GEOLOGICAL SURVEY CIRCULAR 891

Coal Resource Classification System of the U.S. Geological Survey

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By Gordon H. Wood, Jr., Thomas M. Kehn,
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FOREWORD

In order to use coal resource terms with precision and common understanding and to compare resource data effectively, the authors developed a standardized, definitive, broadly applicable classification system to derive uniform, coordinated coal resource estimates. The principles of the system for all mineral resources are given in USGS Circular 831. Personnel engaged in coal resources work are to use the definitions, criteria, guidelines, and instructions incorporated in this coal resource classification system in all U.S. Geological Survey publications.

Director, Geological Survey

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Coal Resource Classification System of the U.S. Geological Survey

By GORDON H. WOOD, JR., THOMAS M. KEHN, M. DEVEREUX CARTER, and WILLIAM C. CULBERTSON

INTRODUCTION

Coal is the most abundant fossil fuel in the United States. Knowledge of the size, distribution, and quality of the Nation's coal resources is important for governmental planning; industrial planning and growth; the solution of current and future problems related to air, water, and land degradation; and for meeting the short- to long-term energy needs of the country. Knowledge of the Nation's coal resources is also important in planning for the exportation and importation of fuel.

Many estimates have been made of the coal resources of the Nation, the resources of other nations, and for the world as a whole. Because of differing systems of resource classification, these estimates vary greatly in magnitude within this Nation and other nations; geologic analysis shows some of these estimates to be little more than educated guesses. The accompanying coal resource classification system of the U.S. Geological Survey is recommended as an aid in solving the problems caused by the differing systems.

A detailed resource classification system should identify deposits of coal by areal location, distance from points of information, thicknesses of coal and overburden, rank and quality, and estimates of quantity. Classes in the system, furthermore, should impart some idea as to economic, technologic, legal, and environmental factors affecting the availability of coal.

A coal resource classification system was published jointly by the U.S. Bureau of Mines and the U.S. Geological Survey in 1976 as Geological Survey Bulletin 1450–B and was believed to be a successful modification of an already existing system into the ideal system. However, Bulletin 1450–B left unanswered many questions concerning how to estimate coal resources and did not provide sufficient criteria, guidelines, and a methodology so that comparable estimates would be obtained by all workers using the same data.

The Survey and the Bureau of Mines decided in 1977 that the coal resource classification system, as outlined in Bulletin 1450–B, should be revised and expanded to provide a more definitive and less ambiguous coal resource classification system. The revision was to document standard definitions, criteria, guidelines, and methods to be used in estimating coal resources. Standardization of the elements of the system should result in comparable estimates by different workers using the same data.

In 1980, the two agencies published Circular 831, "Principles of a Resource/Reserve Classification for Minerals" (U.S. Geological Survey, 1980). The circular, which outlines a classification system for all mineral commodities, filled the classification needs of the Bureau of Mines, which was no longer responsible for coal resource classification, and was the basis for this revision of the coal resource classification system by the Geological Survey. The revision, embodied in this report, has two main objectives: (1) to provide detailed information lacking in Bulletin 1450–B; and (2) to provide standard definitions, criteria, guidelines, and methods required for uniform application of the principles outlined in Circular 831.

HISTORY OF THE CLASSIFICATION SYSTEM

Almost since their inceptions in 1879 and 1920, respectively, the U.S. Geological Survey and the U.S. Bureau of Mines have conducted modest ongoing programs in coal resource estimation and analysis. Between

1909 and World War II, tonnage estimates of the coal resources and reserves of the United States were summary totals derived for areas from estimates that were calculated by gross statistical methods. These early estimates were inadequate for the needs of the 1940's because they did not separate thin from thick coal beds, distinguish shallow from deeply buried coal, separately quantify identified resoures and undiscovered resources, or discriminate the quality and rank of coal on the basis of physical and chemical criteria.

