting of the coal face. Chain haulage still provided transport of the shearer across the face, but by the early 1970's, hydraulic tram units were employed, which regulated haulage speeds in relation to cutting power requirements.

Operational improvements developed during the 1966-75 era included the one-web back method of support advance. The one-web back system kept the supports one cutting web away from the face conveyor so that the supports could be advanced without having to first advance the face conveyor. This allowed supports to be advanced immediately after the shearer passed, which improved roof control in friable roof geologies by minimizing the time during which the roof in front of the roof supports remained unsupported. An improved travel way was also provided, and the one-web back system became the standard operating mode by the end of this era (*9*).

Souder and Palowitch indicated that the high-capacity support era was characterized by fewer technical failures and discontinuances than any of the preceding eras (*7*). This era marked the first viable commitment to longwall mining by the U.S. coal mining industry. Utilization rose by 266 pct from the previous era and included a large number of operators who had employed more than one longwall system in the past. By 1975, 58 longwall faces were operated by 28 different coal companies. Eastern Associated was the leading operator with 16 faces in 5 different coal seams in West Virginia. The improved roof control provided by the high-capacity supports contributed to significant improvements in both production and labor productivity. Average annual face production increased by 45 pct and work-force productivity increased by 47 pct from the previous era. On average, longwall faces were producing 196,000 tpy at a productivity level of about 25 tpwd. By 1975, longwall mining accounted for 3.1 pct of the total underground coal production. An assessment of performance during this era is shown in table 4. Meanwhile, room-and-pillar mining systems saw dramatic reductions in productivity because of constraints in drivages under unsupported roof imposed by the 1969 Coal Mine Health and Safety Act (*14*).

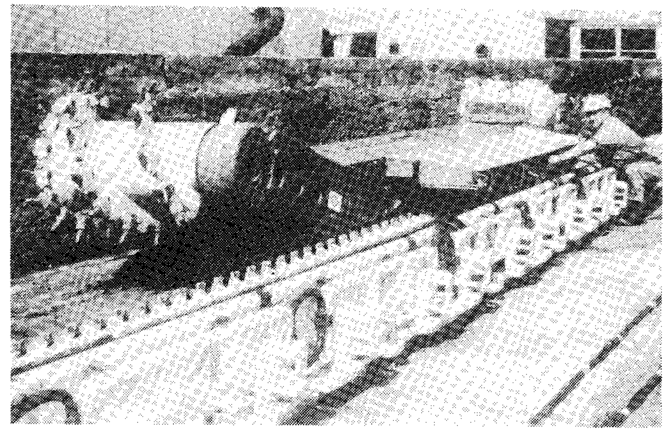


Figure 19.—Double-drum, ranging-arm shearer.

The Bureau's involvement during the high-capacity support era was limited essentially to some in-mine studies to assess longwall performance, with an emphasis on ground control. Several visits were made to European mines and equipment manufacturers by prominent Bureau personnel to accelerate the modification of foreign longwall equipment to American conditions and to gain first-hand information of European operating experiences. Several trials in shortwall mining demonstrations were sponsored by Bureau research. The shortwall system attempted to employ a continuous miner and a pair of shuttle cars to extract a wide cut using the general longwall mining concept. However, shortwall mining was short lived because of ground-control difficulties associated with maintaining a 13-ft-wide cut and because of the success of longwall mining.

Table 4.—Summary assessment of longwall performance during 1966-75 era

	1966	1975	Annual average
Utilization .... number of faces ..	18	58	33
Coal production .... pct of underground mining ..	0.7	3.1	2.0
Average face production .... tpy ..	125,000	157,000	[1]196,000
Average face labor productivity .... tpwd ..	20	30	25

[1]Maximum production of 288,000 tpy occurred in 1969.

A major deterrent to early applications of longwall mining was the large capital investment for equipment purchases. As longwall mining became more successful, these equipment purchases were more easily justified.

1975-85 Era—Shield Supports

The development of the chock support and the increase in support capacity to control massive strata common to many U.S. coal seams led to the establishment of longwall mining as a potentially viable mining system. However, failures were still being experienced because of the inadequacy of the chock supports to control competent strata that tended to cave in large pieces, exerting rotational moments or horizontal displacements on the support structure. Figure 20 illustrates a chock support damaged from excessive horizontal loading. The frustrations and failures experienced by Old Ben in the Illinois coal basin between 1962 and 1970, where each of the six attempts at longwall mining failed, best exemplify the inadequacy of the chock design in these conditions. It was not until the introduction of the shield support in 1975, with its improved lateral stability and additional roof cover, that longwall mining proved successful in the Illinois region, signaling that the last major impediment to longwall utilization was overcome.

Analysis of the geometry of the chock and shield supports reveals a basic difference in their mechanics. As seen in figure 21, the canopy of the chock is connected to its base only by the hydraulic leg cylinders, which were pin jointed at the ends. To provide a measure of horizontal stability, stiff rubber mounts were typically employed at the leg joints. Excessive horizontal displacements produced moment transfer through the leg joints, causing severe damage to the hydraulic leg cylinders in several installations. External horizontal load components were generated typically by conditions where the canopy could not be set parallel to the base. Such conditions were prevalent under friable roof, such as the erratic shalely roof that existed in Illinois in the Old Ben Mines. In contrast, the canopy and base of the shield support are connected mechanically by structural members other than the hydraulic leg cylinders to provide horizontal stability to the structure. Hence, the leg cylinders are not subjected to damaging bending moments and the support overall is much more stable.

The first shield-supported face installed in the United States was by Consolidation Coal Co. (Consol) in 1975 at their Shoemaker Mine near Moundsville, WV. From the very beginning, encouraging results were obtained. The face produced 750,000 tons in its first year of operation (*15*). This compares with an industry average annual face production of 196,000 tons for the high-capacity chock-support era (1966-75). Shortly after this initial shield installation, a shield-supported face at Consol's Robinson Run Mine set a daily production record of 12,395 tons, which contrasts with a maximum daily production of 6,000 tons for chock-supported faces (*16-17*). The Bureau sponsored shield installations at Kaiser Steel's York Canyon Mine in New Mexico and Old Ben Coal's No. 24 Mine in Illinois in 1975 and 1976, respectively (*18-19*).[9] Both installations were highly successful in demonstrating the application of this new longwall technology to areas where previous attempts at longwall mining had failed; namely, deep cover mines with thick sandstone roofs common to western mines and friable erratic roofs under moderately shallow cover in the Illinois coal basin.

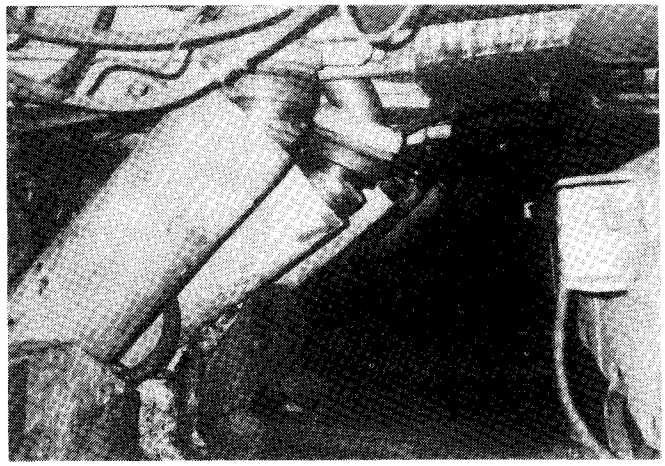


Figure 20.—Damaged chock support from horizontal forces.

The outstanding successes of these initial shield installations accelerated utilization of this technology. As shown in figure 22, shield utilization rose dramatically from their introduction in 1975 to 1982, when 83 pct of the longwall faces were shield supported. By 1985, just 10 years after introduction, the roofs over nearly 90 pct of the operating longwall faces were supported by shields.

The basic shield design itself underwent several developmental changes during this era, as illustrated in figure 23. The most significant design improvement was the incorporation of the lemniscate linkage into the caving shield assembly. Previous designs had the caving shield connected directly to the base, which caused the tip of the canopy to transcribe an arc as the shield was lowered and raised. The lemniscate system provided vertical travel of the canopy throughout its operating range, which minimized the unsupported span in front of the shield. The Bureau sponsored the first lemniscate-guided shield design at Old Ben's No. 24 Mine in 1976. Improvements in the supporting efficiency provided by the leg forces were also made by moving the leg connection from the caving shield to the canopy. This design also eliminated a troublesome connection point between the rear of the canopy and the caving shield, where the collection of debris caused

[9]See footnote 4.

