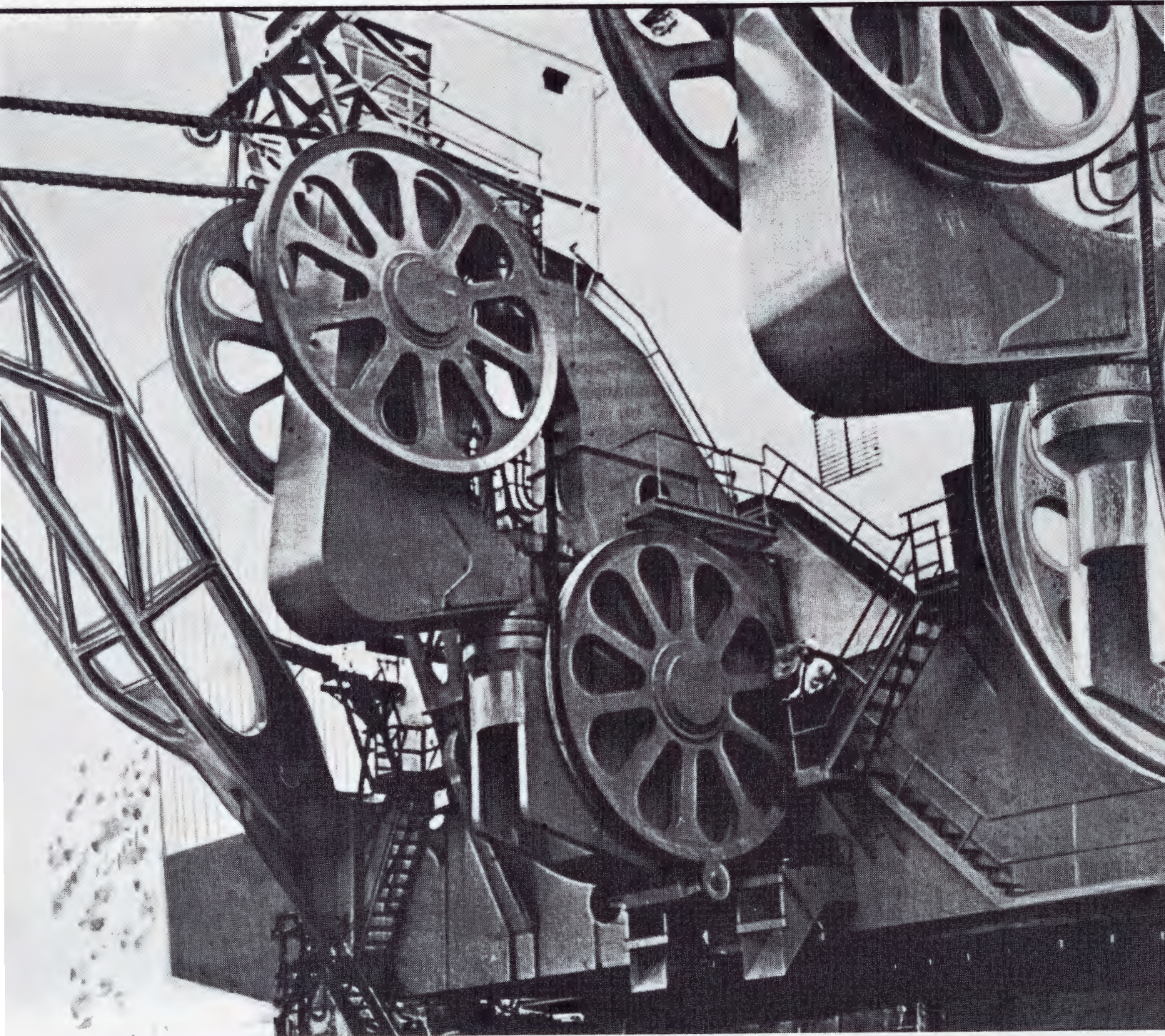


THE DEVELOPMENT OF SURFACE COAL MINING IN INDIANA

Special Report 35



State of Indiana
Department of Natural Resources
GEOLOGICAL SURVEY

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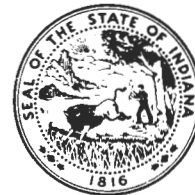
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COVER: The era of colossal midwestern excavating machinery culminated in the construction of Big Muskie, a 220-cubic-yard dragline used in Ohio. (See the discussion on p. 25.) The photograph was published in 1969 (Coal Age, v. 74, no. 12, p. 51) and has been retouched and artistically enhanced by Wilbur E. Stalions.

The Development of Surface Coal Mining in Indiana

By DENVER HARPER

DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY SPECIAL REPORT 35



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The Development of Surface Coal Mining in Indiana

By DENVER HARPER

Foreword

Reserves of surface-minable coal in Indiana are a great store of wealth whose exploitation since 1915 has transformed the physical and economic landscape of Indiana's southwestern counties. In studying the coal resources of Indiana, the Indiana Geological Survey has compiled much engineering, economic, historical, and geologic information on the surface-mining industry. This report is a chronicle of surface mining in Indiana that is based primarily on two sources: publications of the U.S. Bureau of Mines and *Coal Age* magazine. It is a compilation of more than 110 articles—most dealing with mining practices at specific surface mines in Indiana—spanning 63 years. In this report emphasis is placed on technologic advances that opened new reserves and permitted growth of coal production in the state. Recent events that have affected Indiana's coal industry, such as the development of unit trains, changes in the structure of the coal industry, and the opening of midwestern markets to western coal, are briefly discussed.

Introduction

Men have quarried stone and mined ores from open pits for millenia, but surface mining of coal on a large scale is a recent development. Much of the history of large-scale surface mining was made since World War I in the midwestern states of Ohio, Illinois, and Indiana, where geography makes available large markets for coal, and where geology and topography make possible the use of widespread, area-type surface mining.

Thickness of the coal seam is an important geologic factor affecting underground mining. The dimensions of underground workings bear a relation to human stature, and

problems arise when the seam is too thin or too thick to accommodate workers and the tasks they must perform. But underground mining has the advantage that under ideal conditions only the coal itself is removed, and the costly removal of valueless rock strata above and below the coal is minimized. For most of the history of coal mining in most areas, underground mining prevailed. In Indiana underground mining dominated coal production until the 1930's, but it has accounted for less than 3 percent of the state's output in recent years.

In surface mining miners remove the rock overlying the coal (called overburden) first, and then they remove the coal in a separate operation. When this method is used, the thickness of the coal seam is less important than it is in underground mining. Rather, it is the ratio of the overburden thickness to the seam thickness that is critical. Very thin seams may be removed if the overburden is thin, and no special problems are created by mining thick coal. Because coal must lie near the surface to be extracted by this method, reserves of surface-minable coal in most major coal-producing areas are small when compared with reserves of underground coal. At present the official estimate of surface-minable coal in Indiana is about 1.8 billion tons, or about 11 percent of total reserves.

Successful area-type surface mining requires nearly level terrain and nearly flat lying coal seams so that the thickness of overburden is almost constant across wide areas. In the important surface-mining districts of Indiana (fig. 1) the land has relatively little relief, and some coal seams of the state are extensive and dip westward at only about 30 feet per mile. Large surface mines are possible under such conditions. For each of the past

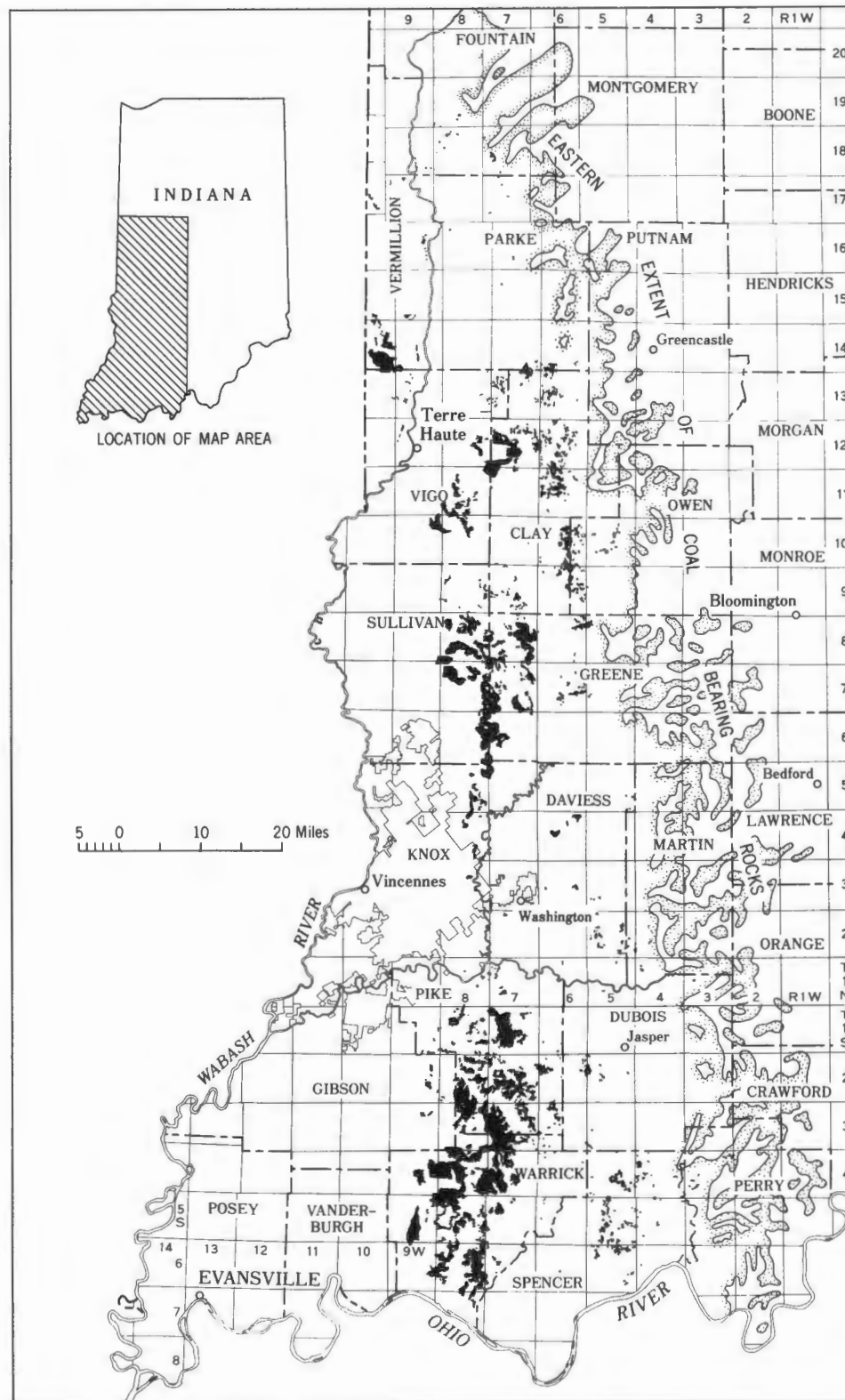


Figure 1. Map showing areas surface mined for coal in Indiana.

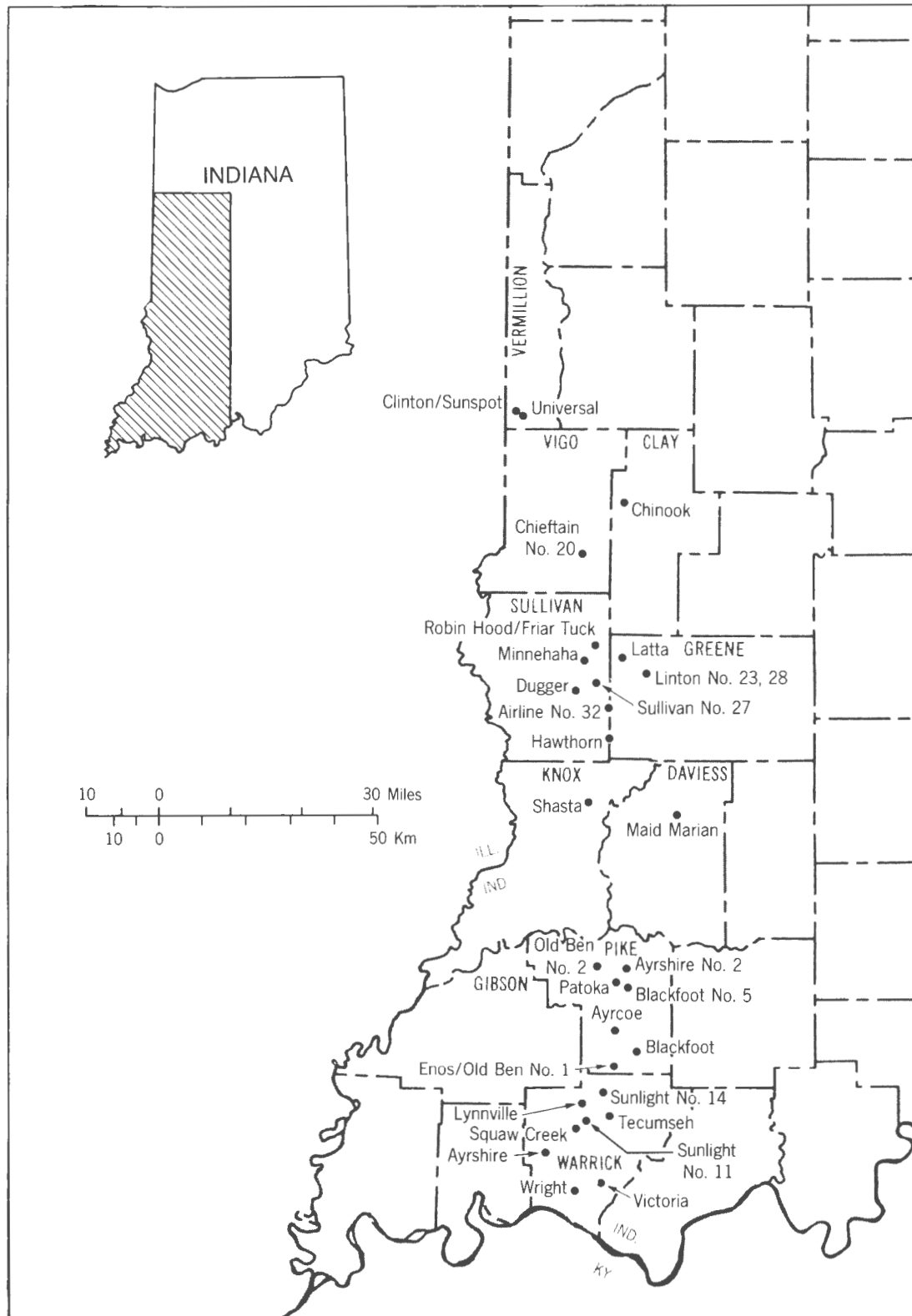


Figure 2. Map showing locations of selected major surface mines (active and inactive) in Indiana.



Figure 3. Horse-drawn slip scoop, one of several animal-powered forerunners of modern surface-mining machinery. From Wier, 1959, p. 11.

40 years, 10 to 19 large active mines have produced more than two-thirds of the state's annual surface output. Taken together, the mines shown in figure 2 are the source of about 80 percent of the state's total cumulative surface output. Large numbers of small mines have contributed the remaining 20 percent.

Not only is the thickness of overburden important to surface mining but so is its character. Unconsolidated overburden, such as glacial or stream deposits, is easy to dig, and much early mining was done where such overburden directly overlies the coal. But where it is thick, such overburden may create problems of stability of steep slopes within the mine pit. In Indiana large-scale surface mining has been conducted mostly where the unconsolidated overburden is less than 50 feet thick. The character of the consolidated (rock) overburden also influences the profitability of surface mining. Thick, strong strata may interfere with preparatory blasting of the overburden and make removal of the blasted material more difficult. Local geologic struc-

tures, such as domes, troughs, and faults, may affect maneuverability of digging machines and haulage vehicles and may affect drainage of the pits. Coal seams of Indiana commonly show local doming and troughing, and minor faulting and other seam discontinuities, such as rock partings, commonly have an adverse effect on local mining.