After World War II, requests from the public indicated the need for more detailed information about the occurrence, distribution, and availability of the Nation's coal resources. These requests indicated that a more detailed coal classification system was needed and that it should be based on bed-by-bed analysis of thicknesses of coal and overburden, reliability (distance from control points) of areal data, rank of coal, and several chemical parameters related to determining quality and usage. As a result, ongoing programs of the Geological Survey and the Bureau of Mines for geologic mapping and engineering evaluation were expanded, and programs for appraising the coal resources of the Nation on a State-by-State and a bed-by-bed basis were initiated.

After much consultation with potential users, the Geological Survey and the Bureau of Mines revised their procedures and prepared new definitions, criteria, and guidelines to be followed in estimating coal resources. The main elements of the programs used after World War II to 1976 were as follows:

1. Estimates of resources and reserves were based on existing information. Initially, attempts were not made to estimate the Nation's total coal resources or reserves; however, such estimates were long-term objectives.
2. Estimates of resources and reserves were prepared on a State-by-State basis.
3. Estimates of resources and reserves were divided into precisely defined categories such as rank, thicknesses of coal and overburden, and distance from points of information.

The estimates of coal resources and reserves from World War II to 1976 were prepared in formats suitable for use by geologists and engineers, coal specialists, and economists working for the coal industry and government. These formats included geologic maps, coal bed maps, tables, and diagrams of resource and reserve data segregated into categories suitable for comparison with similarly categorized data from other sources.

Experience with the classification system utilized from World War II until 1976 gradually showed the need for still greater detail. It also showed the need for rigidly enforced standards that would lessen individual geologic and engineering judgments in the interpretation of data and methods. Adoption of such standards should result in reproducible and comparable estimates from the same data and would allow adoption of computer technology.

In 1976, the Geological Survey and the Bureau of Mines adopted a modification of the 1944–75 system by publishing U.S. Geological Survey Bulletin 1450-B titled "Coal Resource Classification System of the U.S. Bureau of Mines and U.S. Geological Survey." This bulletin has been the standard reference for coal resource/reserve work by many Federal and State agencies.

COAL RESOURCE CLASSIFICATION SYSTEM

The classification system presented herein is an expansion of the system adopted in 1976. It employs a concept by which coal is classified into resource/reserve base/reserve categories on the basis of the geologic assurance of the existence of those categories and on the economic feasibility of their recovery. Categories are also provided for resources/reserve base/reserves that are restricted because of legal, environmental, or technologic constraints. Geologic assurance is related to the distance from points where coal is measured or sampled; thicknesses of coal and overburden; knowledge of the rank, quality, depositional history, areal extent, and correlations of coal beds and enclosing strata; and knowledge of the geologic structure. Economic feasibility of recovery is affected not only by such physical and chemical factors as thicknesses of coal and overburden, quality of coal, and rank of coal, but also by economic variables—such as price of coal, cost of equipment, mining, labor, processing, transportation, taxes, and interest rates, demand for and supply of coal, and weather extremes—and by environmental laws, restrictions, and judicial rulings. For example, the Clean Air Act of 1970 issued standards that severely limited the emission of sulfur by new coal-burning powerplants and, as a result, made the low-sulfur, low-rank coal deposits of the Northern Great Plains economically competitive. Similarly, environmental restrictions on the surface mining of coal and the need for adequate reclamation of mined areas has adversely affected the economic and technologic feasibility of extracting coal from some near-surface deposits.

The classification system is designed to quantify the total amounts of coal in the ground before mining began (original resources) and after any mining (remaining resources). It is also designed to quantify the amounts of coal that are known (identified resources) and the amounts of coal that remain to be discovered (undiscovered resources). The system also provides for recognizing amounts of coal that are (1) standard distances from points of thickness measurements—measured, indicated, inferred, and hypothetical; (2) similar to coal currently being mined (reserve base and inferred reserve base); (3) economically recoverable currently (reserves and inferred reserves); (4) potentially recoverable with a favorable change in economics (marginal reserves and inferred marginal reserves); and (5) subeconomic because of being too thin, too deeply buried, or lost-in-mining. Finally, the system allows tabulation of coal amounts that are restricted from mining by regulation, law, or judicial ruling.