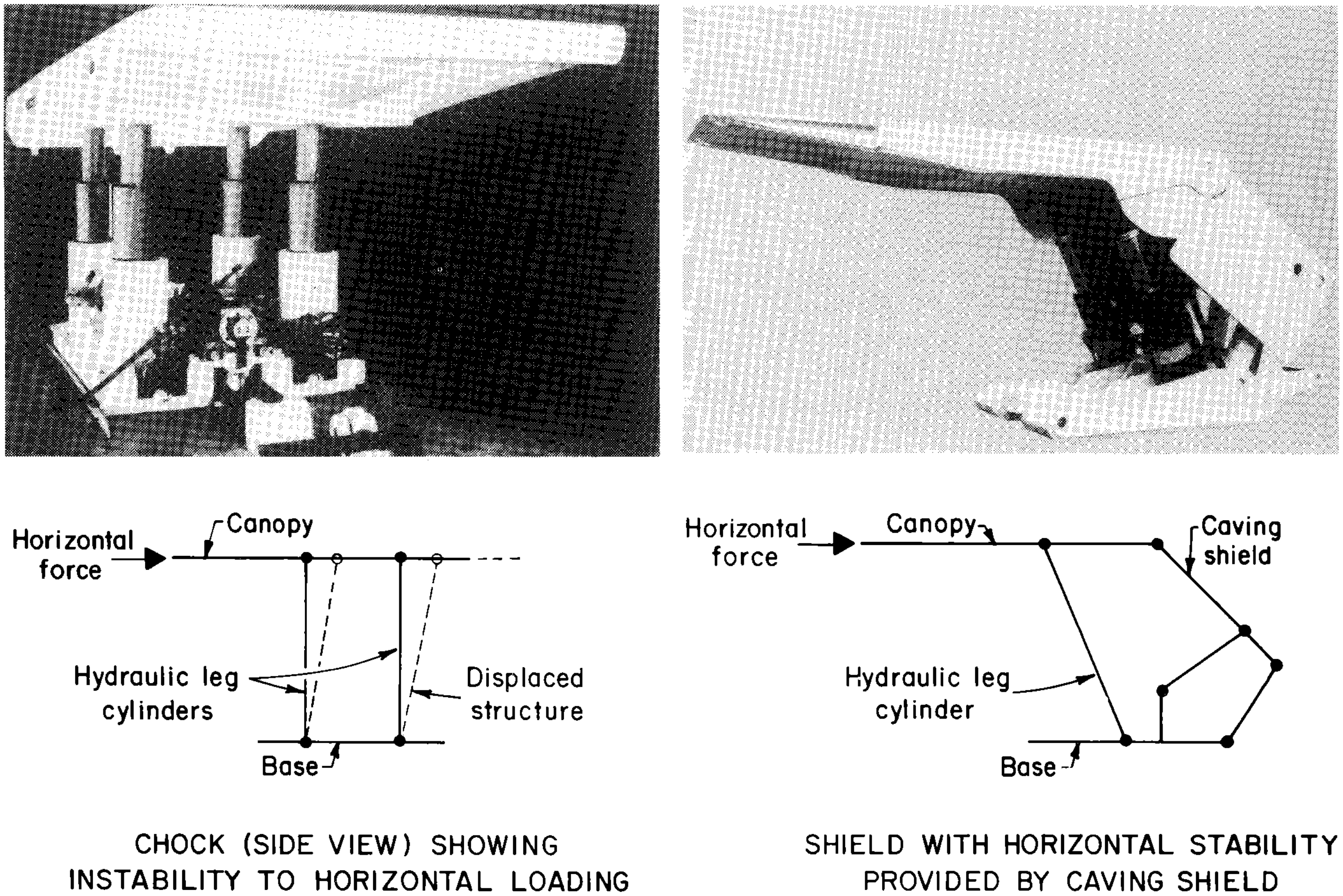


Figure 21.—Comparison of chock and shield support constructions and stability.

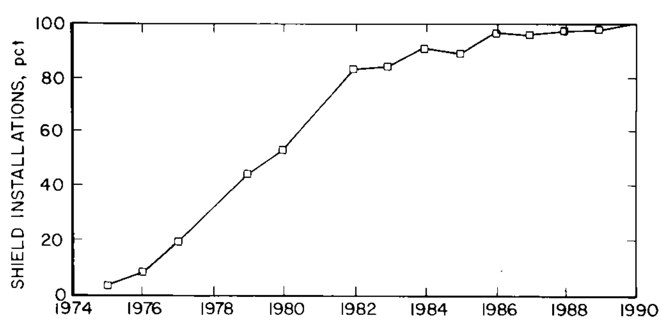


Figure 22.—Historical development of shield utilization.

problems in maintaining a level canopy attitude sufficient to provide full roof contact along the entire canopy. Both two-leg and four-leg shield designs were employed, although the tendency was toward two-leg shields, as shown in figure 24. Four-leg shields were mostly used in deep cover and in conditions where the immediate roof cantilevered beyond the rear of the supports (*20*).

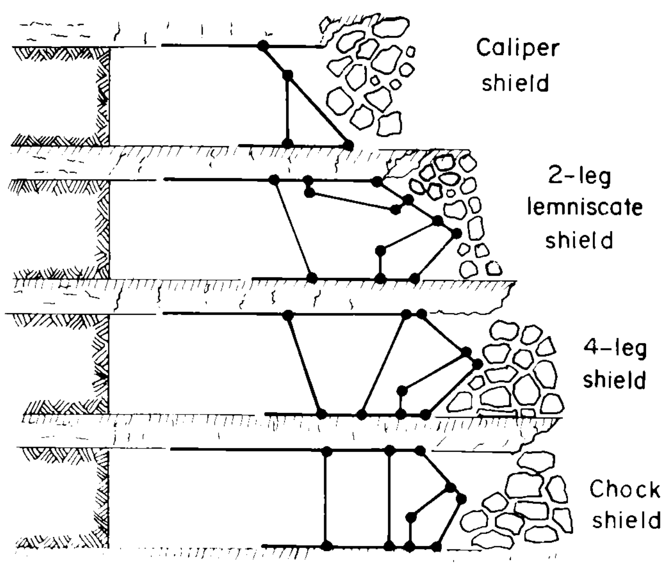


Figure 23.—Modifications of basic shield design.

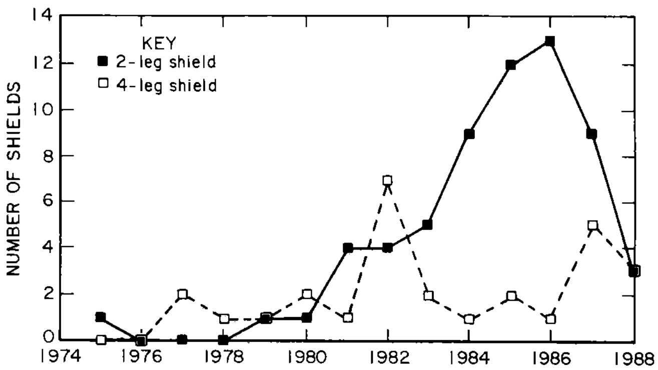


Figure 24.—Trends in two- and four-leg shield selection.

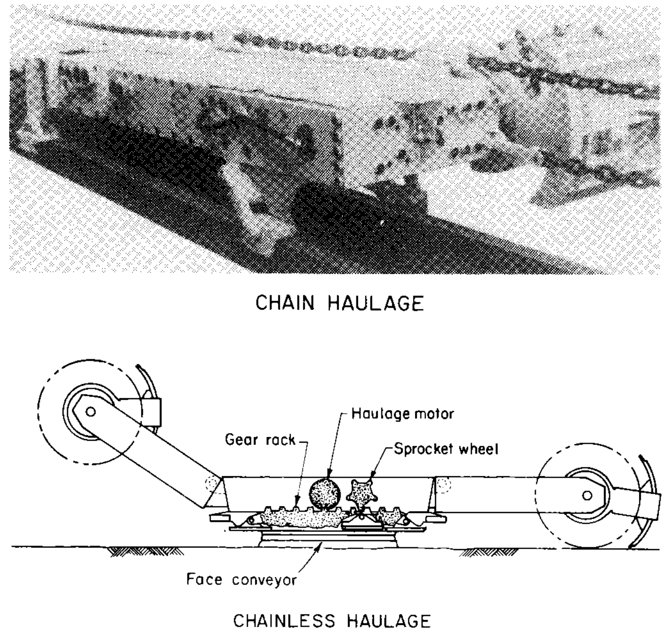


Figure 25.—Chain and chainless shearer haulage.

Average support capacities fell slightly from 1975 to 1980 (see figure 5), because early shield installations were typically 350 to 360 tons (force) while the existing chocks were as high as 700 tons (force). For example, in 1976, average support capacity for chock installations was 462 tons (force) and 582 tons (force) for frame supports, while the six shield installations averaged 347 tons (force). Support capacities rose slightly from 1980 to 1985 as shields began to replace chock systems and higher capacity shields were installed. By 1985, 90 pct of the operating longwalls employed shield supports and the average shield and chock capacities were nearly equal at about 500 tons (force).

Although the development of the shield was the most significant technological advance of this era, several other technological advancements were made.

1. *Chainless Shearer Haulage.*—A significant safety hazard was eliminated when chain-haulage shearers were replaced by track-mounted hydraulic or rack-and-pinion haulage. The elimination of the haulage chain was considered a major safety improvement since the energy developed in the chain represented a potentially fatal safety hazard. Figure 25 illustrates both chain and chainless shearer haulage systems.