Throughout history operators of large-scale surface mines in the midwestern United States have relied on shovels and draglines to remove overburden. The amount and the thickness of overburden that can be removed depend on the size of available shovels and draglines. Because reserves of surface-minable coal that can be mined by any given size of machinery are soon exhausted, the growth of coal production by surface methods has required constant technologic advances that have made available larger machines able to exploit new reserves under greater thicknesses of overburden. Before 1969 the digging capacity of shovels and draglines almost doubled every 10 years. This growth made possible a great increase in the thickness of overburden that

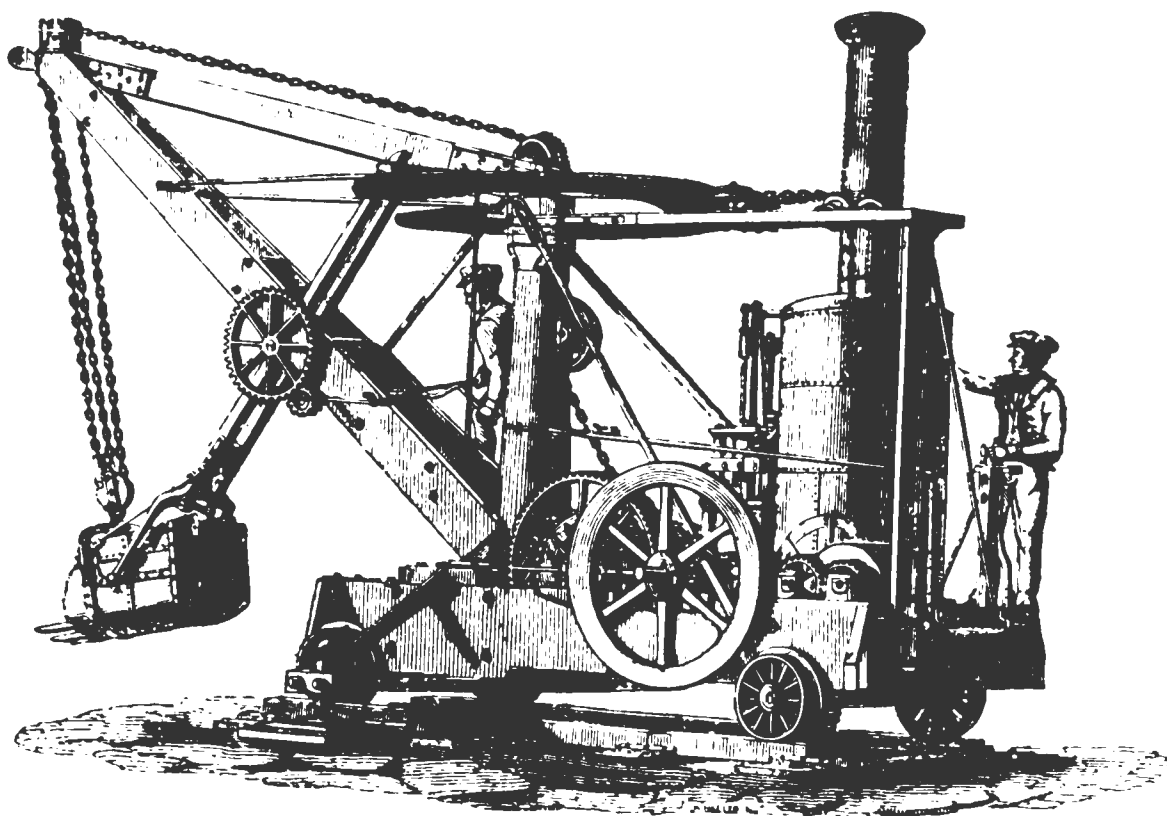


Figure 4. First steam-powered excavating shovel, invented by W. S. Otis about 1840 and used initially for railroad construction work. From Coal Age, 1967a, p. 110.

could be handled. The increase in capacity of shovels and draglines required many engineering refinements in their construction and the development of many supporting technical and managerial functions.

Origin of Surface Mining

During the late 19th century many experiments for developing surface mining of coal were conducted in Illinois, Indiana, Missouri, and Kansas. The earliest stripping in the midwestern United States was in 1866, when a pit was opened on Grape Creek near Danville, Ill., only a few miles west of Vermillion County, Ind. Operators opened other pits during the late 1860's and the mid-1870's in Missouri, Illinois, and Kansas. Animal-drawn plows and scrapers were used for removing overburden at the first mines (fig. 3). Workers removed overburden during

the summer months, then handloaded the coal and transported it to market by wagon during the following winter. The coal was prepared for removal by blasting. Workers drilled holes into the coal by hand, then enlarged the bottoms of the holes (known as springing) by discharging small quantities of black powder in the bottoms of the holes. Larger charges of black powder were then used to break the coal so that it could be easily loaded.

Using a machine to remove overburden was first attempted in 1876 near Pittsburg, Kans. Two men who had prior experience with steam shovels in railroad construction obtained an Otis steam shovel, which had been invented about 1840 (fig. 4). By using this so-called "railroad-type" shovel, which was light in weight and incapable of revolving, the mine operated for several years, and overburden as much as 12 feet thick was removed.



Figure 5. Dredge purchased by two dredgers from Lafayette, Ind., in 1885 and erected on a wooden frame in the Mission coalfield near Danville, Ill. Efforts to use such dryland dredges for coal stripping lasted only about 5 years. From Holmes, 1924a, p. 798.

Between 1885 and 1900 operators introduced several different types of machines in the Mission coalfield near Danville, Ill. These included a wooden dredge mounted on wheels (fig. 5) and several self-propelled draglines. During this time bucket capacities of such machines increased from three-fourths of a cubic yard to 2 cubic yards. Overburden averaged 10 to 15 feet in thickness. At one operation coal as well as overburden was removed by machine, and therefore handloading was eliminated (fig. 6). During 1903 a dragline capable of revolving 360° was introduced in the Mission coalfield.

Despite the efforts of pioneer surface miners, dredges and draglines were generally unsuitable for removing overburden economically, and after the mid-1900's stripping efforts centered for several decades on mechanical shovels. Revolving shovels capable of digging and dumping in any direction were available by 1910.

Excavation of the Panama Canal relied heavily on steam shovels. That great task began in 1904 and was not completed until 1915. By 1908 more than a hundred shovels, some with capacities as large as 5 cubic yards, were in use in Panama. Not only were some of the equipment and techniques employed in that project later used in some stripping operations in the United States but the removal of 240 million cubic yards of earth and rock probably encouraged some entrepreneurs in their efforts to develop commercially viable coal-stripping operations.

At the early surface mines much human labor was needed, the power of many dredges and draglines was inadequate to remove much overburden, maintenance costs were high, much of the coal produced was full of ash, and operations could be conducted only during part of the year when weather was favorable (and demand was lowest). The production of surface-mined coal never



Figure 6. Handloading coal into mine cars at a surface mine near Danville, Ill. From Andros, 1915, p. 110.

reached significant levels until 1915, when the U.S. Geological Survey first reported tonnage produced by surface mines.

Early Surface Mining in Indiana

Before 1911 records of surface coal mines in Indiana are fragmentary. A single 7,400-pound block of coal was removed from a surface mine in Vigo County and exhibited at the Chicago World's Fair in 1893. A steam shovel was in use at the operation. But these and other surface mines of the 19th century apparently did not give rise to any long-lived mining companies in Indiana.

During 1911 W. G. Hartshorn, Grant Holmes, and R. H. Sherwood placed a steam-powered, rail-mounted shovel into service at the Mission coalfield. The shovel had a capacity of $3\frac{1}{2}$ cubic yards, could revolve a full 360° on its base, and was

equipped with hydraulic equalizing jacks. Hand shovelers loaded the coal onto small mule-drawn mine cars. Hartshorn had previously operated a small shaft mine near Danville, Ill., and Sherwood, who would later become one of the most prominent figures in the surface-mining industry of Illinois and Indiana, had been a railroad contractor in New York City. Sherwood later reminisced (Coal Age, 1954, p. 61) about the reluctance of the Marion Steam Shovel Co. to design a shovel capable of removing 30 feet of shale and gravel to exploit a 7-foot-thick seam of coal:

*** the Marion Steam Shovel Co., of Marion, Ohio, who had reluctantly undertaken to design and build this machine, had stipulated to Mr. Hartshorn that a shovel of the kind that he wanted possibly could not be made strong enough to stay together, and that in no event would they undertake to build it with any



Figure 7. Flooded strip pit, a hazard of surface mining. This shovel belonging to Hartshorn, Holmes, and Sherwood was almost submerged by floodwaters in 1913. From *Coal Age*, 1954, p. 61.

guarantees as to performance.*** Inasmuch as it was going to be very difficult for them to quote a price on such a "massive" heretofore unknown piece of equipment, they proposed that the price to be paid should be based on a price per pound f.o.b. factory.

Shortly after Hartshorn acquired the shovel (1913), the Ohio Valley and the surrounding areas had the worst flood in their history, and the shovel was submerged by floodwaters (fig. 7). The miners constructed a levee along a neighboring creek, commenced pumping, and drained the pit in 5 months. The mine was later profitable, and by 1918 Hartshorn and Sherwood owned stock interest in five mines near Danville, Ill. During that year they sold their entire holdings "*** to a man representing eastern capital" and paid their stockholders (mostly citizens of Danville) a liquidating dividend of 100 percent of their original investment. The mines that they sold

later served as the foundation of the United Electric Coal Co. Sherwood went on to found and direct other important midwestern mining companies, including the Central Indiana Coal Co., part of which was later acquired by the Peabody Coal Co., and the Sherwood-Templeton Coal Co., which was later acquired by the Templeton Coal Co. Also in 1911 the Rowland Block Coal & Clay Co., predecessor of the Maumee Collieries Co. (later acquired by the Peabody Coal Co.), began operations near Patricksburg in Owen County. Its founder, George Rowland, was a civil engineer who entered the mining business in 1908.

During 1912 the Bucyrus Co. placed a model comparable to the Marion stripping shovel on the market. Full-revolving coal-loading shovels soon followed; one of the first was used by the T. J. Forschner Coal Co. of



Figure 8. Preparing coal for loading at the Enos Mine in the 1920's. To combat the reputation of surface-mined coal for poor quality, operators during the 1920's employed teams of laborers equipped with scrapers, shovels, and wire brooms to remove dirt from the top of the coal seam before loading. From *Coal Age*, 1929b, p. 335.

Linton. After 1915 steam-powered loading shovels, which had first been used at some operations about 1900, soon eliminated handloaders at all major surface mines.

By 1915 steam-powered stripping shovels with capacities of 7 cubic yards were proving commercially successful in southeastern Kansas, southwestern Missouri, Illinois, and Indiana. The first electric-powered (AC) stripping shovel appeared in Ohio in the same year.

The labor cost of surface mining was only about half that of underground mining, and as much as 25 feet of overburden could be removed to recover 3 or 4 feet of coal. Unfortunately, surface-mining methods introduced many impurities into the coal, and the "dirty" product sold for 20 cents per ton less

than coal from underground mines. (Indiana bituminous coal generally sold for \$1.20 per ton in the decade before World War I and for \$1.50 to \$2.50 per ton in the decade after the war.) After World War I operators attacked this problem by arming workers with shovels, wire brooms, and water or compressed-air hoses and directing them to clean carefully all loose soil and rock from the coal after the overburden had been excavated and before the coal was loaded out. Sometimes team-drawn scrapers were also used for this task (fig. 8). During the late 1920's at the Enos Mine in Pike County seven men worked ahead of the loading shovels to reduce contamination of the coal. In 1929 at the Ayrshire pits in Pike County caterpillar tractors with bulldozer scraping attachments were used for

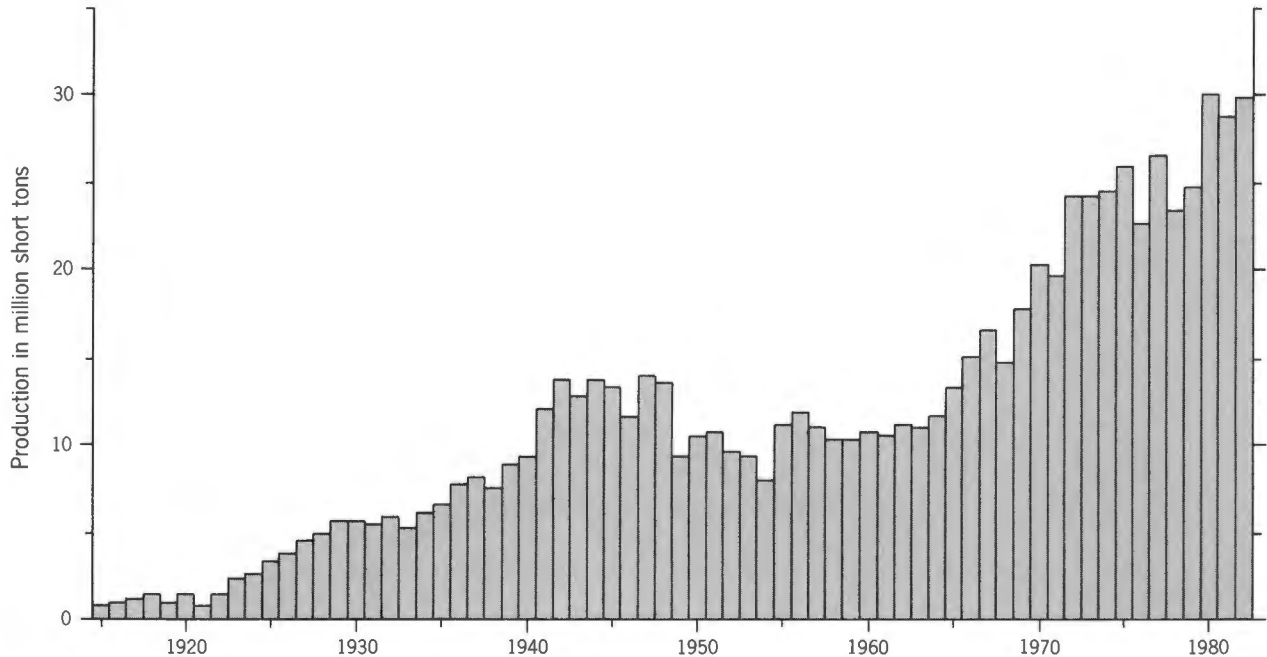


Figure 9. Graph showing annual production of surface-mined coal in Indiana, 1915-82. Data for 1966 and 1974 are estimated.

cleaning the top of the coal seam before loading. Beginning in the late 1920's mechanical preparation following loading also lessened the problem of dirty coal.

Much early stripping was done near the weathered zone of outcrop, so that in some places no amount of preparation could improve the quality of the coal, easily identified by orange stains on the surface of the fragments. Because of this poor reputation, almost all Indiana's strip-mined coal was consumed within the state, where the added cost of transportation was small.

Surface Mining in Indiana Between the Wars

BOOM CONDITIONS IN SURFACE MINING AFTER WORLD WAR I

Underground coal mining in Indiana slumped severely after World War I, but more promising events happened in the surface-mining industry. Until 1921 coal produced by surface mining in Indiana fluctuated around the prewar level of 1 million tons per year (fig. 9). The maximum dipper capacity on stripping shovels increased to 8 cubic yards,

draglines were reintroduced in 1919, and the thickness of overburden that could be removed increased from 25 feet to 50 feet by 1923. Despite the reputation of surface-mined coal for poor quality, a boom in surface reserves developed, and in 1919 the Indiana mine inspector (Littlejohn, 1920, p. 328) reported that " * * * land formerly taxed at \$20 per acre became \$200 per acre when strippable coal was discovered to lie underneath it."

In contrast with Vermillion, Vigo, Clay, Sullivan, and Greene Counties in Indiana, little underground mining was ever done in Warrick and Pike Counties. In Warrick and Pike Counties coal was generally believed to be thin, transportation costs to major markets in the north were greater, and competition from nonunion underground operations in nearby western Kentucky was intense. These disadvantages were less important to surface-mine operators with their lower labor costs than to underground operators.

During early 1920 leasing and purchasing activity in Indiana was greatest in surface-minable reserves of northern Pike County and southern Daviess and Knox Counties. The

Pike County Coal Co. bought or leased more than 10,000 acres for \$75 to \$150 per acre; an additional 15,000 acres were bought or leased by the American Coal Co., the Indian Creek Coal Co., and the Globe Coal Co. and by several smaller companies. The Globe Coal Co. was a predecessor of the Patoka Coal Co., the Ayrshire Collieries Corp., and the AMAX Coal Co. The attention of the coal producers was directed to this area, which had seen little underground mining, by the results of earlier exploratory oil drilling.

By mid-1920 activity spread to southern Pike County, where about six companies leased more than 10,000 acres in a matter of a few weeks in June. New rail lines crisscrossed the territory, and companies engaged in furious trading of coal lands. The Big Four Railroad, which established a coal terminal at Petersburg in 1923, served the new mines of Pike and Gibson Counties. Coal from the mines was gathered at the terminal, where trains were made up for shipment northward.

Throughout the mid-1920's the Big Four Railroad and the E & I Division of the New York Central line laid extensive new railroad trackage in the coalfields of southern Indiana to exploit newly acquired lands and to handle the increasing tonnages produced by surface mines.