Two factors have created difficulties in categorizing resources and reserves in all classification systems. First, most geologists and engineers who classify resources and reserves are not experts in the economics of mining, transportation, processing, and marketing. Second, economic conditions change with time, so that the economic viability of coal is relatively fluid. For example, subeconomic resources of today can become reserves of tomorrow as the price of coal rises; conversely, reserves can become subeconomic resources as the price of coal drops. Finally, changing regulations, laws, and judicial rulings can affect mining, transportation, processing, and marketing, and thus the classification of coal resources. The concept of a reserve base was developed to alleviate these difficulties (U.S. Geological Survey, 1976, p. B2).

The reserve base is identified coal defined only by physical and chemical criteria such as thicknesses of coal and overburden, quality, heat value, rank, and distance from points of measurement. The criteria for thickness of coal and for overburden have been selected so that the reserve base includes some currently subeconomic coal. The concept of the reserve base is to define a quantity of in-place coal, any part of which is or may become economic depending upon the method of mining and the economic assumptions that are or will be used. An additional purpose is to aid in long-range public and commercial planning by identifying coal suitable for economic recovery.

Thus, resource specialists need not expend their time identifying the component parts of coal deposits that are currently economically recoverable (reserves) because the reserve base category contains much of the coal that will be classed as reserves in the foreseeable future. Those required to classify coal as being economically recoverable, marginally recoverable, or subeconomic can examine reserve base estimates to locate such coal.

Figures 1 and 2 are conceptual diagrams modified from Circular 831 (U.S. Geological Survey, 1980) that show the relationship of the various classes of coal resources, the reserve base, and reserves. The classes are categorized in both figures according to their degree of geologic assurance (geologic assurance or proximity to points of control increases to the left), and according to their degree of economic feasibility of recovery (economic feasibility of mining increases upward). The resource/reserve base/reserve categories (classes) that can be used are not limited to those shown in figures 1 and 2 nor to the categories described in succeeding pages. For example, a particular bed of coal may be identified as being low-sulfur (0–1 percent), low-ash (0–8 percent), high-volatile A bituminous, and premium coking coal; other beds of coal may be identified as medium-sulfur (1.1–3.0 percent), high-ash (> 15 percent), high-volatile bituminous, surface-minable cannel coal, and so forth. The ability of the classification system to precisely describe the characteristics of a body of coal allows the coal resources of the United States to be divided into many hundred resource classes or categories.

The hierarchy of coal resources shown in figure 3 illustrates the conceptual relationships between the classes of resources as distinguished by their definitions and criteria. Examination of figures 1, 2, and 3 makes clear that each succeeding class in the hierarchy from original and remaining resources to reserves is included in the overlying classes. Original resources include remaining resources and cumulative depletion. Remaining resources include identified and undiscovered resources (divisible into hypothetical and speculative resources). Identified resources include measured, indicated, inferred, and demonstrated resources. Measured and indicated resources contain coal classed as reserve base, and inferred resources contain coal classed as inferred reserve base. Some measured, indicated, and inferred resources are subeconomic because they are too thin to mine or are buried too deeply to be mined by current extraction techniques; furthermore, parts of the reserve base and inferred reserve base are potentially subeconomic because they will be lost-in-mining. Reserves and inferred reserves are economically minable as of the time of classification. The reserve base and inferred reserve base also contain some coal that is believed to be potentially economic and which is classed as marginal and inferred marginal reserves.