2. *In-Web Shearer.*—The in-web shearer design moved the carriage of the shearing machine from over the conveyor to directly behind the cutting drums. This eliminated the undercarriage clearance restriction that precluded the use of shearers in thin coal seams (less than 42 in).

3. *Center-Mounted Chain Face Conveyors.*—The face conveyor was a significant source of downtime in previous longwall history. The development of center-mounted chain designs, as shown in figure 26, improved the reliability of face conveyors. Previous outboard designs, where the chains were attached to the ends of flights that were the width of the conveyor, were unreliable because of differential chain stretch produced during conveyor advancement.

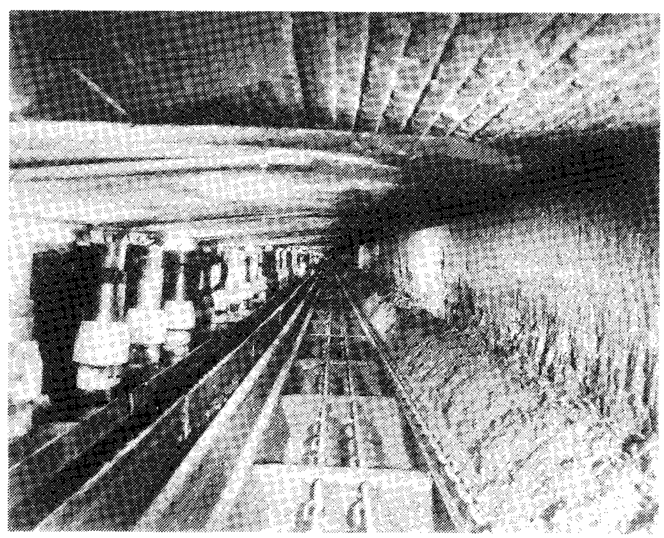


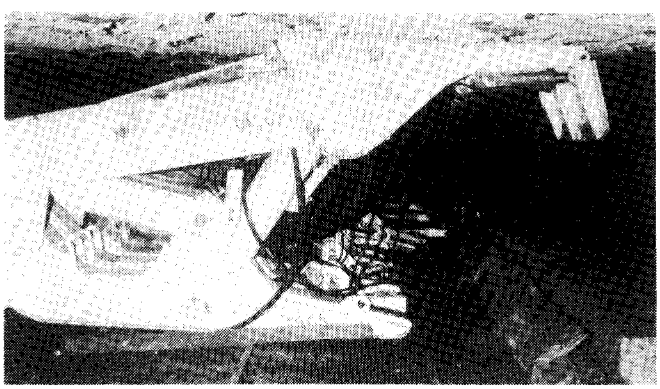
Figure 26.—Center-mounted chain design for face conveyors.

4. *Dust Control.*—Only 48 pct of the longwalls were found to be in compliance with the 2.0 mg/m³ dust standard in 1978 and only 35 pct in 1980 (*21*). Shearer systems presented the biggest problem because of dynamic cutting, large volume of coal extracted, and secondary degradation

during loading and transport. By 1985, the number of longwalls in compliance improved to approximately 80 pct because of improvements in water and ventilation applications, as well as improvements in drum and cutting bit design.

The Bureau made significant contributions in promoting the utilization of longwall mining during this era, as shown in table 5.[10] Bureau-sponsored research totaled approximately $67 million during this period. Included in these efforts were early demonstrations of shield supports at York Canyon and Old Ben No. 24 Mines (fig. 27) and demonstrations of (1) thin-seam longwall mining (fig. 28), (2) single-entry gate-road design in the Sunnyside Mine (fig. 29), (3) multilift extraction of a thick seam at Mid-Continent Resources' L. S. Wood No. 3 Mine in Colorado (fig. 30), (4) steeply pitching seam extraction at Snowmass Mine in Colorado (fig. 31), and (5) an advancing longwall trial (fig. 32). Another experimental trial was the use of a tunnel-boring machine at Federal No. 2 Mine (fig. 33) for single-entry panel development. Full-scale experiments were also conducted in the application of water-jet cutting for coal extraction, as shown in figure 34.

[10]See footnote 4.



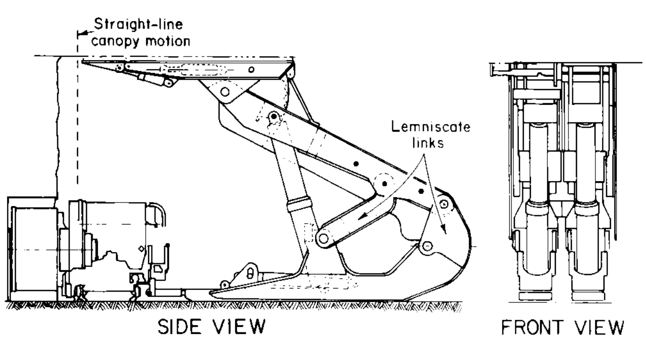


Figure 27.—First lemniscate-guided shield system (Old Ben No. 24 Mine).

Table 5.—Bureau longwall research activities during 1966-75 era

	Expenditure, 10^6 $
York Canyon Mine shield demonstration	3.6
Old Ben No. 24 Mine shield demonstration	3.6
Single-entry trial	.5
Thin-seam trial	4.4
Water-jet cutting	.6
Multilift demonstration	11.5
Mine roof simulator	6.8
Tunnel-boring entry development	4.0
Advancing longwall trial	11.5
Steeply pitching seam trial	4.2
High-capacity face conveyor	4.1
Automation research	12.0

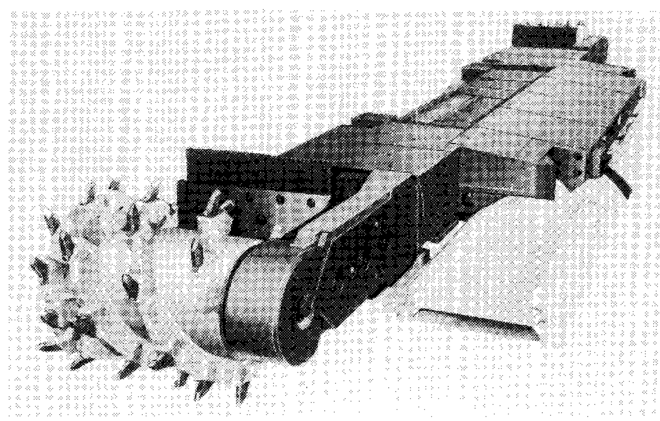


Figure 28.—In-web shearer used for thin-seam longwall mining.

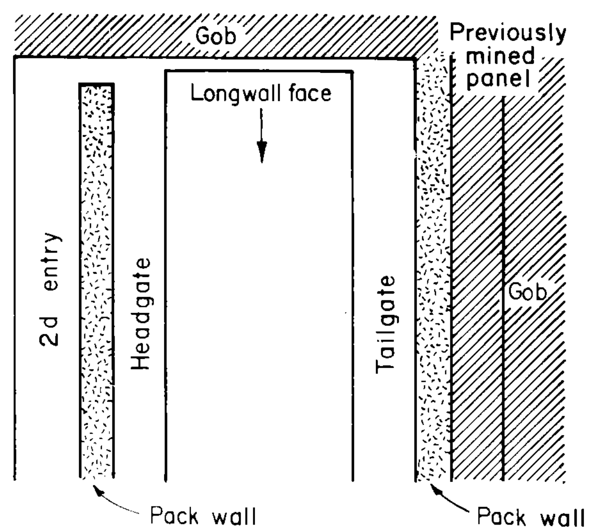


Figure 29.—Single-entry gate-road design. ("Longwall face" arrow indicates direction of mining.)