Early in 1921 the Pike County Coal Co., which had been active in acquiring strippable coal property in Indiana, sold all its holdings in Pike County to the Howe-Coulter Coal Co. of Chicago. Trading of some coal properties degenerated into legal battles when the increasingly complicated web of deeds, options, sales, and deals became fouled. By 1923 it was reported in *Coal Age* (p. 690): "Practically all of the coal land between Petersburg and Evansville has been taken over by various companies, all of which will be opened in the near future."

Interest was also directed to properties farther north, in Sullivan and Greene Counties, where deep mining had long been important. R. H. Sherwood opened his first independent strip mine, the Robin Hood Mine, during 1917 near Dugger. In later years a series of mines named after characters from the legend of Robin Hood dotted the landscape of Indiana and Illinois: Robin

Hood, Allendale, Friar Tuck, Nottingham, Little John, Maid Marian, and Will Scarlet. Sherwood selected these names for the benefit of his son, nicknamed Robin.

In a strongly unionized state with abundant strippable reserves, the operators of Indiana had powerful incentives to turn to surface mining. Steam-shovel operators earned the highest wages in the coal industry, but relatively small labor forces resulted in low total labor costs. Labor relations and wage negotiations were also simplified. In 1919 a group of surface-mine operators formed the Indiana Coal Association, and the secretary of the association was empowered to negotiate separate and distinct contracts with the United Mine Workers. By 1923, when it became clear that no wage reductions in underground mining were forthcoming following large wage advances achieved during World War I, the upward trend in surface-mined production became evident.

INDIANA AS A FOREMOST PRODUCER OF SURFACE-MINED COAL

With productivity about 2.5 times as great as that of underground mining, surface mining of coal was carried on in 20 states by 1929, but activity was greatest in the midwestern and western states of Indiana, Illinois, Missouri, Oklahoma, Montana, and North Dakota. The use of large stripping shovels was essentially confined to the Midwest and the Southwest. Ohio was the foremost producer of surface-mined coal from 1918 to 1924 but was surpassed in 1925 by Illinois. The production of surface-mined coal in Indiana increased from 2.5 million tons in 1924 to 5.6 million tons in 1929 (fig. 9). During 1926 and 1927 Indiana was the leading producer of strip-mined coal in the nation, and it continued to produce amounts equal to those of neighboring Illinois, which had much larger strippable reserves, during several succeeding decades. Underground production in Indiana plummeted as surface production increased, so the relative contribution of surface mining to the state's total output rapidly increased. By 1929 surface mining accounted for 30 percent of Indiana's production.

In contrast, little interest in stripping was expressed in the important coal-producing

state of West Virginia, and by the late 1920's surface production in Pennsylvania was already declining. But during the late 1930's surface mining increased in Ohio, Pennsylvania, and West Virginia among small-scale strippers. By 1933 surface mines produced 5.5 percent of the nation's coal output. Surface production grew to 10.7 percent of the nation's output by 1941. Among major coal-producing states, Indiana became most dependent on surface-mining methods.

During mid-1924, when underground mines in Indiana were generally operating only 2 or 3 days a week and an exodus of miners from Indiana was beginning, the surface mines of Pike County were in production almost every working day and were successfully competing for markets with the nonunion underground mines of Kentucky and West Virginia. Another spurt of leasing, now principally involving the Patoka Coal Co. (a predecessor of the Ayrshire Collieries Corp. and the AMAX Coal Co.) and the Pike County Collieries Co., occurred in late 1926 and 1927.

Although Pike County was the undisputed center of strip mining in Indiana, by 1926 greater interest was being shown in properties in Warrick and Gibson Counties. By October the Sunlight Coal Co. (later acquired by the Peabody Coal Co.) took over 310 acres of farmland near Boonville at a cost of almost \$40,000, and independent coal men were touring the counties obtaining options. Consequently, the value of Warrick County properties soared. One particular tract bought at auction in June 1926 brought \$64,500; when it was resold 9 months later, it brought \$83,700. Activity declined somewhat by the end of the decade, when the U.S. Bureau of Mines estimated that the cost of strippable land in Illinois and Indiana was generally \$300 per acre for both surface and coal rights. Where land was not suitable for farming, which was common in southern Illinois and southern Indiana, strippable land might be acquired for \$150 per acre.

To the north, the United Electric Coal Co., the largest surface-mining company in the Midwest at that time, began developing stripping operations in Sullivan and Vigo Counties in 1925 and in Vermillion County in

1926. Individual operations tended to be smaller than those in the southern counties. The initial development in Sullivan County was 3½ miles east of Farmersburg, where United Electric had two territories of about 2,000 acres each. Also in 1926 the Mid-Continent Coal Co. (a predecessor of the Electric Shovel Coal Corp., the Ayrshire Collieries Corp., and the AMAX Coal Co.) purchased almost 640 acres near Brazil in Clay County, began laying railroad track, and announced plans for opening several strip mines in that territory. This initial stripping development by Mid-Continent did not proceed smoothly; the equipment, including a large steam shovel, had just been installed when the entire operation was abandoned and the equipment was reloaded and moved to another site near Clinton, where the coal was described as being more accessible. Much later, the Peabody Coal Co. developed its Universal Mine in this same area in southern Vermillion County near Clinton. Interest in the Brazil area remained, however, and in 1927 the Sherwood Coal Co. announced plans to begin mining 410 acres near Carbon in Clay County. Mining of the block coals in some places carried an incentive not present with any other seam. The Big Bend Coal Co. at an operation near Center Point mined and sold not only the coal but also the underclay and part of the roof strata. The roof shale was used in nearby clay factories and cement plants, and the underclay or fireclay was used in producing a fine grade of terra cotta for crockery.

Later, as operators depleted reserves of the most desirable and accessible coal, new mining techniques gained wider acceptance. All early operations mined only the thickest coal seam on a property. In 1938 operators of the Linton Supreme No. 23 Mine in Greene County mined coal from two seams on the same property, but even then such a procedure was rare in Indiana.

TECHNOLOGIC ADVANCES DURING THE 1920's AND 1930's

INCREASE IN DIPPER CAPACITIES

In 1927 maximum dipper capacities of stripping shovels increased from 8 to 12 cubic yards, and maximum overburden thickness that could be handled increased from 50 to

60 feet. In 1928 12-yard shovels were in operation in Indiana and 15-yard shovels were on order. The maximum capacity of stripping shovels reached 35 cubic yards by 1935, when the Tecumseh Coal Corp. placed the first such shovel in service at Boonville. By 1938 average overburden thickness at major operations with large stripping shovels was about 30 feet, and the thickness of coal being mined ranged from 3 to 6 feet. Some companies, however, ventured into overburden as thick as 50, 60, or even 70 feet for short distances.

In the early days of surface mining, steel fabrication of stripping shovels was difficult because it was done entirely with rivets. Hand-operated ratchets were used to drill holes for the rivets, which were then cut off with cold chisels and sledges and backed out by use of punches and sledge hammers. It is therefore not surprising that acetylene welding torches rapidly gained favor, despite many problems with their use, in the construction and repair of large stripping shovels. During 1925 the Maumee Collieries Co. began using electric welding for rebuilding steam shovels and increasing dipper capacities. By the early 1930's welded dippers began replacing cast dippers on new units, and additional increases in dipper capacity resulted. By 1933 a 20-yard unit (equipped with a counterbalance on the hoist) was in operation.

Large dippers had more maintenance problems, and adherence to strict operating rules was required to reduce the amount of punishment they received. Experiments with resistant materials, such as manganese lips used by the Sunlight Coal Co. in 1936, often ended unsatisfactorily. Steel teeth made from a chrome-nickel-molybdenum alloy were also tried. Tungsten-carbide dipper teeth, with their great resistance to abrasion and their relatively low cost, soon became standard equipment.

As always, the cost of surface-mining equipment was considerable. In 1929 the U.S. Bureau of Mines estimated that the cost of a 6- or 8-yard stripping shovel was \$99,000 to \$150,000. By the mid-1930's new shovels cost as much as \$250,000.

ELECTRIC POWER

During the 1920's electric shovels began to

displace steam shovels (fig. 10). Each year electric power became more widely available at lower rates. Crawler-mounted shovels were in use in Indiana by 1920, and in 1926 the United Electric Coal Co. installed an electrically powered crawler-mounted dragline at its mine near Farmersburg.

Although some coal operators hesitated to replace their coal-burning steam shovels with shovels whose power had to be purchased, electrically powered shovels had undeniable operating advantages. Most steam shovels consumed 400 to 600 gallons of water per hour. The water that accumulated in strip pits was not fit for use in steam boilers, so that water had to be piped from streams or wells, in many places over considerable distances, and stored in supply tanks. Also, such water-supply lines had to be buried to prevent freezing during the winter. Although water from wells and streams was superior to strip-pit water, boiler scale still formed and required frequent washing out.

Electric shovels were also more durable than steam shovels. About every 2 years it was necessary to tear down the steam shovels and rebuild them from the ground up. By 1929 electric shovels could provide 5 years of continuous service before requiring such extensive overhaul.

Nationally, steam shovels remained dominant in numbers until 1935, when they were surpassed by gasoline- and Diesel-powered shovels. The number of steam shovels in operation peaked in 1939 and began to decrease the following year. The use of electric shovels increased slowly but steadily, and by 1940 the number in operation exceeded the number of active steam shovels. Indiana operators were quick to adopt electricity, so that by 1938 almost all large strip producers in Indiana used electric shovels exclusively. Diesel and oil-burning units were preferred by producers who worked in areas too small to justify the installation of electric-power lines.

The use of AC power in preparation and other surface plants was almost universal, but there was controversy about the relative merits of AC and DC electric controls for shovels where high starting torques were required. Two forms of electrical drives were



Figure 10. Smoke billowing from steam-powered stripping and coal-loading shovels at a mine near Staunton in 1920. Through the 1920's and 1930's electrically powered shovels replaced steam shovels at many operations. At this mine, operated by the Rowland-Palmer Consolidated Collieries Co., the large stripping shovel is rail mounted, and the smaller coal-loading shovel is crawler mounted. From Baker, 1920a, p. 1145.

available: rheostatic control with alternating current and the direct-current Ward-Leonard system. Ward-Leonard systems were first used on large stripping shovels in 1922 and on smaller loading shovels in 1927. Alternating current was more economical and practical to generate, but direct current had other important advantages, notably higher power factors, lower electrical demand charges, better motor characteristics, and less motor trouble. Consequently, most shovels received alternating current and converted it to direct current with on-board motor-generator sets.

By 1940 power was commonly supplied to surface operations at 4,160 volts AC. Pole lines rather than field cables were still in use at many operations to supply power to electric shovels, even though ground-cable transmission to shovels had been introduced by the Northern Illinois Coal Corp. 11 years earlier and was in use in Indiana at pits of the Maumee Collieries Co.

SIDEWALL DRILLING

As stripping operations moved into areas of thicker and more consolidated overburden, the costs of drilling and blasting overburden came to represent a greater percentage of total costs, and by 1938 about half of the large strip producers in Indiana needed to shoot the coal as well as the overburden. As vertical holes produced by churn-type overburden drills (fig. 11) penetrated more rock units, the probability of tapping water-bearing strata increased. Where water was encountered, gelatin dynamites, which are unaffected by water but more expensive than blasting powder, were needed. Where drilling and blasting of overburden were required, gasoline-driven machines were commonly used to drill holes 4 to 5 inches in diameter at intervals of about 18 feet. The holes were generally sprung or enlarged at the bottom with 40-percent dynamite. When the holes were dry, 12 to 30 kegs of finely divided



Figure 11. Vertical churn drills commonly used before the 1950's to drill overburden. From *Coal Age*, 1966a, p. 119.

black blasting powder were generally used for shooting the rock, and dynamite was used in wet holes. Fuse and detonators or electric detonators with blasting machines were used for initiating the shots.

Where coal shooting was necessary, drills using compressed air or steam supplied from a shovel were employed (fig. 12). The holes were sprung with dynamite, and the coal was shot one hole at a time with one or two kegs of black blasting powder.

In 1930 the Central Indiana Coal Co. introduced large augers for horizontal drilling of overburden. Originally, augers like those at some underground mines were used. R. H. Sherwood later described the original experiments (*Coal Age*, 1954, p. 63):

We simply succeeded in hitching ten 6-ft augers

together, rotating them with an electric motor and forcing them into the highwall with a drum and small wire rope operated by manpower. *** I had appealed to a foremost maker of drill equipment to design such a drill, only to be told it was impossible to drill a 60-ft horizontal hole with sectional drills and keep it straight. *** We patented it, but eventually sold the patent rights to the Sullivan Machinery Co., who redesigned the drill and put it on the market.

A series of horizontal holes, as much as 6 inches in diameter and spaced 15 to 20 feet apart, were drilled to depths of 50 or 60 feet in a line 2 to 3 feet above the coal seam. After five or six such holes were drilled, each hole was sprung to enlarge the end of the hole and to allow loading of a larger charge. As much as 60 feet of overburden could then be



Figure 12. Channel-cutting machine and electric drill used in preparing coal for shooting and loading at the Sunlight No. 3 Mine in 1928. The mine, near Boonville, was operated by the Northern Illinois Coal Corp. From Mullins, 1928, p. 421.

blasted. Problems arose where thick, strong rock strata were present. Double decking, whereby a set of angled holes was drilled up into the overburden above the normal set of horizontal holes, was also used at an increasing number of mines to deal with troublesome strata within a thick sequence of overburden. Some operators achieved further refinements of blasting by using split charges separated by inert stemming.

Horizontal holes were usually dry, and the dryness allowed the use of less expensive blasting powder. Because fewer holes were required and each penetrated only one type of rock, drilling was generally easier. Casing was never required because no loose material was present. In some places overall costs were reduced 50 percent by use of horizontal drilling, which came to be known as the

sidewall method. Commercially produced sidewall drills (fig. 13) were soon on the market, and the technique gained wide acceptance in Indiana during the 1930's.

LIQUID-OXYGEN EXPLOSIVES

Liquid oxygen has a boiling point of -183° Celsius. In 1895 an apparatus capable of liquefying air was invented in Germany, and in 1904 the Dewar flask, a vacuum bottle suitable for storing liquefied gas, was invented in Britain. When liquid oxygen was mixed with carbonaceous matter, it formed an explosive that did not require nitrates, as did most other commercial explosives of that time, including blasting powder and dynamite. After 1897 experiments with liquid-oxygen explosives were undertaken in Europe. World War I provided impetus for



Figure 13. Horizontal, or sidewall, drill in use at the Enos Mine in 1933. Horizontal drilling of shotholes was first developed in Indiana, and for a time this method proved effective in reducing the expense of blasting overburden. From Hall, 1933b, p. 85.

German research in the use of liquid oxygen as a coal-mine explosive because shortages of glycerin, ammonia, and Chilean nitrates soon developed. By the time America entered the war, German mines used liquid-oxygen explosives extensively.

The Allies, who were not short of glycerin and ammonia, made little progress in developing liquid-oxygen explosives. The U.S. Bureau of Mines sent a committee to Europe after the war to investigate German developments. In later years the U.S. Bureau of Mines continued its laboratory and field experiments with liquid-oxygen explosives.

Liquid-oxygen explosives, or LOX, had several advantages over existing explosives: (1) they were cheap, (2) they eliminated the

danger of explosion during transport, (3) they had favorable fume characteristics (large quantities of harmful gases were not produced by their combustion), (4) they were harmless in the event of a misfire (the oxygen simply evaporated), (5) springing was unnecessary, (6) wet holes could be shot, and (7) good fragmentation was the rule. One pound of LOX replaced 2.5 pounds of blasting powder or 1.5 pounds of 40-percent gelatin dynamite.

LOX also had serious shortcomings, most of which related to their application in underground mines. Even in surface mines, however, LOX required rapid and skillful loading. Only a few shots could be fired simultaneously, and mass production and distribution were difficult.



Figure 14. Steam-powered shovel loading coal into railroad cars at a surface mine in Jackson County, Ill., in 1925. From Culver, 1925, p. 30.

In April 1926 the Enos Coal Mining Co. of Indiana became the first coal-mining company to use liquid oxygen in coal stripping. The technique was successful and soon spread to other stripping operations in Illinois and Kentucky and elsewhere in Indiana. Paper or fabric wrappers containing carbonaceous material were soaked in liquid oxygen until saturated. After loading and tamping they were fired in the same manner as other explosives, namely, with caps, electric detonators, or fuses.

RAILROAD AND TRUCK HAULAGE

During the 1920's most operations continued to use shovels to load coal directly into dump or railroad cars (fig. 14). At some mines small (4-ton) dump cars on narrow-gauge track hauled the coal to the tippie, and at other

mines coal was loaded directly into large (15-ton) railroad cars on standard-gauge track.