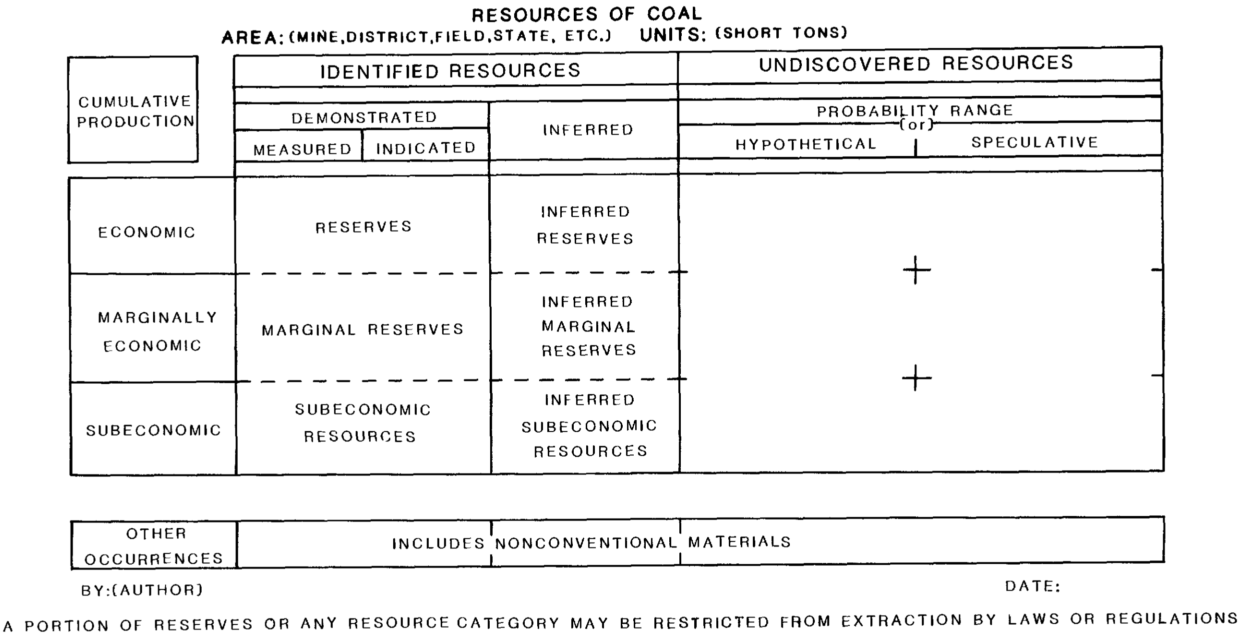

FIGURE 1.—Format and classification of coal resources by reserves and subeconomic resources categories.

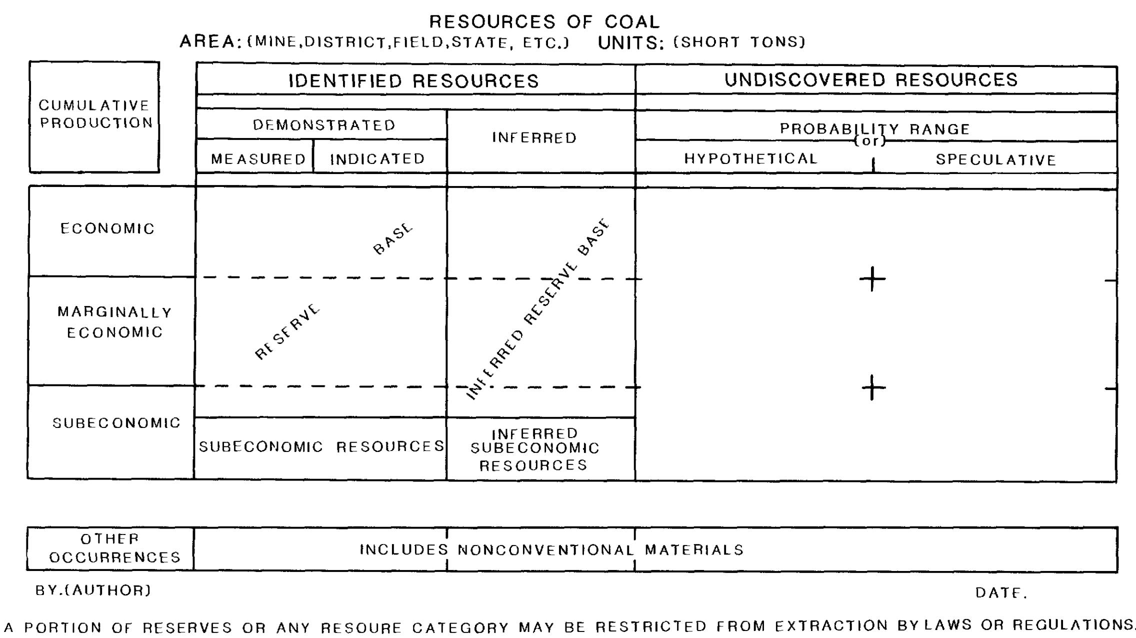

FIGURE 2.—Format and classification of coal resources by reserve and inferred reserve bases and subeconomic and inferred subeconomic resources categories

GLOSSARY OF COAL CLASSIFICATION SYSTEM AND SUPPLEMENTARY TERMS

Some of the following general definitions of coal resources and supplementary terms are amplified elsewhere in this report by criteria and guidelines for usage. The criteria and guidelines may be revised periodically to reflect changing national needs without affecting the definitions.