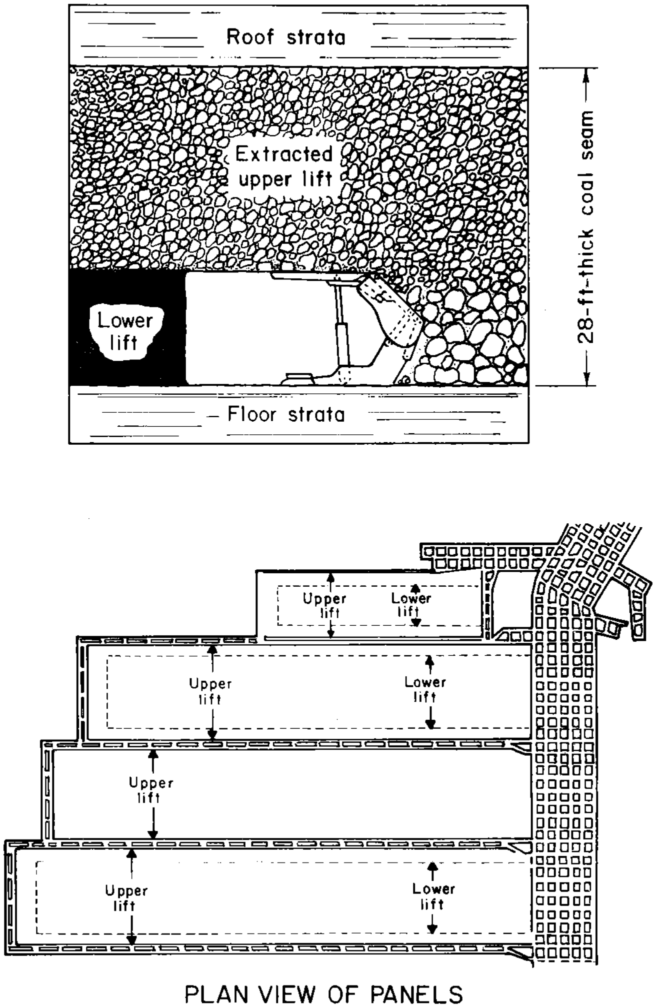
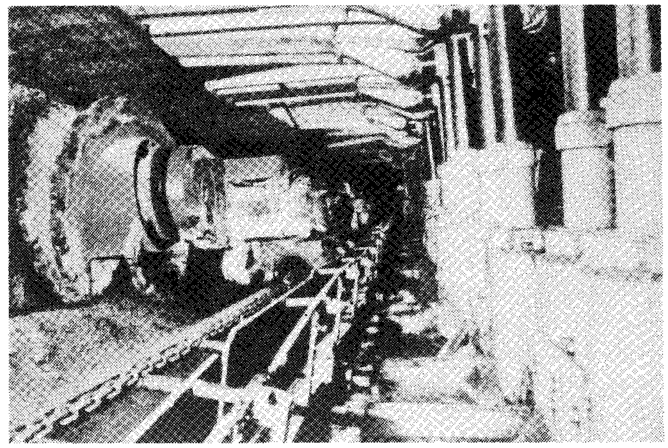


Figure 30.—Multilift extraction of 28-ft-thick seam at L. S. Wood No. 3 Mine.



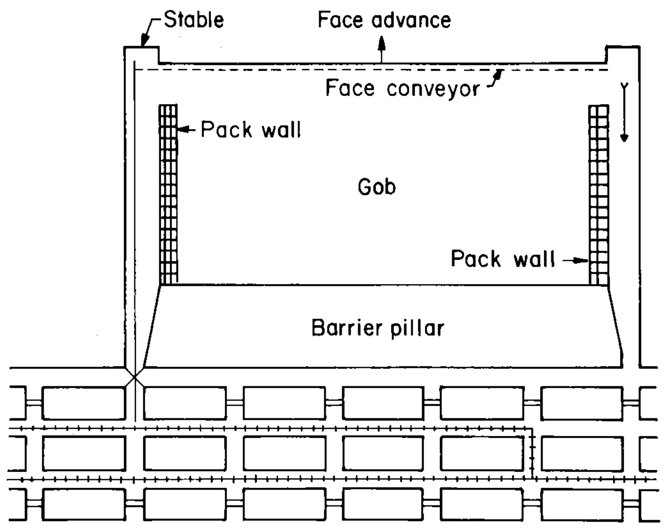


Figure 32.—Advancing longwall trial at Dutch Creek No. 1 Mine in Colorado.

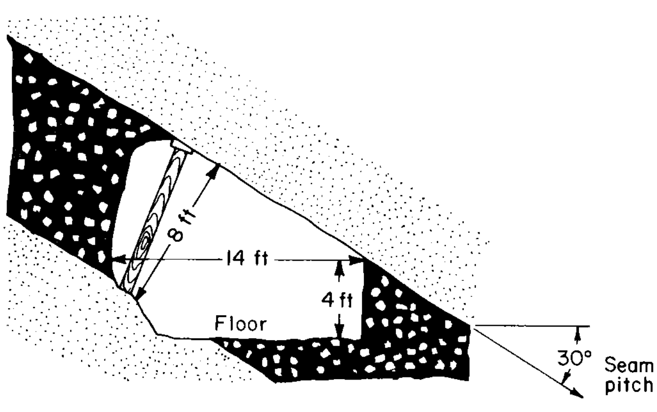


Figure 31.—Entry profile of steeply pitching seam demonstration at Snowmass Mine in Colorado.

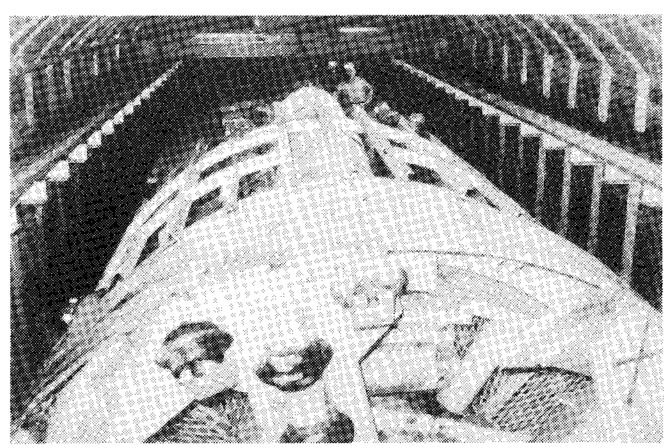


Figure 33.—Tunnel-boring machine used for entry development at Federal No. 2 Mine in Pennsylvania.

In 1979, the Bureau, under contract to MTS Corp., built a sophisticated load frame at a cost $6.8 million for conducting research on longwall support systems. The mine roof simulator, as it was called (shown in figure 35), has the capability to provide controlled loading of up to 1,500 tons (force) vertically and 800 tons (force) horizontally over a 20- by 20-ft platen area to full-scale support structures. The Bureau also initiated a long-range research program to develop an automated longwall system (*22*). Research was conducted on sensors and control systems to provide horizon control for shearers that would detect the coal-rock interface and provide automatic vertical ranging of the shearer drums. This automation technology development continued beyond the completion of this era (1985). Dust-control research by the Bureau also played a major role in bringing longwall operations into compliance with the dust standards.

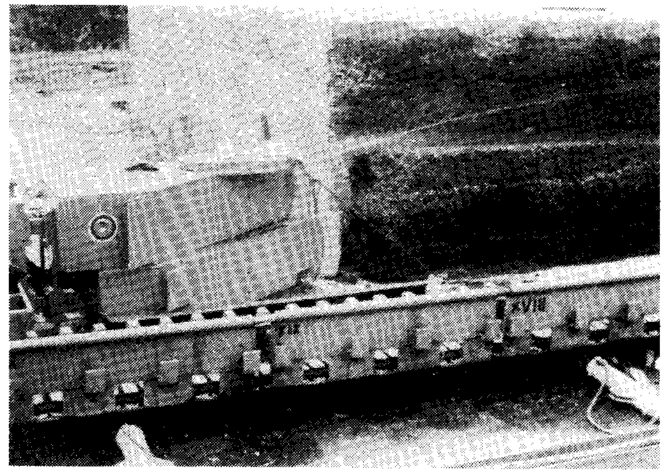


Figure 34.—Surface trials of experimental water-jet cutting system for longwall mining.