Electric locomotives had many of the same advantages as electric shovels, but operators of surface mines were slow to adopt "third rails," and the need to move track frequently at coal mines favored the use of light, easily laid track. During the late 1920's operators of several surface mines in northern Illinois and southern Indiana experimented with the use of gasoline-electric locomotives.

Trackmen were one of the largest occupational groups of laborers in strip mines. At the Maumee No. 20 Mine in 1933, 15 men out of a total work force of 70 worked part time in laying rails. Truck rather than rail haulage was first used in Missouri in 1927, and this change in haulage led to the eventual elimination of rails in surface mines. During 1928 a Kansas



Figure 15. Gasoline-driven shovel used in loading coal into 4- and 6-ton end-dump trucks at a small surface mine near Boonville in the mid-1930's. From *Coal Age*, 1936b, p. 327.

operation introduced drop-bottom trailers. Where preparation plants were far from the strip pits, automotive haulage and rail haulage were sometimes combined. The Patoka Coal Co. of Indiana introduced trucks into its operations in 1934. The Enos Mine adopted tractor-trailer pit haulage for distances as much as 1 mile in 1935, but locomotives were retained for the main haul to the preparation plant. In 1937 the Enos Mine replaced its steam-powered locomotives with electric trains.

In the late 1930's the cost of constructing haulage roads for trucks ranged from \$4,000 to \$10,000 per mile. The subgrade of main truck roads in many places was laid down by hand by using "one-man rock" and then covering by successive layers of gob, cinders,

and crushed limestone. Other operations sometimes simply used crushed limestone or red dog (burned shale from piles of coal-mine waste). The trucks at large operations pulled trailers with capacities from 20 to 40 tons.

In parts of some surface mines steep and rolling grades were encountered. The flexibility of automotive haulage (fig. 15), as it was then called, was particularly useful in such areas and in small tracts too far from existing rail facilities. Steam or electric locomotives, with their larger capacity cars, were still favored at large operations where the coal was thick and level.

DRAGLINES AND SCRAPERS

Along with automotive haulage, small gasoline-powered draglines with bucket capacities

of less than 5 cubic yards became more commonplace in Indiana during the 1930's. At some operations, where overburden was thick or where intermixed hard and soft strata were present, small draglines were used in combination with small shovels. Shovels could dig soft shales without prior shooting, and both shovels and draglines could remove hard rock that had been prepared by blasting. Draglines were used at small-scale mines in pockets or fingers of coal too small to be worth the attention of large stripping shovels. Draglines needed soft overburden with a thickness of less than 50 feet, and in Indiana they found their greatest use in the old Brazil coalfield of Clay County, cleaning out coal left around the margins of the numerous abandoned deep mines. This use of draglines was the main reason why production from the Block coals (Brazil Formation) increased from less than 1 percent of Indiana's total production in 1924 to almost 5 percent in 1937. The tracts exploited by these small units varied widely in extent; the H. A. Siepmann Coal Co. of Coalmont worked territories as small as 4 acres and as large as 600 acres.

In 1937 the Maumee Collieries Co. successfully introduced a 12-yard electric walking dragline into the Old Glory No. 17 Pit in Indiana. Previously, stripping had been performed there by a 7-cubic-yard steam shovel with a maximum stripping limit of 40 feet of overburden. The electric dragline, with a theoretical limit of 80 feet of overburden, extended the life of the mine an estimated 6 years. Concurrently with introduction of the dragline, truck-and-trailer haulage replaced railroad haulage.

PERMANENT STRUCTURES AT SURFACE MINES

In the early 1920's small shovel capacities meant that available reserves at any given site were small; after 8 to 10 years the supply of coal at shallow depth in most mines was exhausted. Strip mines were like temporary encampments, and most preparation plants were crude and cheaply built. Substantial structures for engineering, supervisory, and maintenance personnel were generally not constructed, although the Maumee Collieries

Co. did erect a central shop near Jasonville during 1917. One of the first of its kind in the stripping industry, the shop served for several decades for the manufacture and maintenance of Maumee's stripping and preparation equipment. By the late 1920's some surface mines were so large and so complex that permanent structures were needed. In 1929 the Enos Coal Mining Co.'s operation (later acquired by the Old Ben Coal Corp.) near Oakland City was the largest in the world. Besides a preparation plant and a machine shop, a permanent two-story building housed offices, a conference room, warehouses, and a few living quarters for office men.

TIME STUDIES AND EXPLORATORY DRILLING

As stripping moved out of the experimental stage, more refined engineering techniques were applied. By 1928 the Sunlight Coal Co., which was affiliated with the Northern Illinois Coal Corp., was conducting systematic exploratory drilling and topographic surveys on its properties near Boonville to allow careful planning in advance of actual mining. Daily logs recorded weather and pit conditions, and checkers (mostly cooperative students from a nearby engineering school) were stationed to keep detailed time studies of shovel movements.

Prospecting crews still used well or churn drills rather than core drills. In the coal industry, use of core drills for prospecting was largely confined to the anthracite district of Pennsylvania. Information from core drills was useful where overburden was thick and the position of particular strata was critical to the loading of blastholes. Recovery of core also allowed accurate analysis of coal samples, but the expense of core drilling prevented its more widespread use in bituminous fields.

BEGINNING OF SURFACE RECLAMATION

The effects of early surface mining have been described (Sappenfield, 1940, p. 36):

In the early days of strip mining, overburden was cast haphazardly to one side, the coal was loaded out, and the spoil banks were allowed to stand naked and ugly in unsightly, uneven ridges. Erosion then took control and, in a few short months, these ridges had been cut into grotesque patterns by rain and surface water.

Sumac, scrub oak, blackberry briars, pokeweed and similar undesirable vegetation alone were hardy enough to grow on the overburden slopes.

Disposal of spoil banks was a vexing problem confronting the early surface miners. In Indiana the first attempt at reforestation of surface mines was in 1918, when the Maumee Collieries Co. planted 4,700 fruit trees on spoil banks near Clay City. Three years later the Indiana Legislature passed an act classifying forest land and containing a major incentive for all coal companies to replant their stripped acreage in trees. Specifying a certain density of trees per acre, the act allowed reductions of tax assessments on forest land to \$1 per acre per year. Intensive planting allowed companies to classify their acreage under this special rate. In 1924 several strip-mine operators offered to turn their mined land over to the state to be used as game preserves. Under this proposal the state was responsible for reclaiming the land with vegetation. By 1926 three large companies, Sherwood, Enos, and Central Indiana, were reforesting their spoil banks with cottonwood. The following year the Indiana State Conservation Commission began experiments in reforesting some of the oldest strip-mined land in the state. In 1927 the Enos Coal Co. entered into an agreement with the Division of Forestry to provide for planting spruce trees on its mined acreage, and the Patoka Coal Co. donated to the state 157 acres of land. By the next year large-scale planting of white pines, American red pines, Scotch pines, black walnuts, and black locusts that had been purchased by coal companies from state nurseries was in full swing. Unfortunately, the hardy black locust soon far outnumbered more desirable but less adaptable fruit trees that had been planted earlier.

By 1935 more than a million trees were being planted in Indiana on surface-mined land. The cost of purchasing and planting the trees (generally about 1,200 trees per acre) was about \$20 per acre by 1940. The Maumee Collieries Co. and the Central Indiana Coal Co. donated more than 2,000 acres of reclaimed land around Linton to be used as a city park and as a nucleus for the Greene-Sullivan State Forest. Coal companies

had expressed little interest in retaining ownership of their old spoils and were probably happy to receive almost anything in return for their sale. A change in this attitude began about 1940, when the superintendent of a mine in Illinois began seeding his waste banks and pasturing cattle. R. H. Sherwood entered the farming business by producing crops on several thousand acres of reserve coal lands of the Sherwood-Templeton Coal Co. That company later applied the techniques learned on poor-quality reserve lands to spoil banks left by stripping operations.

Recent Surface Mining in Indiana

GROWTH OF SURFACE MINING

Surface-mined output rose from 10.7 percent of the total national production in 1941 to 24 percent in 1949. After the output of surface mining had fluctuated between 22 percent and 27 percent until 1957, growth resumed and by 1977 surface mines contributed 61 percent of the nation's coal supply.

In Indiana underground production remained at about 54 percent of the state's total output from 1941 to 1951. After World War II underground production in Indiana began to decline rapidly. Some reasons for the decline of underground mining in Indiana were discussed by Harper (1981). As a result, even though surface production showed no real growth between 1942 and 1964 (fig. 10), its contribution to total output reached 69 percent by 1955, and it remained there until 1961. It then increased rapidly to 90 percent in 1967.

The period from 1950 to 1964 was a difficult time for America's coal industry, and at least eight major surface mines in Indiana were closed between 1955 and 1960. Although the coal industry as a whole had difficulties during this period, some aggressive companies managed to greatly increase their reserves through mergers and acquisitions and to experience tremendous growth in production.

After World War II large surface operations designed to be long lived became more common, but compared with deep mines, surface mines consisted of disproportionately more small short-lived mines. In 1956 the



Figure 16. Parallel-tandem mining by the Maumee Collieries Co. in the early 1950's. As overburden at a mine became too thick to be dealt with effectively by existing shovels and draglines operating singly, a shovel and a dragline worked as a team to remove the blasted overburden. From *Coal Age*, 1951c, p. 60.

average length of continuous operation of surface mines ranged from 11 years in West Virginia to 25 years in Ohio. The average life in Illinois and Indiana was 14 years. The national average for strip mines was 17 years, and the national average for all mines was 29 years.

GIANT EXCAVATING MACHINERY

SHOVELS

The national average overburden thickness at surface mines increased steadily, rising from 31.6 feet in 1946 to 39 feet in 1950. As thicker overburden was encountered and as large walking draglines proved their worth, the Maumee Collieries Co. decided in 1950 to institute parallel-tandem operations at its Chieftain No. 20 Mine in Indiana (fig. 16). Under this plan, both a 25-cubic-yard dragline and an 18-cubic-yard shovel were used to remove the 65 feet of overburden that had been encountered at the mine. The dragline preceded the shovel, removing about 60

percent of the overburden and depositing the fragmented rock (spoil) at the maximum distance allowed by its 215-foot-long boom. The shovel then followed, removing the remaining 40 percent of the overburden (which generally contained harder material) and depositing its spoil in the shorter distance between the edge of the coal and the toe of the dragline spoil. The Maumee Collieries Co. later tried more complicated variations on the parallel-tandem scheme in attempts to achieve fuller use of shovels as well as draglines in areas of thick overburden, but by the mid-1950's the need for shovels of larger capacity was evident.

Shovels with capacities of 40 cubic yards were introduced near the end of World War II, but after 1956 the capacity of stripping shovels began to increase dramatically (fig. 17). In 1956 a 60-cubic-yard shovel was introduced. A 70-cubic-yard shovel began operation in 1957, and a 115-cubic-yard shovel began operation in western Kentucky

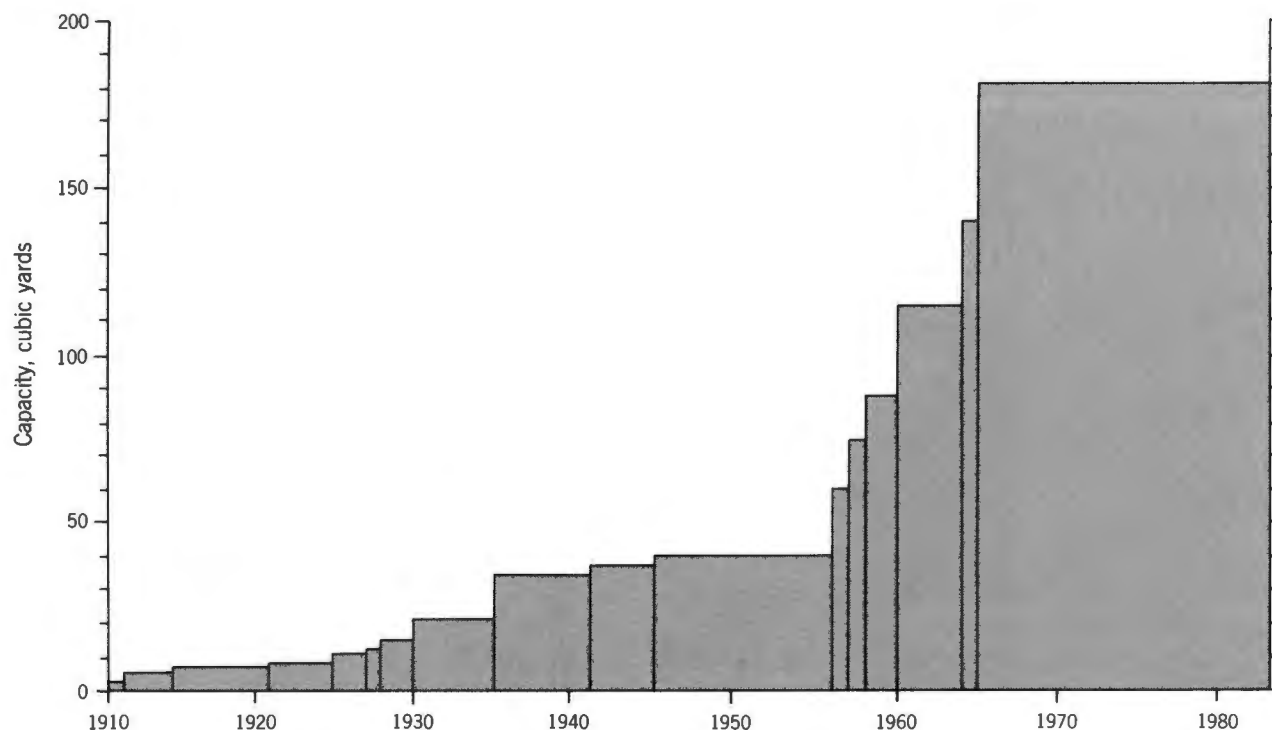


Figure 17. Graph showing the increase in the maximum capacity of stripping-shovel dippers from 1910 to 1983.

in 1960. The capacity of the largest shovels in service had almost tripled in only 4 years. Although the national average thickness of overburden was only about 45 feet throughout this period, the growth in shovel capacity meant that the maximum thickness of movable overburden had increased from 70 feet in 1954 to more than 125 feet in 1959. Maximum shovel size increased to 140 cubic yards in 1964 and 180 cubic yards in 1965.

The voltage used on the first 60-cubic-yard shovel, named the Mountaineer, was 7,200 volts, up from the maximum of 4,160 volts previously in use on the largest shovels. The first 180-cubic-yard shovel, installed at a mine in southern Illinois, was also the first to use 14,000-volt power, independent drive motors on each crawler, automatic hydraulic tensioning of crawlers, automatic leveling, dual gantry, dual crowd racks and drives, and a double-door dipper. Equipped with a 215-foot-long boom, the shovel was more than 21 stories high. This is the largest stripping shovel ever constructed.

The preferred source of power for shovels

and draglines continued to change and therefore to further reduce the diversity that previously existed. In 1949 there were 153 shovels in operation in Indiana; 63 were electrically powered, 63 were diesel operated, 25 were gasoline powered, and two were steam powered. Although the number of gasoline-powered shovels continued to decrease, diesel-powered shovels remained popular through the 1950's.

DRAGLINES

A great surge of interest in draglines occurred between 1946 and 1954; the number in operation throughout the nation rose from 340 units to 800 units. The first 25-cubic-yard walking dragline was installed at the Linton No. 28 Mine in Indiana in 1945. Operated by the Maumee Collieries Co., this unit had a capacity three times as great as that of the largest dragline previously in use. The new dragline recovered premium Survant coal (IV) to a depth of 75 feet in an area adjacent to an area that Maumee had stripped to a depth of 45 feet a generation earlier. Through

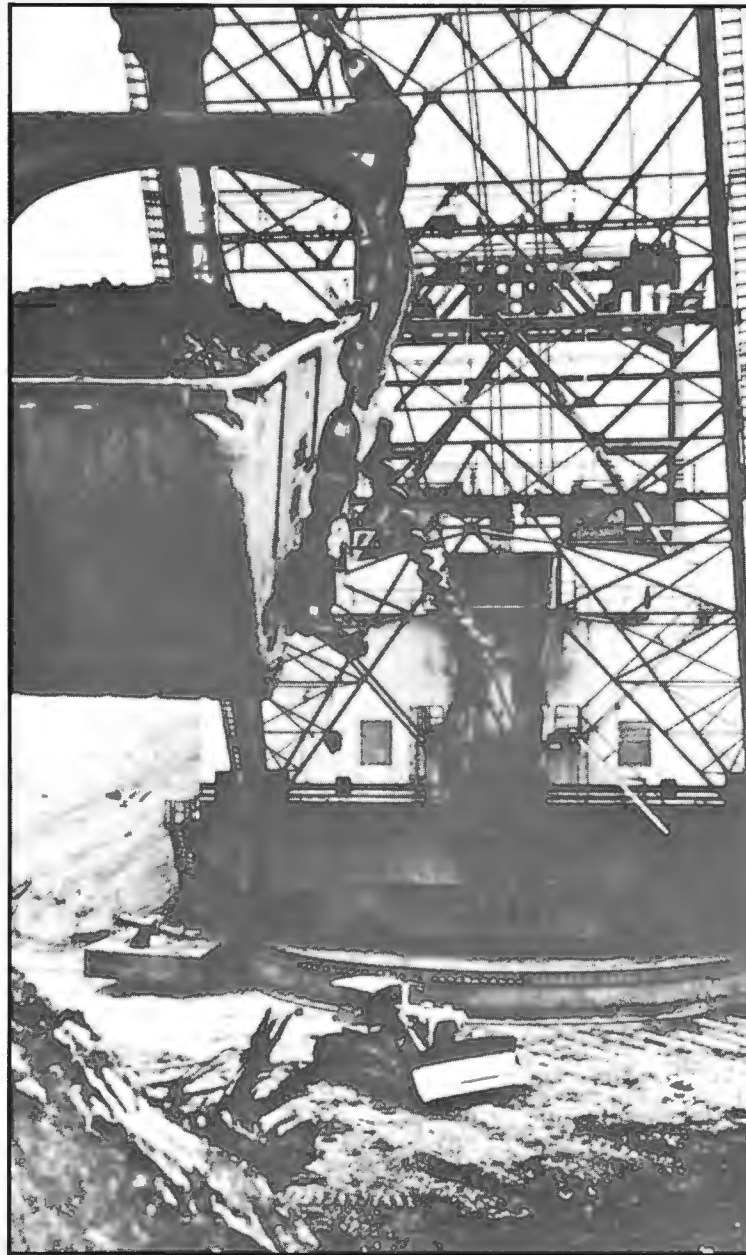


Figure 18. Dragline installed at Peabody's Latta-Dugger Mine in the mid-1960's. When it was installed, it was the largest dragline in operation in the United States. The model was designed for use with a 145-cubic-yard bucket. From *Coal Age*, 1972, p. 66.

most of history the capacity of draglines had lagged behind the capacity of shovels, but the installation of this machine marked the beginning of an enormous expansion of dragline capacity, which in a few years would surpass the capacities of even the largest

shovels. From 1954 to 1961, however, there was little change in the actual number of units in use.

Maximum dragline capacity rose from 85 cubic yards in 1963 to 130 cubic yards in 1967. The 85-cubic-yard dragline, first in-



Figure 19. A 105-cubic-yard shovel in use at the Peabody Coal Co.'s Lynnville Mine in Warrick County. The shovel was obtained in the late 1960's. For scale, note the bulldozer in front of the shovel.

stalled at a mine in western Kentucky, could move overburden as much as 150 feet thick and was the first dragline to use four drag cables and four hoist cables. In 1966 the Peabody Coal Co. installed a 145-cubic-yard dragline at its Dugger Mine in Sullivan County (fig. 18). At the time it was the largest such machine in the United States, but a 220-cubic-yard dragline was already under construction for use in Ohio. The power requirements of the machine at Dugger were equivalent to those of a city of 20,000 inhabitants. Dragline development climaxed in the fall of 1968 with the completion in Ohio of the \$20 million Big Muskie, a 220-cubic-yard machine used to provide coal to the Ohio Power Co. Weighing 13,500 tons, the machine exerted a pressure on the ground of 21 psi and could move at a top speed of 0.17 mph. New features incorporated in Big Muskie included the first use of 5-inch-

diameter wire rope, a hydraulic rather than mechanical walking system, tubular booms, and vacuum circuit breakers rather than oil-filled circuit breakers in the electrical machinery.

TECHNOLOGIC PROBLEMS WITH GIANT MACHINERY

The construction of colossal shovels and draglines was necessary to allow exploitation of ever deeper coal seams. The 140-cubic-yard dragline at Dugger could remove overburden to a depth of 96 feet. Big Muskie could dig to a depth of 185 feet, although it was intended primarily to work in an average 160 feet of overburden. The 180-cubic-yard shovel installed in southern Illinois in 1965 was designed primarily for use in an average 107 feet of overburden, but it could cut a highwall to a maximum height of 190 feet.

This 180-cubic-yard shovel in southern Illinois proved to be the largest shovel ever

used for coal mining in the United States. After 1971 draglines rather than shovels were used almost exclusively for overburden removal at new operations, although smaller shovels continued to remove coal at many mines (fig. 19). During the 1970's stripping shovels, compared with draglines, had several disadvantages. Shovels work at the bottom of the mine pit and dig upward, but draglines sit on top of the highwall and dig downward. Therefore, the maximum overburden that can be handled by a dragline is greater. The largest crawler-mounted stripping shovels were of such size that they threatened to break through the coal that they were sitting on. But draglines encountered relatively few problems with bearing pressure because their walking-pontoon mechanisms provided low ground pressure. Also, the greater flexibility of draglines in digging and placing material proved important in meeting the more stringent reclamation requirements of the 1970's, and the lower initial cost of draglines was attractive. A principal disadvantage of draglines—the need for greater fragmentation of overburden—was significantly offset by lower costs of drilling and blasting resulting from the advent of rotary drills and improved explosives.

By the late 1970's and the early 1980's, use of smaller stripping shovels (generally less than 35-cubic-yard capacity) revived in some Appalachian and western operations where they were teamed with trucks in various haulback-mining arrangements that require lateral movement of overburden material.

The growth in the size of shovels ceased in 1965, and by 1969 it was clear there would also be serious technologic problems in further increasing the size of draglines. The 5-inch-diameter wire rope used on Big Muskie weighed 44 pounds per foot, and its fabrication required extensive changes at considerable cost in the machinery of the wire-rope manufacturer. There was doubt concerning the future demand for such rope; studies for possible use in offshore drilling, salvaging sunken vessels, and heavy towing suggested that the future use of such equipment would be in surface mining alone. Special equipment and methods were needed for field handling such rope, and larger

sheaves and drums were needed to avoid bending the large-diameter rope too drastically. By 1972 some manufacturers were advising against the use of rope of the dimensions used on Big Muskie because of its availability and cost and because of problems in handling and machine design.

A hydraulic walking system was developed and installed on Big Muskie because manufacturers were limited in the size of cam- or crank-operated mechanisms that they could produce. The boom was constructed of eight tubes, each 2 feet in diameter, that were laced together to form two columns. The tubes were filled with pressurized gas so that cracks could be detected by the use of pressure-operated alarms.

Using larger equipment required using greater voltages. To power giant equipment with lower voltages would have necessitated the use of ever larger cables or more cables, whose size and number would have created many problems in handling. The allowable distance between the machine and its substations would also have been seriously limited. Maximum voltages used on stripping machinery increased from 4,160 volts to 7,200 volts in 1956 and to 14,400 volts in 1965. In 1968 a 25,000-volt system was installed for the first time by the Peabody Coal Co. at its surface mine near Dugger. Power was received at 138,000 volts through an air-break switch, fed by pole line to substations through another set of portable air-break switches, reduced in the substations to 23,000 volts by sled-mounted transformers equipped with oil switches, and then distributed to the equipment through a portable cable system. Several years before their introduction into the United States, 25,000-volt systems had been successfully used in other countries. Because the safety of electrical systems depended on the integrity and continuity of their grounding systems, reliable ground-check monitors for use with high-voltage systems of the type used in surface mines were developed by 1979, and these were first installed at Peabody operations in Indiana.

Because of the great number and size of electrical motors and other equipment on the large shovels and draglines, attention had to



Figure 20. View of the interior of Big Muskie, the largest dragline ever built, showing some of the motors and auxiliary equipment required to operate the machine. From *Coal Age*, 1969a, p. 54.

be paid for the first time to ventilation and air filtering on board the huge machines. Ventilation of the 180-cubic-yard shovel required 700,000 cubic feet per minute (cfm) of air, and Big Muskie (fig. 20) required the astounding quantity of 1 million cfm of air.

Besides creating problems in manufacturing components and delivering power, the largest shovels and draglines threatened to overstress mechanical and electrical equipment (fig. 21). The mass of bucket, boom, and cables on a large dragline was so great that lowering and stopping the bucket in the shortest possible time without causing failure of mechanical or electrical components became a delicate matter. Motors, gears, and drums had to be especially designed to cope with the inertial forces that might be encountered, and special electrical interconnections and alarm systems were needed to assure that every motor

carried its share of the load and that damage caused by overloads, loss of power, or failure of mechanical components was minimized.

Operational problems directly related to the size of such machinery included the need for better lighting at nighttime. Because the working area of some machines was larger than a football field and because lights could not be mounted closer to the working surface than 300 feet in many places, more powerful and effective mercury-arc floodlights were needed. Other problems arose with the preparation of overburden and with the handling of the coal that was uncovered in the wider and deeper pits created by the giant machines.

Even before the large machines were created, the size and weight of shovels and draglines created problems in moving such equipment from one mine site to another.



Figure 21. Failed boom on a 140-cubic-yard shovel in western Kentucky. In this 1980 accident there were no injuries, but the accident resulted in a lengthy disruption of production. From *Coal Age*, 1980, p. 37.

Disassembling a unit, transporting the parts to a new site, and rebuilding the unit were commonly used despite the expense and length of time required for completion of such work. Before 1955 overland movement using utility power supplied by powerlines was the only available alternative to disassembly for moving large equipment. But in 1955 the Saxton Coal Corp. of Indiana used two 315-kw mobile generator sets to move a 560-ton 13½-cubic-yard dragline a distance of 7 miles in 7 days. A thousand feet of power cable was used to walk the dragline.

Moving such pieces of equipment was a major engineering feat. For the Saxton move, 6 months of preparation was required to obtain right-of-way easements across private property and working permits for railroad and powerline crossings. The machine created a 100-foot-wide swath along its 7-mile path. Rails and ties had to be removed and replaced at three railroad crossings, protective dirt embankments had to be built across several

highways, and five powerlines (including one that carried 69,000 volts) had to be taken down and rebuilt. Besides crossing the South Fork of the Patoka River, which was diverted at a point where it was 50 feet wide and 12 feet deep, the dragline also passed over the Little Inch and Big Inch gas pipelines.

After Big Muskie, engineering emphasis shifted from increasing the size of draglines to refining their operation and improving their efficiency. Longer booms received much attention when studies indicated that productivity could be improved by lengthening the reach of draglines even while reducing bucket size. By the mid-1970's draglines (as much as 70-cubic-yard capacity) equipped with aluminum rather than steel booms became available. By providing considerable weight reduction, aluminum booms made possible improvements in productivity by permitting the use of longer booms and providing shorter cycle times, reduced maintenance, and reduced erection costs. Studies soon indicated



Figure 22. View from the operator's cab of a 150-cubic-yard dragline in the AMAX Coal Co.'s Ayrshire Mine. Photograph courtesy of the AMAX Coal Co.

that aluminum booms had a fatigue life equaling or surpassing that of steel booms. By the mid-1970's manufacturers were also making available modular draglines using bolted rather than welded members. Easily transported, assembled, and disassembled, such modular equipment promised to make feasible the exploitation of smaller tracts of reserves. The minimum size of reserves had

been related to the size of available all-welded stripping machines.

Much attention was also focused on creation of computerized surface-mine simulation models, development of electronic devices to better monitor dragline operations, and improvements in dragline-operator training. One such computerized simulation model of dragline performance, developed by

McDonnell-Douglas Electronics Co., was first applied to the Chinook and Ayrshire mines in Indiana in 1979 (fig. 22). Results of the test yielded information on possible methods of improving productivity throughout every stage of mining from planning through control. In 1981 testing began at a western mine on a relatively simple electronic system designed by General Electric to warn dragline operators when potentially damaging bucket speeds and cable stresses developed. Under certain conditions the device would override the operator to slow or stop the bucket. Efforts to improve training of dragline operators by sophisticated trainers and simulators like those used in the aircraft industry for pilot training have been underway for several years in cooperative projects between McDonnell-Douglas Electronics Co. and government agencies.

FINANCIAL AND OTHER PROBLEMS

Using monster draglines and shovels was strictly a midwestern phenomenon; only there, where the terrain was relatively flat and where average overburden thickness was steadily increasing, was such equipment needed. In the mountainous terrain of eastern Kentucky and West Virginia, operators practiced contour mining in narrow bands around mountainsides, and the maximum height of few highwalls exceeded 60 feet. In the Midwest, by contrast, the average height of highwalls was approaching 55 feet, and the maximum heights were almost three times that amount. In the midst of these great leaps forward in the capacity of shovels and draglines, it was not possible to foresee when or where the limits would be reached. It was generally agreed, however, that the limits, when finally encountered, would be financial, economic, and legal rather than engineering. According to Coal Age (1966a, p. 127):

How large existing types of stripping machines will become in the future depends to a large extent on economics rather than on equipment design. Equipment manufacturers, for example, report that it is difficult to visualize the top limit for future draglines and shovels. There appears to be no limitation on size since almost every function can be paralleled or multiplied so that individual units can be reduced to meet manufacturing capabilities. * * * How many

[large shovels and draglines] will be working, and when, will depend on economic factors plus the availability of large reserves making possible normal depreciation charges.

The enormous increases in size of surface-mining equipment brought enormous increases in cost. For new-equipment expenditures, coal companies traditionally relied on internally generated funds, capital loans from banks, long-term leasing arrangements, or chattel mortgages secured by the individual items of equipment. Before coal companies were acquired by oil or other large companies, the internally generated funds of most coal companies were relatively meager, and reliance was placed on amortization of previously purchased equipment. Because such a method was clearly insufficient by itself for funding the purchase of the much larger and more expensive equipment of the 1960's, resorting to other sources of funds was increasingly necessary.

In the East and in the Midwest particularly, uncertainty about the provisions of present and future reclamation laws passed or under consideration during the 1960's in response to strong public pressure stirred up doubts concerning the suitability and adaptability of the giant machines to the reclamation work that might be required.

The opening of large acreages of new reserves was probably an important factor in limiting the growth in the size of surface-mining equipment. Beyond a certain point larger machines would not be needed until the opened reserves had been significantly exploited. This factor, together with new transportation links between virgin coalfields in western states and midwestern coal markets, would seriously threaten the surface-mining industry in the Midwest. In the West existing smaller machines were adequate to exploit vast acreages of thick seams under comparatively shallow, easily dug overburden. Early in 1975 the U.S. Bureau of Mines estimated the costs of three hypothetical surface mines in the East, the Midwest, and the northern Great Plains. The initial capital cost of a western mine producing 9.2 million tons per year was estimated to be \$30 million; the initial capital cost of a midwestern mine producing only 6.7 million tons per year was



Figure 23. A 176-cubic-yard dragline at the AMAX Coal Co.'s Ayrshire Mine. This is the largest dragline to operate in Indiana. Photograph courtesy of the AMAX Coal Co.

estimated to be \$55 million. Annual operating costs were estimated at \$21 million and \$22 million. It is probably not entirely coincidental that Big Muskie, the largest dragline ever, went into operation the same year (1969) that the first shipment of western coal was made to the Midwest. In 1970 production began at Peabody's Universal Mine in southern Vermillion County and northern Vigo County. The contract between Peabody and Public Service Indiana providing for delivery of 70 million tons during a 30-year period was described at the time (Coal Age, 1969b, p. 28) as " * * * the consignment of the last major block of strippable coal reserves in Indiana."

Dipper and bucket capacities reached their limits with the erection of a 180-cubic-yard shovel in 1965 and a 220-cubic-yard dragline in 1969. After the 180-cubic-yard shovel was installed, the largest shovel to be built

through 1972 was 125 cubic yards. During the oil shortages of 1973 and 1974, orders for large draglines (although not so large as Big Muskie) increased greatly. The cost of machinery soared, increasing 100 percent between 1974 and 1976. The purchase and erection of a 115-cubic-yard dragline at the Chinook Mine in Clay County cost about \$21 million in 1976. By 1980 dragline prices were as much as \$40 million. Because of the sudden increase in orders in 1976, delivery of many draglines was delayed for as long as 4 years, when economic conditions in the coal industry had worsened and estimates of the anticipated demand for coal had been markedly reduced from those of the early and the mid 1970's. By 1980 a 176-cubic-yard dragline, the largest stripping machine ever to be used in Indiana, was in operation at the Ayrshire Mine in Warrick County (fig. 23).