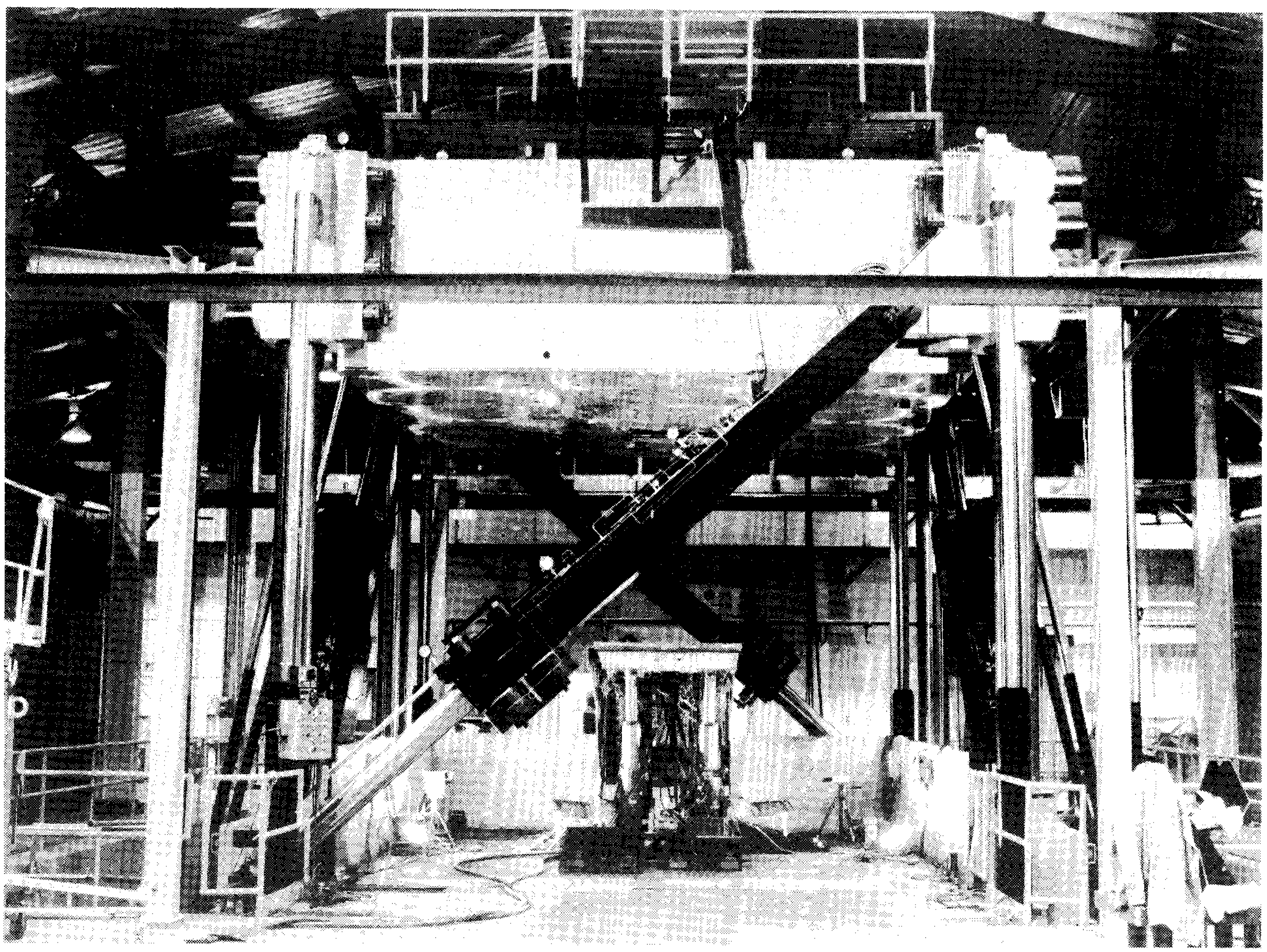


Figure 35.—Bureau's biaxial load frame for evaluating full-scale longwall support structures.

An assessment of average performance during the shield support era is shown in table 6. Clearly, longwall mining reached maturity during this era. The growth rate in utilization (number of longwalls installed per year) increased slightly from the previous era, as seen in figure 36. Overall, utilization more than doubled by 1983, when as many as 118 faces were operating compared with 58 installations in 1975. Production grew from about 3 pct of the total underground production in 1975 to nearly 19 pct by 1985. When the utilization of shield supports became well established (1978), face production increased dramatically, as shown in figure 37. Between 1978 and 1983, average annual face production increased by nearly 250,000 tons (165 pct) from approximately 150,000 to 400,000 tpy, respectively. This compares with a nearly constant face production of about 200,000 tpy for the 7 years preceding the establishment of the shield support. A record daily face production of 21,951 tons was set in 1984 at Island Creek's Dobbin Mine in West Virginia. The mine, operating with an eight-worker face crew, had a work-force productivity of approximately 900 tons per worker-shift. It is estimated that work-force productivity averaged about 41 tpwd during the shield era, an increase of 64 pct from the previous chock and frame support era.

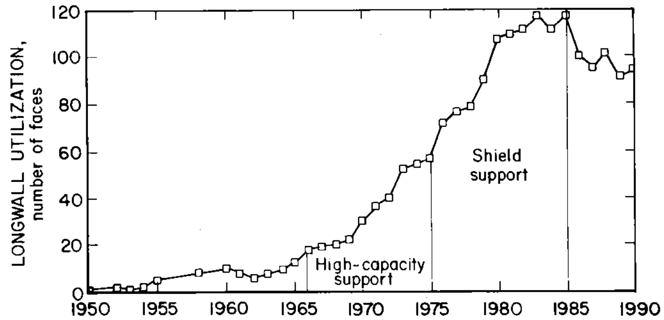


Figure 36.—Longwall utilization showing accelerated growth rates during high-capacity and shield support eras.

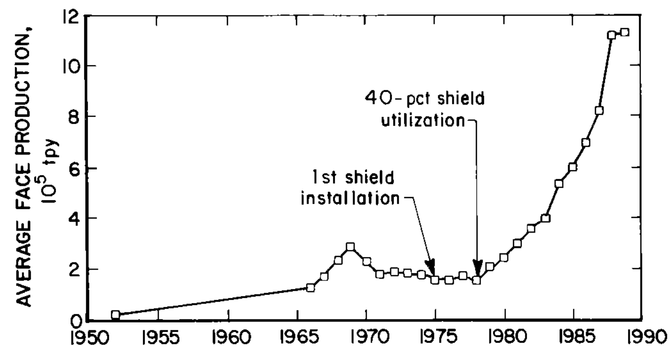


Figure 37.—Historical development of average annual longwall face production.

1985-90 Era—System Automation

The final major development in longwall mining was the introduction of electrohydraulic control systems. Figure 38 illustrates a typical electrohydraulic control unit for shield supports. The motivation for the development of electrohydraulic control systems was to provide a capability for moving a group or batch of supports from a dust-free location so as to reduce the dust exposure to the operator. The electrohydraulic system also provides faster support advance with less labor. In addition to the productivity improvement accrued from the labor reduction, the faster advance times allowed shearer cutting (haulage) speeds to increase, providing an increase in mining rate and hence overall coal production.

This technology was further developed to include a shearer-initiated roof-control system (see figure 39), wherein the shearer emits a signal that is picked up by the shields which in turn activates the execution of the roof support and conveyor advance cycle. This system essentially eliminates the need for shield operators, although current practice is to have one person monitor the system. Shearer-initiated-advance technology also permits multiple supports (two or three) to be advanced simultaneously. This capability allows for the full production capability of the shearer to be realized in most conditions by allowing the shearer to traverse the face at its maximum speed.

Table 6.—Summary assessment of longwall performance during 1975-85 era

	1975	1985	Annual average
Utilization .... number of faces . .	58	118	94
Coal production .... pct of underground mining . .	3.1	18.6	8.5
Average face production .... tpy . .	157,000	604,000	269,000
Average face labor productivity .... tpwd . .	30	64	41

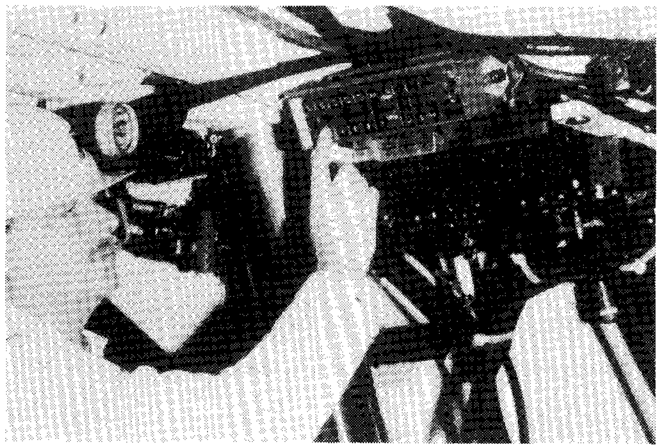


Figure 38.—Electrohydraulic shield-control system.

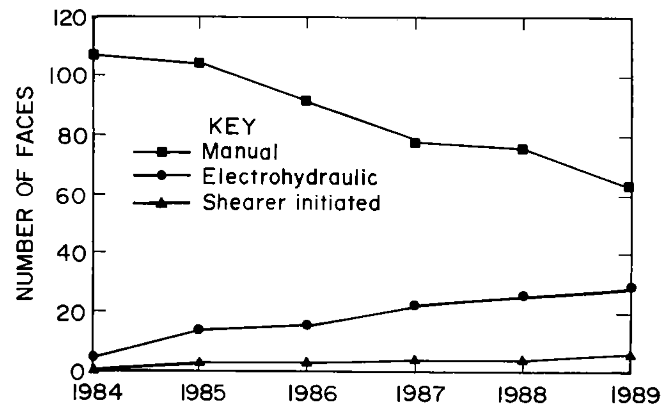


Figure 40.—Trend in longwall roof-control systems.

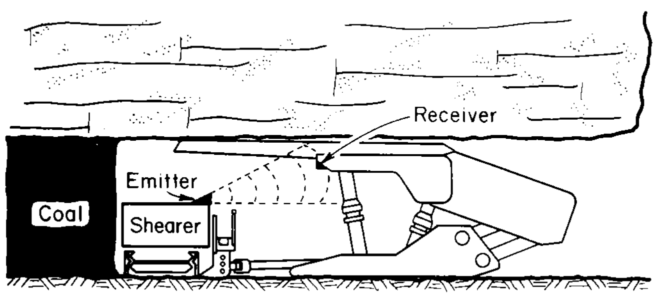


Figure 39.—Shearer-initiated electrohydraulic shield-control system.

The first electrohydraulically controlled shield-support system was installed in 1984 (*23*). Manually operated control systems still dominate longwall operations because of older systems that are still in service, but the trend is definitely toward the application of electrohydraulic control systems, as shown in figure 40. Nearly all shields purchased since 1985 have been equipped with electrohydraulic control systems.

The growth in longwall utilization actually fell during the automation era from a high of 118 installations in 1985 to 95 installations in 1990. This decline in utilization was partly due to economic and market conditions within the industry. Another contributing factor was that the more productive longwall operations were able to meet market demands with fewer operations, as evidenced by the fact that longwall production and work-force productivity continued to increase significantly while the number of installations fell. Annual production for longwalls more than doubled from 1985 to 1990, despite a 19-pct reduction in the number of longwall operations. By 1990, several longwall installations were regularly producing 1 to 2 million tpy. Average annual face production for all longwalls grew from 604,000 tons in 1985 to 1.13 million tons in 1989. An assessment of longwall performance during the automation era is shown in table 7.

The utilization of electrohydraulic shield-control systems undoubtedly contributed to the coal production and work-force productivity increases experienced in longwall mining during the automation era, but other technological developments also contributed. In addition to the faster shearer haulage rates, wider web shearer drum designs provided for increases in production for each face pass. Web depths for shearer extractions increased from a standard of 28 to 30 in. in the 1970's to a maximum of 40 in. in 1990. Likewise, as shearer power availability increased, haulage speeds increased from 20 to 30 ft/min in the 1970's to 40 to 50 ft/min in the late 1980's.

Table 7.—Summary assessment of longwall performance during 1985-90 era

	1985	1989	Annual average
Utilization . . . . number of faces . .	118	92	102
Coal production . . . . pct of underground mining . .	18.6	29.0	23
Average face production . . . . tpy . .	604,000	1,131,000	873,000
Average face labor productivity . . . . tpwd . .	64	149	109

Another development that contributed to the increase in longwall production was a significant increase in face width that began around 1980 and accelerated in 1984, as shown in figure 41. Figure 42 shows that there has been a direct correlation to increased longwall production with the increases in face width. The primary benefit derived from the increase in face width is that the shearer spends a proportionally less amount of time at gate-road end operations at reduced mining rates. Longer panels reduced the number of moves and also helped to increase production. Suboleski and King also attributed recent strides in longwall production and work-force productivity to such less quantifiable factors as (1) more mature work force, (2) newer mines that are more effectively planned to accommodate longwall operations, and (3) production incentive management techniques (*24*). Longwall mining reached maturity during the shield era and began to be optimized during the automation era from technological advancements, improved planning, and better management techniques.

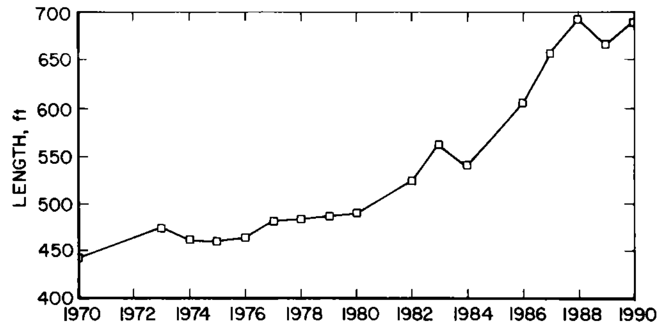


Figure 41.—Historical trend in longwall face widths.

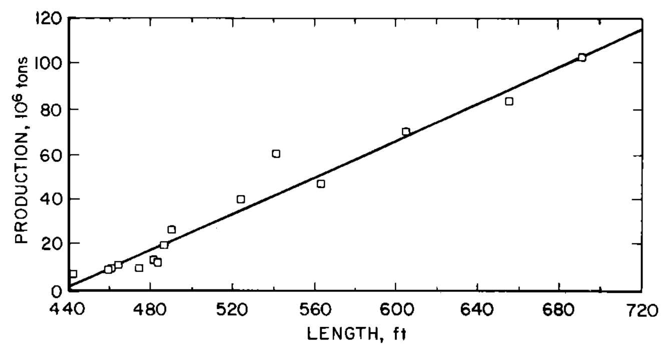


Figure 42.—Correlation between longwall face widths and production.

COMPARATIVE SUMMARY

A comparative summary of longwall performance for each of the six technological eras is shown in figure 43. This figure depicts average performance measures in terms of utilization, face production, percentage of underground coal mined by longwall, and work-force productivity.

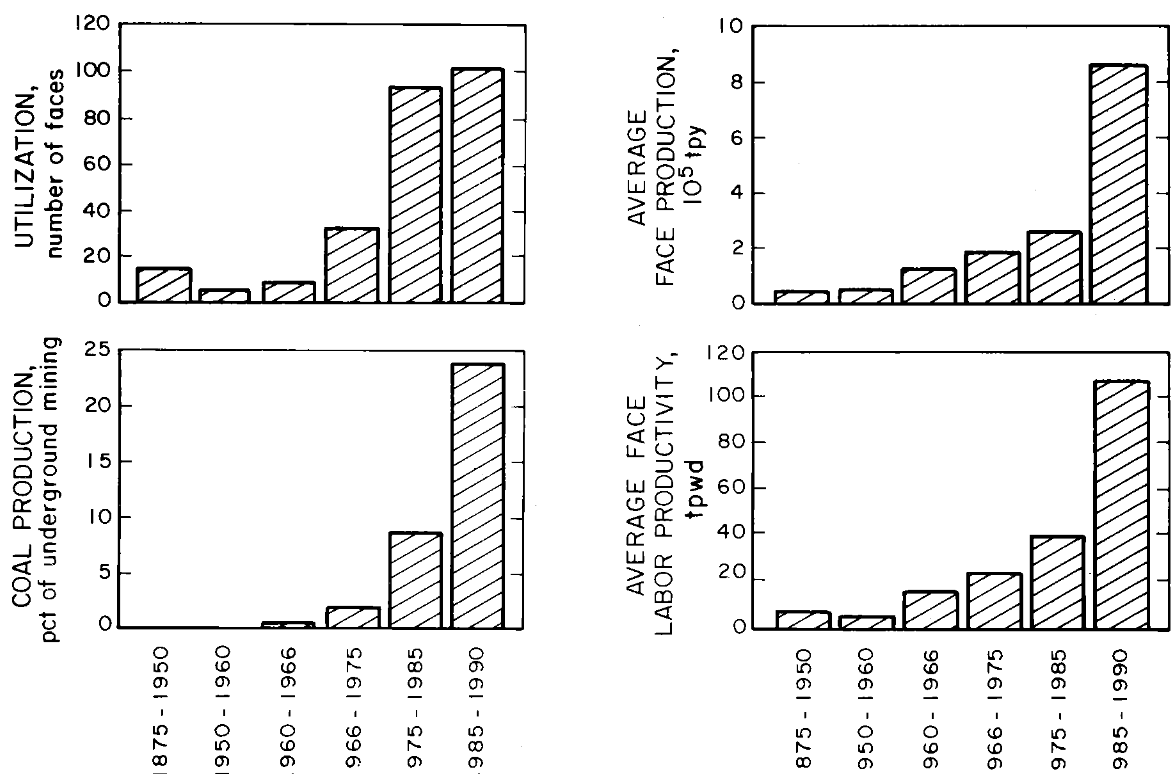


Figure 43.—Summary of longwall performance by era.

These are average measures of performance for the era and do not represent maximum values.

Face production, contribution of longwall mining to underground coal production, and work-force productivity all realized the largest increase during the system automation era (1985-90), while the number of longwall installations increased the most during the shield era (1975-85). An analysis of the trends that were responsible for these gains in longwall performance is described in the next section.

TREND ANALYSIS AND FUTURE PREDICTIONS

Historical trends in longwall development regarding utilization, face production, support capacity, and face widths have been examined and future predictions for the decade of the 1990's have been made by extrapolation of current trends and speculation of anticipated behavior. Projections of continued and new technological developments are also made.

LONGWALL UTILIZATION

A review of longwall operations during the modern era (1950-90) shows three general trends in longwall utilization, as shown in figure 44: (1) slow growth rate from 1950 to 1969, (2) fast growth rate from 1969 to 1983, and (3) a declining utilization from 1983 to 1990. The dramatic increase in growth beginning in 1969 can be attributed to the enactment of the 1969 Coal Mine Health and Safety Act, which provided incentive to pursue the longwall method, and to the technological advancements in equipment that made longwall mining a more viable mining method. The decline in utilization in the mid-1980's was a surprise to most analysts at the time who were predicting continued longwall growth well into the 1990's. To some extent, longwall mining became a victim of its own success. The dramatic increases in production that was realized in the 1980's made it possible to meet supply demands with fewer operations, as evidenced by the continued increase in production during the decline in the number of operating longwall faces.

Contrary to the prediction of 200 or more operating longwall installations by the early 1990's, the recent trend, as shown in figure 45, suggests a gradual increase in utilization to about 110 installations by 1995. Longer term growth will depend largely upon market demand. But there is also an upper limit to the number of longwalls that can be effectively employed. It is unlikely that any one mine can realistically employ more than two operating longwalls. Constraints to longwall utilization per mine are primarily methane liberation (ventilation), transportation of the coal out of the mine, and prep plant capacity. It is unlikely that the growth rate observed from 1969 to 1983 will be seen again in the near future.