The period of maximum growth in the size

of shovels and draglines was from 1956 to 1969. Growth had been initiated during the economically difficult mid-1950's by the last of the early, regionally based coal companies. It was continued by aggressive, rapidly expanding companies that used opportunities during the late 1950's and the early 1960's to become nationally based. As expansion of these individual companies by merger and acquisition ceased and as western reserves were developed and midwestern coal markets were opened to western producers, shovels and draglines ceased growing in size.

AUXILIARY DEVELOPMENTS

BUCKETWHEEL EXCAVATORS

Bucketwheel excavators are a type of excavating machine that is entirely different from either shovels or draglines. Digging is done by evenly spaced buckets attached to the periphery of a rotating wheel. Continuous digging is possible because the material flows from the buckets onto a conveyor system and then to the discharge point. Bucketwheel excavators were first used primarily in Germany.

A bucketwheel excavator was first used in the United States in Illinois in 1944 at a surface mine of the United Electric Coal Co. After 1954 several other large bucketwheel excavators were installed at surface mines in Illinois. Under specialized geologic conditions, bucketwheel excavators can move large volumes of overburden material, but the early models installed in the United States were misapplied in many places, were subject to mechanical breakdown, and therefore were not fully used. Large German bucketwheel excavators were introduced into the United States in the early 1960's, but despite great success with such machines in Europe, they have continued to see little use in the United States outside Illinois, the Powder River Basin of Wyoming, and the lignite fields of North Dakota. None have been used in Indiana. Because of recent improvements in digging capability and greater flexibility in spoil disposal, smaller bucketwheel excavators have shown some promise for greater use under geologic conditions previously considered too difficult.

ROTARY DRILLING

Since the advent of surface mining, the average overburden thickness and the ratio of overburden removed to coal recovered have increased. The need to deal with heavier overburden resulted in greater use of power drilling to prepare overburden for excavation by blasting. By 1950 more than 70 percent of total surface production came from mines where overburden was drilled and blasted.

Of all drills in use in 1950, two-thirds were horizontal type, and the rest were vertical type. But vertical churn drills and sidewall drills could not handle the thicker and more consolidated overburden, and during the 1940's use of rotary machines of the type developed for drilling oil wells increased (fig. 24). Larger hole diameters allowed the drilling of fewer individual holes and the loading of more explosives. By 1952 the Maumee Collieries Co. was drilling 12-inch holes instead of 6-inch holes as in 1945. In 1950 the Enos Mine first used a dry-type vertical rotary drill, which had Tri-Cone bits and allowed much faster drilling than the older wet-type rotary drill. Enos's installation marked the beginning of a rapid conversion from the older churn and wet-type rotary drills.

The new drill used by Enos was originally designed for quarrying and then adapted for coal stripping. Although Enos's model was electrically powered, models equipped with gasoline and diesel engines were also available. Pressurized air at 95 psi cooled the bit, forced fine cuttings from between the bit and the hole wall, and blew rock chips out of the path of the bit. The pressurized air and suction eliminated the use of water, the need to maintain costly and troublesome waterlines and water trucks, and the danger of freezing in cold weather. With the same crew size as before, the new drill could produce three times as many holes as a churn drill.

Maumee officials helped to develop a dry-type rotary drill that first went into operation during 1952 at the Sullivan No. 27 Mine near Linton. Drilling 10-inch holes, the new unit replaced three vertical drills and a sidewall unit and allowed an 80-percent reduction in drilling manpower.



Figure 24. Rotary drills using oil-well-type drill bits for drilling shotholes in overburden. During the 1940's these rotary drills widely replaced churn-type drills like those in figure 11. The electrically driven drills shown here produced 8-inch holes. From *Coal Age*, 1946a, p. 83.

Drilling was speeded by other technical developments. Truck-mounted units were redesigned to allow more rapid setup, and the length of individual drill stems was increased to reduce the number of drill-stem sections needed to complete the holes. Taller masts were installed on drills to reduce the time needed for making and breaking pipe joints.

By the mid-1960's rotary drills were capable of drilling holes 15 inches in diameter, and the larger holes allowed the use of even greater explosive charges. Manufacturers were reportedly waiting with designs for machines capable of drilling 20- or 30-inch holes, but the need for such equipment did not arise. By the early 1980's the largest drill in use was 17½ inches in diameter. For favorable preparation of the overburden, greater emphasis was placed on carefully regulated sequential blasting rather than on

the use of fewer but more powerful blasts. Some dry-type rotary machines also were used for horizontal drilling during the 1960's, and new drilling techniques, such as two-level sidewall drilling and angled sidewall drilling, were developed. Decked charges were increasingly used to deal with thicker and harder strata.

BLASTING

The increased use of draglines meant that more thorough fragmentation of overburden was needed. Easy digging for draglines required 50 percent more explosives than the amount of explosives needed for shovels. The use of larger amounts of explosives to fragment thick overburden more thoroughly often produced increased noise and vibration, which resulted in more complaints from neighboring property owners.

During 1949, when the Maumee No. 27 Mine was operating just a mile from Dugger, complaints from residents about the noise and vibration mounted. Several changes in techniques were tried at that operation as well as at other mines. At first, the problem was attacked by simply reducing the number of holes fired at any one time. Shots became more numerous so that the same tonnage could be mined, and some shooting was done at night. The night shooting resulted in a great increase in complaints. Next, 25-millisecond-delay blasting caps were alternated with the instantaneous blasting caps that had been used exclusively before. Variations in the actual delay times resulted in highly variable vibrations from one shot to the next.

In 1951 MS connectors, which had been patented in Britain, became available in the United States. These devices consisted of a length of detonating fuse with a 16-millisecond delay (therefore the name MS) built into it. Use of the MS connector with a detonating fuse allowed precise 16-millisecond delays between holes in a shot. Maumee officials determined that use of the delays resulted in a reduction of vibrations. After testing was completed, all four Maumee mines began using the detonating fuse and MS connectors.

AMMONIUM NITRATE-FUEL OIL EXPLOSIVES (ANFO)

Surface reserves overlain by thin, loosely consolidated overburden were being rapidly depleted, and blasting costs were quickly becoming a major item of concern to surface operators. As one writer said (Coal Age, 1946b, p. 101), "the prime requisite for successful stripping and low shovel maintenance is a high wall so thoroughly blasted and broken up that the excavator can handle it without hesitation." In 1954 it was discovered that ammonium nitrate, a cheap and abundant form of agricultural fertilizer, could be made explosive by mixing it with about 6 percent fuel oil, a mixture referred to as ANFO. Robert Akre and Hugh B. Lee, Sr., of the Maumee Collieries Co. were responsible for introducing ammonium nitrate blasting to coal mining, and in 1955, after spending 2½ years in developing this product, they received patents for the first such explosive,

Akremite. Advertised as a "make-your-own" stripping explosive, Akremite made use of low-cost and widely available materials, such as commercial-grade ammonium nitrate (a fertilizer then costing only about 3¾ cents per pound) and carbon black. Since World War I ammonium nitrate had been used as the chief ingredient in many different explosive mixtures, but the concept of eliminating entirely the other explosive ingredients, such as nitroglycerin, was new.

The discovery of Akre and Lee was described (Davis and Flowers, 1955, p. 72):
 * * * if carbonaceous material of the proper character were added to ammonium nitrate it was possible to detonate completely the mixture if a granular non-caked charge is tightly packed in a flexible package, then placed in a blasthole in such manner that all air pockets are eliminated. With tight stemming, the charge can then be detonated by a primer charge adjacent to the packaged ammonium-nitrate mixture. Thus, the Akremite method employs materials having theoretical properties long known to the explosive industry, but now prepared in a manner leading to a fuller realization of these potentials.

The primer, used to detonate 300 pounds of Akremite, consisted of 20 pounds of cap-sensitive explosive packaged in a polyethylene sack. The primer package had the added advantage of eliminating the excruciating headaches often suffered by shooting crews who handled unwrapped gelatin dynamites. Holes were linked through the detonating fuse and MS connectors. The patents obtained by the Maumee Collieries Co. covered all details and applications involving use of the Akremite method in bank shooting and open-cast operations (fig. 25) and procedures related to the preparation and use of the primer charge. Maumee gave surface-mine operators the right to use Akremite methods and gave instructions and training in compounding, packaging, handling, loading, and shooting and also continued advice and consultation. Akre was superintendent of drilling and shooting at Maumee Collieries and had worked for several years as a field representative of a major powder company.

Besides being cheap, ANFO was much safer than conventional high explosives, requiring only blasting caps or fuse for detonation of a



Figure 25. Blasting with ANFO in 1955. From Davis and Flowers, 1955, p. 71.

primer charge that initiated the explosion. It could be shipped at ordinary commercial freight rates rather than at the higher fixed-explosive rates. In 1955 it was estimated that licensed users who mixed their own Akremite could cut their explosive costs in half. The principal disadvantage of the compound was the need for keeping it perfectly dry, but this problem was soon solved by prepackaging Akremite in polyethylene bags. Prepackaging in polyethylene bags also enabled the 50-pound cartridges to be loaded more easily into the shotholes (fig. 26). By 1960 special initiators designed for use with ANFO replaced the high explosives previously used for that purpose.

Blow charging of bulk ANFO became popular at some operations; not only was the speed of loading increased but also the

density of charge was greater. By the mid-1960's machines for blowing 240 pounds of ANFO into a hole in 3 minutes were available. Where prepackaged explosives were used, loading by hand was still practiced; explosives could be purchased in packages, or they could be mixed and packaged at the mine.

Chemical additions to ANFO and improved methods of detonation also received attention. Thermal priming of ANFO with metallized slurries was found to increase the energy of the mixture, so that fragmentation was significantly improved and shooting and drilling costs were reduced. Previously, slurries (gelled mixtures of ammonium nitrate and water) were sensitized by adding TNT, nitrostarch, or smokeless powder as well as metal flakes. By the mid-1950's slurries



Figure 26. Shooters loading a 20-pound primer packed in a polyethylene wrapper. Fifty-pound cartridges of ANFO were similarly packed. A typical hole at the Maumee No. 20 Mine in 1955 was charged with 350 pounds of ANFO and 40 pounds of primer. From Davis and Flowers, 1955, p. 70.

sensitized by adding only flaked metals, particularly aluminum, were finding acceptance in the coal industry after their widespread acceptance in other mining and quarrying operations. Because they contained no high explosives whatever, these over-metallized slurries were highly insensitive and therefore safe. Detonation was accomplished by using cast primers containing high explosives, such as pentolite. The use of these over-metallized slurries was especially indicated in part or all of deep, large-diameter holes penetrating hard layers.

Pumpable mixtures of ANFO and detonatable emulsions of ANFO have recently been used at some midwestern surface mines (Chironis, 1985, p. 82). Such mixtures are more water resistant, provide more energy, and allow improved coupling of the explosive to the blasthole wall than conventional bulk or packaged ANFO.

There has also been experimentation in Indiana recently with blast casting. In traditional surface mining, blasting is performed only to fragment the overburden, so that it can be moved more easily to the spoil



Figure 27. Tractor-trailer truck being loaded in a pit at the AMAX Coal Co.'s Ayrshire Mine. Photograph courtesy of the AMAX Coal Co.

bank by the primary stripping machine. With blast casting, as much rock as possible is cast onto spoil during blasting, and chemical energy is substituted for mechanical energy. The method has been little used and is applicable only under special conditions.

TRUCK HAULAGE

The use of larger shovels and draglines was accompanied by the introduction of larger

off-highway haulage trucks for transport of coal from the strip pits. Rear-dump, unitized-body trucks were favored for hauling coarse rock over relatively steep grades, and tractor-trailers were favored for hauling lightweight flowing material over level ground.

The Enos Mine achieved a substantial increase in average daily output after 1957, when 44-yard trucks were replaced by



Figure 28. Bulldozers and earthmovers removing rock in the intervals between several coal seams that are being mined at a small surface mine in Daviess County. The bulldozers are equipped with ripping shanks, and the earthmovers are the type commonly used in construction work.

tractor-trailer haulers of 63-yard capacity. But before 1963 truck sizes had changed little at most operations since the 1930's, when 40-ton trucks had first gained acceptance. The development of larger and more durable tires, larger horsepower engines, and stronger transmissions led to the introduction of a 100-ton semitrailer at an Ohio mine in 1963. Widespread acceptance was rapid and a round of size increases was triggered; maximum capacity doubled in only a single year from 120 tons in 1964 to 240 tons in 1965. The 240-ton trucks were designed on a shuttle-car principle, and tractors and controls at each end made turning around in the pit unnecessary. By 1966 it was estimated that haulage costs had been reduced by 10 to 50 percent since World War II, but it was foreseen that further cost reductions would be difficult and that future gains would be much smaller. Testing with steel-cord tires,

whose thin walls and shallow treads allow rapid heat dissipation, began in 1964 in Illinois. In 1971 a prototype turbine-electric off-road rear-dump hauler was introduced. A turbine wheel turned by the combustion of air and fuel generated electric power by way of a turbine alternator. Rectified from AC to DC current, power was distributed to the electric traction motors in each wheel. For reasons of cost, efficiency, and reliability, mechanical-drive trucks have continued to be favored over electric-drive trucks for many applications, especially where a wide range of gradients and speeds is encountered. By 1980 rear-dump trucks of 350-ton capacity were available, but most operators continued to use trucks of 170-ton capacity or less (fig. 27).

BULLDOZERS, SCRAPERS, AND HYDRAULIC EXCAVATORS

Before World War II surface mining on a large



Figure 29. Hydraulic excavator in a front-end-loader configuration being used to load coal at a small surface mine in Knox County.

scale was the area type and was essentially confined to the Midwest and Ohio, where seams are relatively level and the terrain is relatively flat. Beginning late in World War II, much lightweight equipment for road building or other construction work was used for contour-type surface mining in eastern and southern coalfields.

The use of bulldozers for various functions at small operations came into increasing favor after World War II. Some small strip mines even substituted bulldozers for shovels and draglines. A three-bulldozer operation near Boonville was handling overburden as much as 55 feet thick in 1951 and producing as much as 1,000 tons of coal per day. Most of the tracts worked were small, between 3 and 16 acres, and represented pieces of coal left by earlier deep or strip mining. Exploration drilling was not done; prospecting consisted of inspecting the surface along the outcrop and looking for signs of subsidence from old

deep workings. But in all other respects mining was similar to conventional small-scale surface mining, including shooting of the overburden.

State and federal reclamation laws passed in the 1970's included strict provisions concerning replacement of topsoil and final contouring of land. A variety of earthmoving equipment that had long been used in the construction industry began to see widespread use in the coal-mining industry. Besides larger and more powerful bulldozers, tractor-towed scrapers, hydraulic excavators, and front-end loaders proliferated at surface mines. Such equipment proved essential in meeting the legal requirements of separately stripping and replacing topsoil and of building necessary ditches, dikes, and settling ponds. As the size, power, and versatility of such equipment increased through the 1970's, some small operations came to rely entirely on scraper-dozers or hydraulic excavator-dozers



Figure 30. Aerial view of a dragline (110-cubic-yard capacity) at work in the AMAX Coal Co.'s Chinook Mine. Photograph courtesy of the AMAX Coal Co.

teams and not only used them for reclamation but also substituted them for draglines. The increasing difficulty of procuring draglines was another incentive for adopting such equipment.

At some operations large clawlike ripping shanks were attached to heavy and powerful tractors. This permitted ripping of overburden that formerly required drilling and blasting (fig. 28).

The all-hydraulic excavator was first produced in Germany in 1954, but it was not introduced to the United States coal industry until 1975. After 1976 demand for such equipment—both in front-shovel and backhoe configurations—grew rapidly, and several American companies began challenging German manufacturers with their own models. Within a few years models were available with bucket capacities of 40 cubic yards and capability of penetrating a face to a height of

39 feet. In 1978 the Sugar Creek Mine in Indiana was reported to be the first all-hydraulic-shovel mine in the United States. Excavators with 10-cubic-yard buckets were used at that operation to strip overburden. Many hydraulic excavators in several different configurations are currently used for various tasks at Indiana surface mines (fig. 29).

RADIOS AND AERIAL MAPPING

During 1948 the Sunlight Coal Co. installed two-way FM radio units that linked operators' cabs on stripping shovels with the company's main office. With properties scattered over 200 square miles, the 20- to 30-mile range of the radios ensured more effective and inexpensive control of operations by management. By 1950 radios were being installed at other operations. The transmitting and receiving units installed in the company cars were bulky and occupied much of the trunk

space. The radios found their greatest use in calls for equipment parts and calls for emergency maintenance and restoration of power.