FACE PRODUCTION

A historical perspective of average annual face production for the modern era is shown in figure 46. Coal production per face increased gradually from 1950 to 1966, as longwall reached its initial stage of application by several mines. Face production improved significantly for a short time, from 1966 to 1969, largely because of the improved roof control provided by the high-capacity support systems. Production then declined for 3 years as a result of ground-control difficulties experienced in massive sandstone and limestone strata conditions mostly in the Illinois coal basin and from consequences of the 1969 Coal Mine Health and Safety Act. A stagnant period existed from 1971 to 1978. After 1978, production accelerated sharply in nonlinear

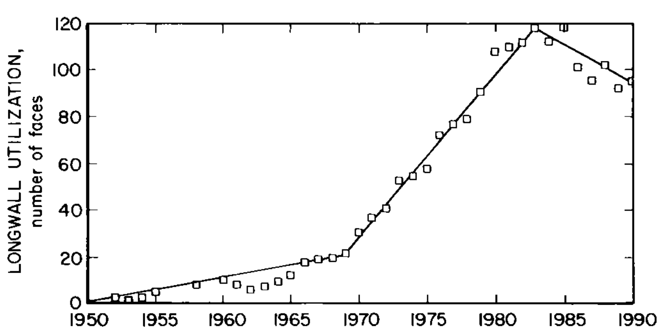


Figure 44.—Trends in modern longwall utilization.

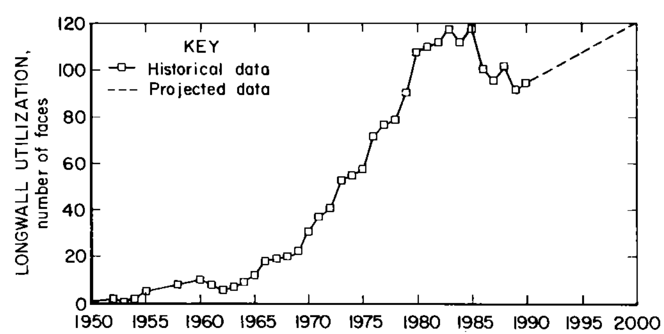


Figure 45.—Projection of longwall utilization to the year 2000.

fashion. While several factors were responsible for this increase in production, it is interesting to note that the acceleration in production in 1978 occurred when shield utilization became established. Figure 47 shows a correlation between shield utilization and total longwall production. In 1978, shield utilization reached about 40 pct, which corresponds to the acceleration in longwall production shown in figure 46.

A continuation of the trend established since 1978 would suggest an average face production of about 2.2 million tons per face by the year 2000, as shown in figure 48. However, the recent annual increases in production of 20 to 30 pct are not likely to continue indefinitely. There is some evidence that this increase in production is inordinate. Performance during the past 2 to 3 years would suggest an increase in average annual production of 1.35 million tons per face by the year 2000. As newer mines are built to accommodate high production longwall operations, higher production measures are likely. Hence, it appears that a more reasonable expectation for annual longwall production by the year 2000 is about 1.75 million tons per face. If coal demand increases beyond this production capability, new longwalls will have to be installed in greater numbers than recent trends indicate since it is unlikely that production above this predicted level can be met solely by improved efficiency through technological improvements.

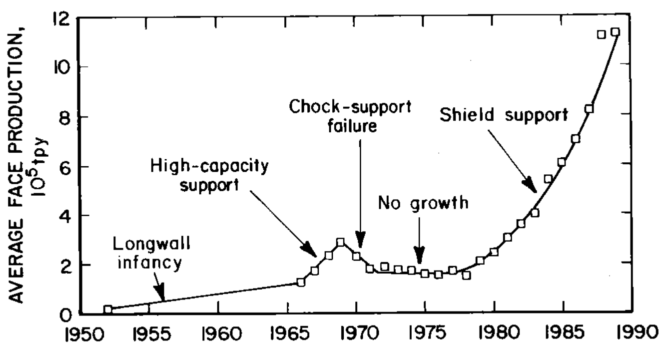


Figure 46.—Historical trends in average annual longwall face production.

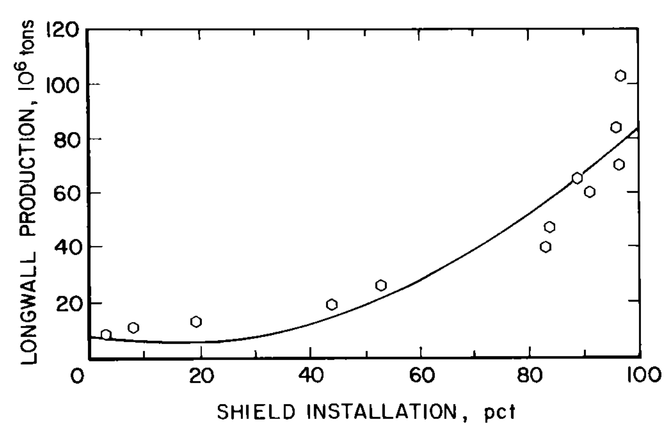


Figure 47.—Correlation between shield utilization and longwall production.

SUPPORT CAPACITY

Support capacity continues to be an issue of interest and debate in longwall mining. A review of support capacity during the modern era, as shown in figure 49, shows four general trends. Support capacity increased gradually from 1950 to 1966. From 1966 to 1972 when high-capacity support systems were introduced, support capacity grew dramatically at a rate of about five times that of the previous trend. Capacity remained essentially constant at 475 tons (force) for the next 8 years as the higher capacity chock supports were being replaced with lower capacity shields. In 1980, support capacity grew at a rate similar to that of the 1950-66 period as shield capacities were increased. At present (1990), there is some evidence that the increase in support capacities is again leveling off, suggesting that more optimal levels of support capacity are being employed.

The average support capacity for longwall installations operating in 1990 was about 560 tons (force) compared

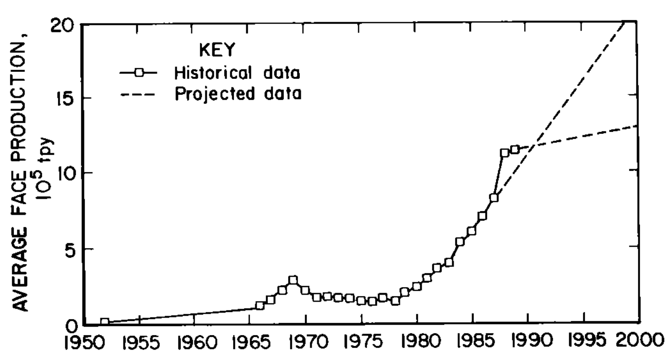


Figure 48.—Projection of average annual face production to the year 2000.

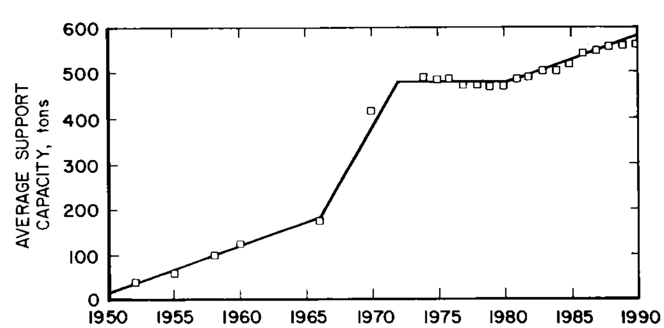


Figure 49.—Historical trends in longwall support capacity.

with 469 tons (force) in 1980. The current trend established since 1980 suggests average support capacity for all longwall installations to be about 635 tons (force) by the year 2000 (see figure 50). Since little research has been done in optimizing support design and capacity, long-term trends beyond the year 2000 are at best speculative. There is, however, some evidence to suggest that lower support capacities can be effective under certain mining conditions.

Maximum support capacities have increased slightly from 700 tons (force) in 1980 to 800 tons (force) in 1990. It is unlikely that maximum support capacity will grow beyond 1,000 tons (force) with current designs because of the physical size required for the hydraulic leg cylinders to accommodate larger capacities. Since yield pressures have historically remained constant at about 6,200 psi, leg diameters will have to increase to provide the higher support capacities.

The increase in support capacity during the decade of the 1980's has been justified under the premise that heavy-duty supports will last longer and provide more effective ground control in difficult seam conditions. However, experience has shown that increased durability has not been realized generally, as failures of high-capacity supports continue to occur. It is speculated that the primary reason for the lack of improved durability with high-capacity supports is that setting forces and shield stiffness have increased in direct proportion to the increases in yield capacity. The increase in setting force and shield stiffness caused the higher capacity supports to be stressed to roughly the same degree as the lower capacity supports; hence, no improvement in durability or life span was realized.

FACE WIDTHS

Table 8 shows the distribution of face widths for longwall faces operating in 1990. The historical trend has been an increase in face width, as shown in figure 41. The average face width in 1990 was 690 ft, although there were 12 installations with face widths greater than 800 ft. The longest reported face width in 1990 was 915 ft on four installations in Ohio and Illinois. Average face widths are speculated to continue to increase throughout the decade of the 1990's since operators are likely to continue to employ wider faces on newly developed panels. A continuation of the recent trend, as shown in figure 51, would suggest an average face width of about 1,000 ft by the year 2000. However, this is probably optimistic in terms of the incorporation of new installations, and a more reasonable expectation for average face widths by the year 200 is 900 ft.

Table 8.—Distribution of face widths for faces operating in 1990

Width, ft	*Number of faces*
300 to 400	1
400 to 500	3
500 to 600	18
600 to 700	37
700 to 800	23
800 to 900	8
900 to 1000	4

It is likely that maximum face widths are approaching an upper limit of about 1,200 ft with current technology. The primary constraint to further increases in face widths remains the power limitations and chain strength of the face conveyors. Capital equipment costs for the face supports and conveyor will eventually become a limitation as well.

NEW TECHNOLOGICAL DEVELOPMENTS

Increased automation will continue through the decade of the 1990's, providing an extension of the current automation era. A wider employment of shearer-initiated electrohydraulic control systems for shield support automation is anticipated. By the year 2000, it is probable that the majority of the longwall faces will incorporate these fully automated systems. Performance monitoring of shield behavior is likely to be expanded to include real-time monitoring and display of shield loading on a personal

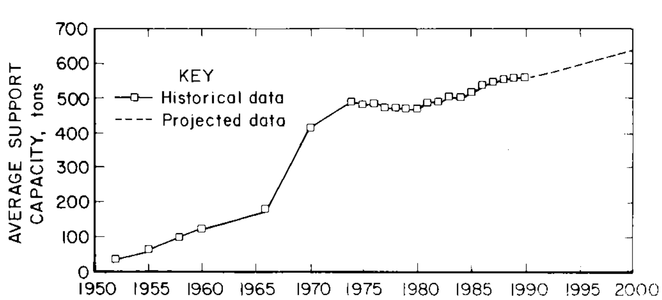


Figure 50.—Projection of longwall support capacity to the year 2000.

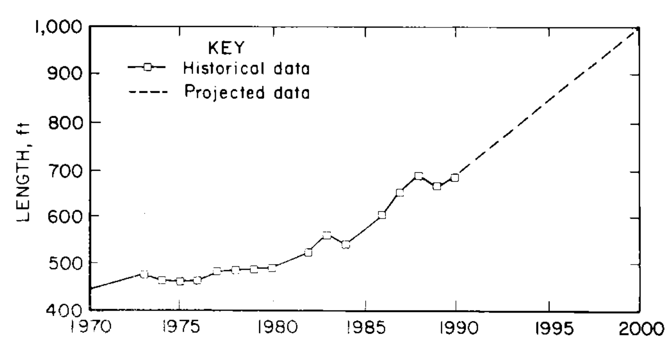


Figure 51.—Projection of average face widths.

computer screen at a remote location. A worthwhile goal will be to develop algorithms that could optimize shield capacity utilization to match geological conditions. This would maximize shield life while avoiding overstressing of the immediate roof and floor strata.

The most pressing automation requirement is for technology that can detect roof and floor boundaries (*25*). This technology would provide automated shearer horizon control and hold the potential for removing the shearer operator from the hazardous environment near the active machine. Research in this area has been ongoing for the past 20 years, and while progress has been slow, several recent developments show promise. The most promising systems include infrared mapping of the heat generated by the cutting picks, differences in machine vibration signatures when cutting coal and noncoal, and natural radiation detection of near-seam roof strata. It is likely that some form of automated, or at least teleoperated, shearer horizon control system will be available by the turn of the century, providing the final step toward a totally automated longwall mining system. A fully automated plow face using an automated shield advance system is currently in operation at U.S. Steel Corp.'s No. 5 Mine in West Virginia. Longwall automation is likely to continue to evolve over the next 20 years as current research is perfected and implemented into system design.

It is also likely that the basic equipment design of the future will be much the same as it is today. The most significant equipment change probably will be an increase in shield canopy width from the current 1.5- to 2.0-m widths. The benefits of the wider canopy design would be a reduction in support cost per unit foot of supported face since a considerable portion of the support cost is the machining and manufacturing of the hydraulic leg cylinders. This may also provide some reduction in the time it takes to move a face from a completed panel to a newly developed panel since fewer supports would be employed.

CONCLUDING REMARKS AND SUMMARY

The contribution of longwall mining toward improving the safety and productivity of underground coal mining is unparalleled in mining history (*26-29*). It has been more than 50 years since mechanized loaders and continuous mining machines made a similar impact on the productivity of the U.S. coal industry. Longwall mining has become and will continue to be a major factor in the ability of the United States to remain a world leader in coal production. If current trends continue, as shown in figure 52, longwall mining could account for as much as 50 pct of the underground coal mined in the United States by the year 2000.

Longwall mining has evolved into the safest, most productive, and most conservative of underground mining systems. Each of the six technological eras chronicled in the history of longwall mining made unique contributions to its efficacy. The development of the shield support probably had the most impact. Table 9 compares longwall utilization, annual face production, and total production for the pre-shield and post-shield eras. Maximum face production increased by 292 pct from 288,363 tpy to 1.13 million tpy, while utilization increased by 470 pct from an average of 17 faces prior to the shield era to 97 faces during the shield era. Technological improvements will continue to provide gains in face production, but these advancements probably will not be as great as those experienced during the decade of the 1980's. The next major accomplishment likely will be a fully automated longwall system that can be operated at a remote location beyond the immediate face area. Prototypes of such a system should be in place by the turn of the century and again mark a major and possibly the final milestone in the long history of longwall development.

Table 9.—Comparison of longwall performance with and without longwall shield supports

	Pre-shield period			Post-shield period		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Utilization . . . . number of faces . .	17	1	55	97	58	118
Coal production . . . . pct of underground mining . .	1.7	0.1	3.4	13.4	3.1	29
Face production . . . . 10^3 tpy . .	178	20	288	471	152	1,131

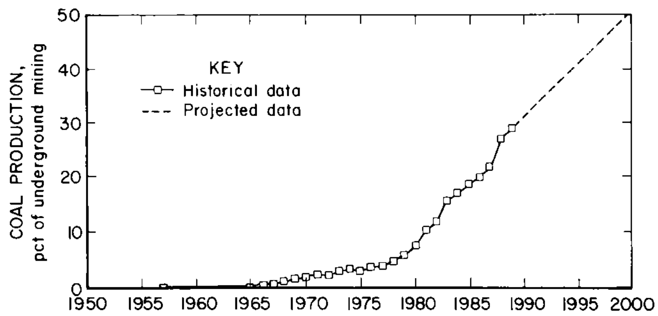


Figure 52.—Projection of longwall coal production to the year 2000.

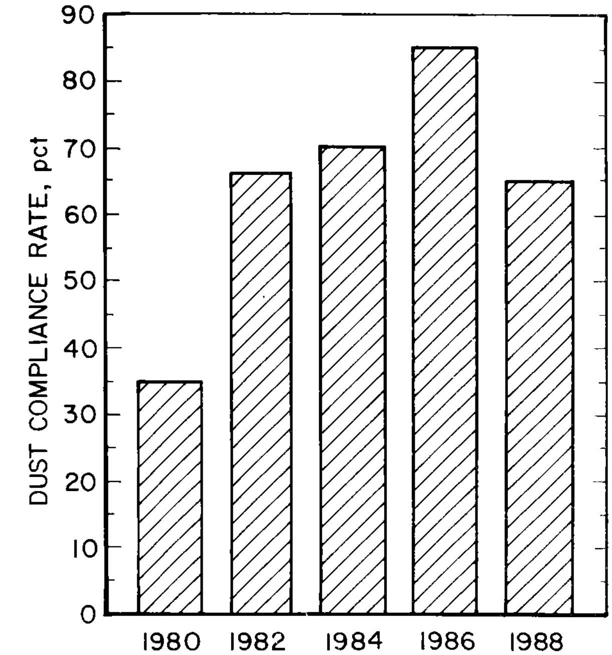


Figure 53.—Dust compliance rates for U.S. longwall industry.

While the future for longwall mining looks promising, there are some concerns that pose threats to its future utilization and development (*26*). The biggest concern is that of surface subsidence. While U.S. coalfields are not typically located in heavily populated regions, subsidence of the surface is inherent to the longwall method of complete extraction. Although the subsidence is predictable, it is, at present, largely uncontrollable. Methods to control subsidence through backfilling behind the supports remain cost prohibitive. Legislation to control mining subsidence could pose a severe threat to the longwall method of mining coal in the United States.

Respirable dust is likely to remain the major health concern during the next decade. As figure 53 indicates, longwall compliance rates are again declining as production outpaces current dust-control technology. Only about 63 pct of the operating longwalls currently meet the regulated dust standards on a routine basis.

The Bureau is continuing a research program to improve the health and safety and productivity of longwall mining. This research includes (1) continuing efforts to provide automated shearer horizon control, (2) efforts to optimize shield design and utilization, (3) dust-control research to bring high-productive longwalls into compliance, (4) pillar and gate-road design to provide effective ground control while maximizing resource recovery, (5) improved subsidence prediction and abatement technologies, and (6) real-time hazard warning systems to alert the operator of ground control and environmental safety hazards. Through these research efforts, it is believed that longwall mining will continue to be the safest and most productive mining system well into the next century.

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