What two-way radios did for strip-mine management, the use of aerial mapping did for strip-mine engineering departments. Both owed much to wartime developments. Although aerial surveys of stripping operations had occasionally been conducted for many years, before 1950 most strip-mine operators performed resource evaluations, geologic studies, reclamation planning, and topographic mapping by ground-based methods. During the late 1940's, however, strip-mine operators discovered that aerial topographic mapping had been refined to the point that it could meet any civil-engineering requirement. Therefore, maps of acceptable quality could be obtained at less than two-thirds (and for some at less than one-fifth) the cost of those produced by ground surveys, and the photographs themselves could be used in the office for stereoscopic studies and the production of photomosaics that served as excellent reconnaissance maps (fig. 30).

RECLAMATION AND THE FORMATION OF FARM COMPANIES

Strip-mining laws passed before the mid-1960's in West Virginia, Pennsylvania, Ohio, Illinois, and Indiana had certain common features. Operators were required (1) to obtain licenses or permits (costing upward from \$50 per year and in some places requiring additional acreage charges), (2) to post bonds (as much as \$1,000 per acre in Pennsylvania, but generally less than \$5,000 total), (3) to file progress reports, and (4) to grade and replant the mined area. The regulations governing reclamation varied widely; some states required only that no unmined coal be left exposed, and other states required leveling of the mined areas and careful reforestation or restoration to agricultural use. Therefore, the costs of reclamation varied widely from state to state, and operators in each state argued against stricter regulations on the ground that they would be placed at a competitive disadvantage with their neighbors.

In 1941 the State of Indiana passed a law

requiring the planting of trees on spoil banks. In 1939 West Virginia had been the first state to enact a law controlling surface mining, so that Indiana was the second state to take such action. Indiana's first reclamation law required that companies attempt to revegetate mined land, but there was no provision to ensure that such efforts would be successful. Emphasis was placed on establishing forests or pastures.

In 1951 the law was amended to allow the planting of farm crops, hay, and grasses and to allow the use of reclaimed land for grazing as well as reforestation. Permits for undertaking surface mining were issued by the state at a cost of \$100 to \$500, depending on the size of the proposed operation, and companies were required to revegetate each year an area equal to the area affected by the mining operation. The state also required the posting of bonds of \$200 per acre for every acre affected by mining. After mining was completed, operators were required to grade the tops of ridges to a minimum width of 8 feet and to grade isolated peaks to a minimum width of 15 feet. A rolling topography was required near public highways. Still, there was no provision to ensure that revegetation would be successful.

The law was amended again in 1963. The amendment required that certain acid-forming rocks were to be buried and that land used for agriculture was to be traversable by farm machinery, but bonding requirements were reduced.

Even before the 1951 amendment was passed, R. H. Sherwood had encouraged farming as a sideline for some reserve acreage of his company, and he was anxious to experiment with farming on reclaimed land. By 1956 the Sherwood-Templeton Co. was farming more than 3,000 acres in Daviess, Greene, and Sullivan Counties and was employing a full-time farm manager and 25 farmhands. The farm holdings were divided into three parts: Sherwood-Templeton Farms, Stonefort Farms, and Maid Marian Farms. Maid Marian Farms had started as a cooperative venture between the Sherwood-Templeton Coal Co. and its tenant farmers. The coal company had decided to furnish fertilizer to permit rebuilding of the soil on

parts of its holdings. After the first year of the program some farmers doubled their average corn yields, and Sherwood-Templeton decided to form the corporation Maid Marian Farms.

Other coal companies, such as Ayrshire Collieries Corp., rented much of their farm acreage to tenants on a share-lease basis and also did extensive farming on their own. Between 1939 and 1950 the Ayrshire Collieries Corp. acquired 210 million tons of coal reserves, half of which were surface reserves. In 1945 Ayrshire formed a farming subsidiary, Meadowlark Farms. Involving reserve acreage as well as mined land, agricultural programs under the direction of a farm-management specialist were carried out in Vermillion, Clay, Sullivan, and Pike Counties in Indiana as well as in several counties in Illinois. Projects by Ayrshire included the establishment of a herd of hogs in Vermillion County, sheep and cattle in Illinois, and a tree-nursery project in Pike County.

As the competition between stripping companies to acquire reserve acreage increased, problems in the proper management of this acreage grew. Irwin Reiss, general manager of Meadowlark, said (1950, p. 83): It is only natural when a farmer sells his land on a sales contract to a strip-mining company that he tries to get everything out of that land that he can while he is still on that farm. This means that he is going to plow up every square foot of that land and put it into cash crops. He is going to forget about plowing down clover and following good rotation. He isn't going to maintain his buildings. *** And after the coal company gets title to the land, it is only natural for the new owners, because they are not interested in the farm business, to put the land out on a rental basis as long as it will produce something and somebody is willing to pay the rent.

Although this system presented little problem with land that was destined for stripping in the near future, some companies

in their competition for reserves acquired acreages where stripping was not planned for 5 to 100 years. Reiss noted (1950, p. 83) that " * * * if exploitation practices are permitted to run their course, there will be lots of rundown farm sites and submarginal land in communities that otherwise would be prosperous." By 1950 Ayrshire had begun farm projects involving more than 27,000 acres, and only 3 years later its farming operations embraced 57,270 acres of stripped and reserve land in Illinois, Indiana, and Kentucky. Much of the strippable land in southern Illinois and southwestern Indiana is overlain by eroded or naturally infertile, nonproductive acres. Where small farmers had been scratching out a subsistence existence, much land was improved and made more productive under the central control and with the financial backing of the mining companies. Where possible, scientific methods of soil treatment were used to rebuild land damaged by improper farming methods, and in other areas progress was made in reforestation or in rendering the land suitable for livestock farming. By 1953 Meadowlark Farms was annually producing large quantities of beef, pork, and mutton. Published articles describing Meadowlark's operations emphasized the efforts made to restore nonproductive land, but large acreages of fertile, productive land were also acquired along with the bad by the corporate farms, and in mining districts dramatic and permanent changes in landownership patterns were made.

Beginning in the early 1960's, public concern for the environmental and health effects of coal mining and coal use began to heighten. The first reclamation law in Illinois was passed in 1961. Before that time reclamation had been carried out under various voluntary programs, so that when the law was passed, only about 55 percent of the mined land in that state had been successfully reclaimed. The strip-mine law of Pennsylvania

Figure 31 (on facing page). Highwall, pond, and grasslands resulting from surface mining in Warrick County. A, This unreclaimed highwall was left by surface-mine operators before present reclamation laws were passed. B, This pond and these grasslands were created by a surface-mining company working under present reclamation laws. A shovel, a drill, and a dragline are visible on the horizon.



A



B

that was amended in 1964 imposed much more stringent regulations on operators, and reclamation laws in Illinois and Indiana were again tightened in 1967.

The Indiana law of 1967 was the first major revision since 1941. This law was to be administered by the Department of Natural Resources, formerly the Indiana Department of Conservation but renamed in 1965. Operators were required to plan in advance for use of the land after mining was completed. Standards were established for leveling peaks and ridges and creating lakes. On reclaimed land to be used for row crops, grades were not to exceed 8 percent, and maximum slopes of 25 percent and 33 percent were set for land to be used for pasture and for forest. The operators were charged a fee of \$50 plus \$15 per acre to be mined. Performance bonds of \$2,000 or 300 times the number of acres involved, whichever was greater, were also to be posted. Repayment of the bond was to be withheld until reclamation was established and the success of revegetation was ensured. Fines as much as \$5,000 could be levied for failure to observe the provisions of the law. The law was amended in 1974 and in 1977 to change fee and bond requirements.

Political talk and legislative action became particularly heated in other states, such as Kentucky, West Virginia, and Ohio. Kentucky passed a surface-mining law in 1966. In West Virginia a stringent surface-mine act was passed in 1967, and in 1971 an amended strip-mining law placed a 2-year moratorium on strip mining in 22 of the state's 55 counties where there had previously been no such mining. A new surface-mining law, based on Pennsylvania's law and requiring much more detailed preplanning of reclamation than the previous regulations, was enacted in Ohio in 1972. Enactment of legislation in West Virginia and Kentucky severely restricted the use of conventional contour mining in the mountainous regions of those states. New techniques, such as haulback (lateral-movement) mining and mountaintop removal, were developed there to cope with the new legal conditions.

Lack of federal involvement had been an

impediment to passage of needed mining laws. State legislators had been reluctant to enact regulations that might place the mining industry of their state at a disadvantage in competing with the industries of states with less stringent regulations. But by the late 1960's the federal government was heavily involved in formulating regulations to govern surface mining of coal as well as other minerals. Bills were introduced to require permits, advance mining and reclamation plans, performance bonds, and enforcement, and criteria were proposed regarding water pollution, air pollution, and reclamation. Finally, in August 1977, the Surface Mining Control and Reclamation Act was signed into law. Besides establishing minimum national standards for the conduct of mining and reclamation, the act of 1977 created the Office of Surface Mining Reclamation and Enforcement. It also provided that mining and resource research institutes and coal-research laboratories be established in various coal-producing states. The Abandoned Mine Reclamation Fund, supported by a severance tax on coal, was created for reclaiming mined lands that had been inadequately restored before passage of the act of 1977.

Because of the diverse mining conditions in the United States, primary responsibility for developing and enforcing regulations was left to the states. But eight performance standards dealing with topsoil, hydrology, dams and embankments, use of explosives, contour of the land, and revegetation following mining were established by the law. Special standards for mining on steep slopes and prime farmland were also established. Civil penalties (as much as \$5,000 per day) and criminal penalties (as much as \$10,000 and 1 year in prison) were authorized for violation of the act.

The act of 1977 met strong resistance from many persons in the coal-mining industry. Hundreds of companies have brought dozens of legal suits against those government agencies involved in formulating and enforcing the act. Several provisions of the act have been challenged as being too restrictive. Litigation continues at present. The mining industry has also supported congressional

action aimed at modifying the act. Although the industry has vigorously challenged the act in the courts, compliance by coal companies with provisions of the act has generally been good. The scars of past mining remain highly visible, but present companies that comply with current laws restore the land to a condition that is almost indistinguishable from natural landscapes (fig. 31).

MAJOR COMPANIES

After 1950 a great merger movement gained momentum in the United States. The character of these mergers differed from that of previous mergers. After 1960 most mergers involved the formation of conglomerates, by which one company acquired another company in an unrelated field. Studies in the early 1950's suggested that profits were disproportionately higher in industries in which productive capacity was largely controlled by only a few companies. The idea that large companies and industries with concentrated ownership were in a better position to perform basic and applied research and to improve productivity, were financially stronger, and benefited from better professional management was promoted. It was also generally believed that such industries would be better able to deal with labor and possibly to wield some influence on price levels.

As late as the mid-1950's most small- and medium-sized companies in the bituminous coalfields of the Midwest and elsewhere were still family owned or were closely controlled by a single family or a small group of families. This situation in the major coal-producing regions was to change first in the Midwest, where concentration of ownership rapidly increased after the mid-1950's. By 1960 the top 20 coal companies in the Midwest controlled 89 percent of production, and the top four companies controlled 52 percent. Accompanying this increase in concentration was an increase in the operating rate of midwestern mines above the national average, a decline in excess capacity, a great increase in average mine size, a disproportionate share in the highly desirable national utility market, and higher average company earnings on net worth than for eastern coal companies. These

conditions in the Midwest seemed to bear out the predictions of some economists regarding the advantages to be reaped from greater industrial concentration.

A great and far-reaching change in the ownership of coal companies took place in the late 1960's. Unlike merger movements in the early 1900's and late 1920's, when coal companies acquired other coal companies in the same or different geographic regions, even the largest coal companies were subject to acquisition by corporations that had previously had no interest in coal mining. Oil companies and diversified-mining companies were the most important group of purchasers.

The first important merger in the coal industry occurred in 1959, when the Freeman Coal Co., ninth largest coal-producing company in the United States, was acquired by the General Dynamics Corp. In 1966 the nation's second largest coal producer, the Consolidation Coal Co., was acquired by the Continental Oil Co. In 1968 the nation's largest coal producer, the Peabody Coal Co., was acquired by Kennecott Copper, and in the same year the third largest coal company, the Island Creek Coal Co., was acquired by Occidental Petroleum. After these three giants of the coal industry had fallen, most other coal companies were subject to acquisition within a few years.

PEABODY OPERATIONS IN INDIANA

The Peabody Coal Co. was formed in 1955 by consolidation of the original Peabody Coal Co. (reincorporated in Illinois in 1928, when it consolidated almost a dozen companies) and the substantially larger Sinclair Group of eight companies (also centered in the Midwest and including the Sentry Royalty Co., the Sinclair Coal Co., and others). As a result of the merger, Peabody commanded assets of more than \$100 million and had reserves of 1.7 billion tons. Supplying 27 electric-utility companies under contracts ranging in length from 1 to 28 years, Peabody soon assumed the rank of the nation's second largest coal company.

The Sinclair Coal Co. had acquired the Victoria Coal Corp. in 1951 and had opened the Victoria Mine in Indiana in 1954. In 1955

operations began at the new Lynnville Mine near Boonville, and in 1957 the company acquired one-half interest in the Tecumseh Coal Corp. of Indiana. With a projected output of 2 million tons per year, the Lynnville operation was destined to be the state's largest surface operation. Coal from Peabody's operations was sent to market in railroad cars of the New York Central Railroad, in trucks for distribution to local industrial plants, and in Ohio River barges loaded at the Yankeetown Dock (a joint venture) near Newburgh. Late in 1959 Peabody went on to acquire the four mining properties of the Maumee Collieries Co. of Indiana, which had an annual production of about 1.6 million tons at that time.

In only 3 years, between 1954 and 1957, Peabody's annual national production skyrocketed from about 7 million tons to 23 million tons, surpassing the output of U.S. Steel in 1957. Peabody, one of the first American coal companies to seek and achieve an international position, began exploratory drilling and mining in Australia in 1956. By 1960 Peabody's production of almost 29 million tons was nearly equal to that of Pittsburgh Consolidated. Other important companies were acquired in Ohio and Illinois, and joint ventures were undertaken in Kentucky and Ohio. Additional expansion into Missouri, Oklahoma, Arkansas, Colorado, and Alabama soon followed. Peabody's shipments of coal from its Big Sky Mine, opened in 1968 near Colstrip, Mont., marked the beginning after 1968 of the invasion of midwestern markets by western coal. Prospecting in the southwestern United States resulted in the location of the Black Mesa reserves, where mining began in 1970 on 64,000 acres of reservation lands belonging to the Navajo and Hopi Indians. Mining operations began in Utah in 1972. By 1970 Peabody's coal reserves exceeded 8 billion tons, and its annual production was about 60 million tons. Since 1971 Peabody has been the nation's leading coal producer. Production in 1982 was 57.7 million tons.

Peabody was a highly successful and still-growing company when it was acquired by Kennecott in 1968. Shortly afterwards the Federal Trade Commission issued a complaint

alleging that Kennecott's acquisition of Peabody was a violation of section 7 of the Clayton Act. Divestiture was sought on the ground that the transaction would substantially lessen competition. In 1977 Peabody was sold to a consortium of six companies.

Almost half of the major active and inactive surface mines in Indiana shown in figure 2 belong to Peabody or its predecessor companies.¹ Controlling large tracts of surface lands in Indiana—almost twice as many as any other coal company—Peabody and its affiliated companies should remain Indiana's principal coal producer for many more years.

AMAX OPERATIONS IN INDIANA

The Ayrshire Collieries Co. was formed in 1939 by the merger of two Indiana surface-mining companies, the Patoka Coal Co. (associated with the Globe Coal Co.) and the Electric Shovel Coal Corp. (a successor of the Mid-Continent Coal Co.). By 1963 the company had grown to become the eighth largest coal company in the nation; its output was 7.8 million tons from 11 active operations in Indiana, Illinois, and western Kentucky. Ayrshire's reserves were estimated to be more than 700 million tons. Subsidiary companies were involved in selling Ayrshire's production (Republic Coal & Coke), in farming reserve and reclaimed coal lands (Meadowlark Farms, Inc.), in loading Ayrshire's production onto rail and river barges (Yankeetown Dock Corp.), and in developing and producing railroad accessories (Railway Service & Supply Corp.). The company also acquired substantial reserves in some western states.

AMAX, Inc., is a diversified company producing a wide variety of mineral commodities, including aluminum, iron ore, petroleum, lead, nickel, copper, and molybdenum. The company began coal production after it acquired Ayrshire Collieries in 1969.

The acquisition of Ayrshire by AMAX was

¹In acquiring many mines, Peabody and other successor companies acquired only part of the assets and assumed only part of the obligations of predecessor companies. Also, several major mines in Indiana are joint ventures involving coal, utility, and other companies.

agreeable to both sides. AMAX quickly effected changes in the management and the policies of Ayrshire. The name Ayrshire was dropped in 1972, when the company became AMAX Coal.

The AMAX Coal Co. soon opened two new midwestern surface mines, the Leahy Mine (1971) in southern Illinois and the Ayrshire Mine (1974) in Indiana. In 1973 the Belle Ayr Mine in Wyoming was opened. Planned to be the largest surface coal mine in the nation, the mining complex near Gillette, Wyo., comprised 950 million tons of reserves in two large blocks. Production of low-sulfur sub-bituminous coal from the complex was 24 million tons per year by 1980. Coal is shipped to utilities as far away as Ohio and Louisiana. By 1982 AMAX Coal's production had grown to 38.9 million tons.

Eight of the major surface mines in Indiana shown in figure 2 belong to AMAX or its predecessor companies. AMAX and its affiliated companies have large tracts of surface lands in Indiana and lease substantial additional acreage.

OLD BEN AND BLACK BEAUTY OPERATIONS IN INDIANA

Since 1909 Old Ben Coal has been a major producer of coal in southern Illinois from a series of large underground mines. In 1965 the company extended its operations into Pike, Warrick, and Gibson Counties, Ind., after it purchased the Enos Coal Mining Co. from the Interlake Steel Corp. Interlake received cash and stock in Old Ben and entered a 15-year contract with Old Ben to purchase coal for use in coking at its operations in Chicago. Other coal mines in Indiana were acquired from the Princeton Mining Co. and the Blackfoot Coal and Land Co. When it was the ninth largest coal-producing company in the nation, Old Ben became a wholly owned subsidiary of Standard Oil of Ohio (Sohio) in 1968.

In recent years the Black Beauty Coal Co. has consistently ranked as the fourth largest coal-producing company in Indiana, and its annual production in 1984 was equal to about 54 percent of Old Ben production.

WESTERN COAL MOVING EASTWARD

During the 1950's, because of increasing rail-transportation costs, serious efforts were made to develop coal-slurry pipelines. Although railroad companies have successfully combated this threat legislatively, they also have undertaken steps to lower freight rates, so that rail transportation would be competitive with other forms of transporting coal.

In 1963 several eastern railroads began using unit coal trains and integral coal trains. Unit trains are trains of conventional size and equipment that operate between a single origin and destination with private cars and assigned locomotives on a regularly scheduled cycle. Integral trains differ from unit trains in that they are larger and specially designed to load and unload rapidly. In the Midwest, early in 1963 Peabody Coal made an agreement with the New York Central and the Northern Indiana Public Service Co. to supply coal with special 100-car trains from its mines near Lynnvile to power plants in Hammond.

Before 1960 coal mining west of the Great Plains had been insignificant compared with coal mining in the eastern states, but throughout the 1950's exploration and leasing were done in all the coal-bearing states of the West, from Montana and Washington to New Mexico and Arizona. In 1960 a breakthrough was made by a coal company into the utility-fuel market of the Southwest (previously dominated by gas and oil), and a coal leasing and mining boom began in Utah, New Mexico, and Arizona.

Once the exploration, leasing, and development of western coalfields had begun, coal companies soon began to turn to long-established and large markets in the Midwest as well as to the rapidly growing markets of the Southwest and the Pacific Coast. With the development of unit trains and the passage of restrictions on the sulfur content of coal burned in power plants, western production began to encroach on coal markets of the Midwest. In August 1968 the Peabody Coal Co. announced an agreement to supply 2 million tons of low-sulfur coal per year to a utility in Minnesota. From a new mine near Colstrip, Mont., coal traveled 850 miles

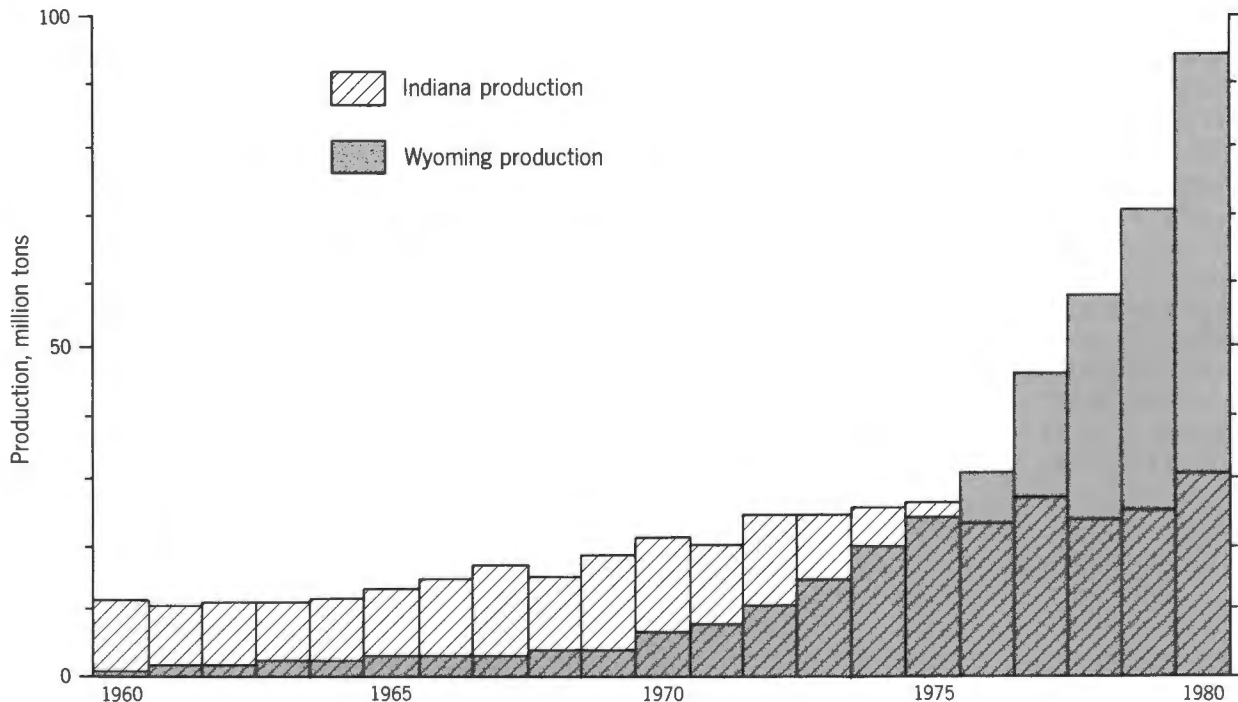


Figure 32. Graph showing production of surface-mined coal in Indiana and Wyoming, 1960-80. Production of coal from surface mines in Indiana has shown modest growth since 1970, but production from surface mines in newly developed coalfields in Wyoming has grown spectacularly and is mostly destined for out-of-state consumption.

eastward on unit trains of 12,000-ton capacity.

By the early 1970's tightening supplies of natural gas, increasingly long and costly lead times for nuclear power plants, restrictions on the sulfur content of coal, and questions regarding the reliability of flue-gas desulfurization techniques left eastern and midwestern utilities scrambling for low-sulfur coal. As sulfur restrictions tightened, midwestern utilities sought low-sulfur coal from mines as far west as Utah. Between 1969 and 1970 shipments of low-sulfur coal on the Burlington Northern Railroad doubled, and experiments were undertaken with transferring such shipments onto Great Lakes vessels. Through history the overall national flow of coal had been westward, but now the flow was clearly changing. In size the most notable single mining development was the AMAX Coal Co.'s Belle Ayr Mine, opened in the Powder River Basin in Wyoming in 1972. In 1981

production from this single mining complex was 15 million tons—equal to half of Indiana's total production. By mid-1973 coal was traveling from Montana and Wyoming by unit train as far east as Chicago. In 1981 Wyoming produced 103 million tons of coal (fig. 32) and Montana produced 33 million tons. In that year 2.8 million tons of Wyoming coal reached as far east as Ohio and 8.6 million tons and 2.6 million tons were shipped to Illinois and Indiana. Greater penetration of midwestern markets may yet occur.

By 1982 western coal represented 27 percent of national production. Technologic developments in the gasification, liquefaction, or desulfurization of high-sulfur eastern coals could greatly diminish the attraction of western coal to eastern consumers. The competitive balance between coal produced in the West and in the Midwest is also sensitive to changing freight rates. Higher freight rates or continued blockage of more efficient

transport by slurry pipelines might be beneficial to Indiana producers. But many large companies have huge investments in western reserves and are committed to their exploitation. Extra-high-voltage electrical transmission, unit trains, and slurry pipelines are now permanent features of the economic landscape, and the thickness of some western-coal deposits and the relative ease with which they can be mined and transported promise to make western coals attractive to eastern consumers. Some western surface mines have been developed on a scale vastly greater than the largest midwestern surface mines. Innovations in equipment design and mining procedures suitable for use under western geologic, topographic, and climatic conditions have been abundant, but many of these innovations have little applicability to midwestern conditions.

Summary

Surface mining of coal requires the removal of vast quantities of valueless overburden, and significant surface mining did not develop until about 1911, when equipment manufacturers made available shovels of size, power, and maneuverability adequate for the task. Miners of surface coal were active in Indiana at least as early as 1893, and by 1915 about 600,000 tons of surface-mined coal was being produced annually in the state. Periods of rapid growth in production occurred in Indiana during 1921-29, 1933-42, 1963-72, and 1979-80, so that by 1982 more than 29.8 million tons of surface-mined coal was produced annually in the state. Through history surface mines of the state have produced more than 800 million tons of coal.

Shortly after World War I a boom began in Indiana. Numerous mining and land companies leased land throughout the 1920's, first in Pike County and later in Warrick, Sullivan, and Clay Counties. The Sherwood-Templeton Coal Co., the Central Indiana Coal Co., the Ayrshire Collieries Co., the Enos Mining Co., and the Maumee Collieries Co. were among the most successful of the early mining companies. They were moderate-sized regional companies, and their survival depended on their ability to open up new midwestern reserves through technologic advance. Large

mines made possible by geologic and topographic conditions in Warrick, Pike, Sullivan, Greene, Clay, Vigo, and Vermillion Counties have played an important role. During any given year for the past 40 years, fewer than 20 large active mines have accounted for more than two-thirds (and in some years as much as 96 percent) of the state's annual surface output.

Reserves of surface-minable coal are subject to constant redefinition as technologic advances make possible the removal of greater thicknesses of overburden and the exploitation of deeper coal. From 1911 to 1968 the maximum bucket capacity of shovels and draglines increased from 3 cubic yards to 220 cubic yards. This technologic advance, together with advances in supporting mining services, meant that the maximum depth of coal capable of being recovered increased from less than 30 feet to 190 feet. But the current official estimate of the reserves of surface-minable coal in Indiana is about 1.8 billion tons, or only about 2.3 times the total amount that has already been mined.

During and after the economically difficult period from 1950 to 1964, many of the mines and reserves of the early mining and land companies of Indiana were acquired by the Peabody Coal Co. (1955-59), the Old Ben Coal Co. (1965), and the AMAX Coal Co. (1969). By the late 1970's outright ownership of surface lands by coal companies amounted to more than 220,000 acres in 13 counties (fig. 33). Almost 90 percent of this acreage was owned by the three largest companies. Sixty-eight percent of Indiana's total coal production in 1982 was derived from mines operated by the three largest companies.² Besides the three major companies, about 50 other companies have been actively engaged in producing coal in Indiana in the early 1980's. Fewer than six of these have consistently produced more than 500,000 tons per year each, but recent production trends strongly indicate that these smaller companies will continue in the near future to grow in absolute and relative importance in Indiana's coal industry.

² This includes joint ventures with nonmining companies.

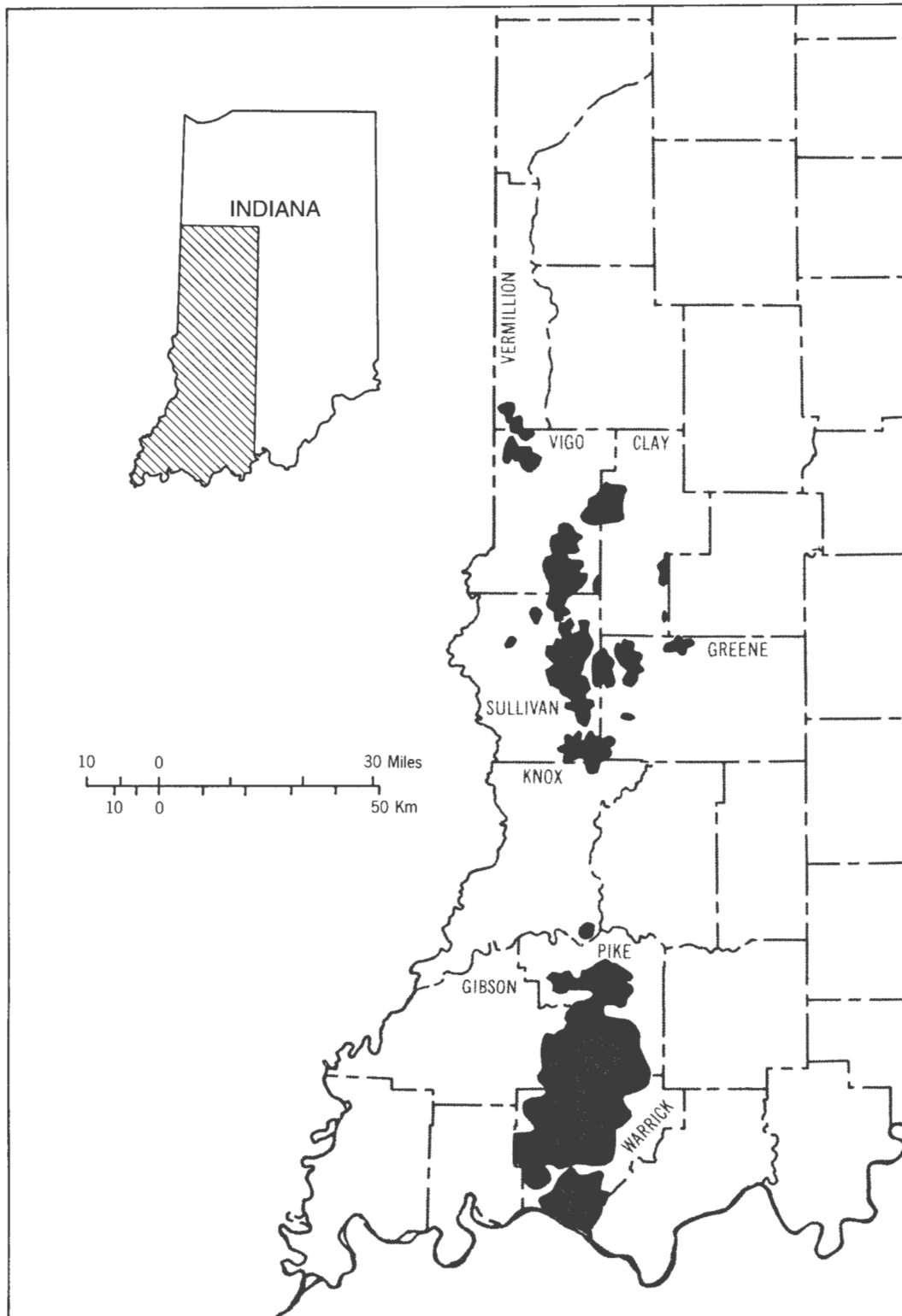


Figure 33. Map showing areas in Indiana in which ownership of surface lands by coal companies is significant. Compiled from information in county platbooks.

Until recently, accessibility to markets and geologic and topographic conditions favorable to the development of area-type mining made the midwestern states of Ohio, Indiana, and Illinois foremost among surface-mining states, and the surface-mining companies of those states were pioneers in technologic advance. Maximum growth of shovels and draglines occurred between 1956 and 1969, when certain individual companies were aggressively expanding by merger, acquisition of reserves, and increase in capacity. The development of more efficient methods of transporting coal (after 1961), the replacement of regionally based companies by nationally based companies (after 1966), and the opening of surface mines in western states (after 1968) may reduce the incentive for further technical advance along conventional lines—that is, deeper mining with larger shovels and draglines. The interdistrict competition that formerly served to spur technologic advance applicable to midwestern surface mining may operate less effectively. If no further significant technologic advance occurs, existing surface-minable reserves in Indiana could sustain production at current levels for several decades, after which the successive closing of large area-type surface mines would bring to an end the era of large-scale surface mining in the state. Production might then once again be contributed primarily by regionally based companies working relatively small tracts with smaller equipment and more flexible techniques than those currently used by large companies. Even though the combined production of such smaller operations might increase, the loss of production from large operations would probably result in an overall decline in Indiana's coal output and increased importation of coal from other states.

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