All definitions herein refer only to usage in this coal resources classification system and are not intended as definitions of the terms relative to any other usage.

Comparative values for units in the metric and English (U.S. Customary) systems of measurement are based on the Handbook of Chemistry and Physics by R. C. Weast (1971, p. F-242-F-263).

Note.—Glossary terms and specific criteria are cross-referenced within this report. To aid the reader, glossary items, beginning below, are printed in **boldface** type, and specific criteria, beginning on p. 24, are printed in ***boldface italics***.

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accessed.—Coal deposits that have been prepared for mining by construction of portals, shafts, slopes, drifts, and haulage ways; by removal of overburden; or by partial mining. See **virgin coal**.

acre.—A measure of area in the United States: 43,560 square feet; 4,840 square yards; 4,046.856 square meters; 0.4046856 hectare; 0.0015625 square mile; 0.0040468 square kilometer.

acreage.—The number of acres at the ground surface

acre-foot (acre-ft).—The volume of coal that covers 1 acre at a thickness of 1 foot (43,560 cubic feet; 1,613.333 cubic yards; 1,233.482 cubic meters). The weight of coal in this volume varies according to **rank**.

acre-inch (acre-in.).—The volume of coal that covers 1 acre at a thickness of 1 inch (3,630 cubic feet; 134.44 cubic yards; 102.7903 cubic meters). The weight of coal in this volume varies according to **rank**.

agglomerating.—Coal that, during volatile matter determinations, produces either an agglomerate button capable of supporting a 500-gram weight without pulverizing, or a button showing swelling or cell structure.

anthracite or **anthracitic.**—A rank class of nonagglomerating coals as defined by the American Society for Testing and Materials having more than 86 percent fixed carbon and less than 14 percent volatile matter on a dry, mineral-matter-free basis. (*Anthracite* is preferred usage). This class of coal is divisible into the semianthracite, anthracite, and meta-anthracite groups on the basis of increasing fixed carbon and decreasing volatile matter. (See table 1.)

ash.—The inorganic residue remaining after complete incineration of coal.

ash content.—The percentage of a laboratory sample of coal remaining after incineration to a constant weight under standard conditions following D-2795-69 (ASTM, 1981, p. 335-342).

ash free.—A theoretical analysis calculated from basic analytical data expressed as if the total ash had been removed.

as-received condition or **as-received basis.**—Represents an analysis of a sample as received at a laboratory.

assess.—To analyze critically and judge definitively the geologic nature or economic potential, significance, status, quality, quantity, potential usability, and other aspects of coal resources and reserves.

assessment.—A critical analysis based on integrating, synthesizing, evaluating, and interpreting all available data aimed at a judgment of the geologic nature or economic potential of the coal resources and reserves of an area, field, district, basin, region, province, county, state, nation, continent, or the world. An *assessment* differs from an estimate, which is a determination of the amount of coal in an area. An estimate or estimates may be the principal data used to assess the coal resources and reserves of an area. See **economic assessment** and **geologic assessment**.

auger mining.—A method often associated with contour strip mining to recover additional coal after the overburden to coal ratio has become too great for further contour mining. Coal is produced by boring into the coal bed much like a carpenter's wood bit bores into wood. An auger consists of a cutting head and screw-like extensions.

bed.—All the coal and partings lying between a roof and floor. The terms "seam" and "vein" should not be used.

bench.—A subdivision and (or) layer of a coal bed separated from other layers by partings of non-coal rock.

bituminous coal.—A rank class of coals as defined by the American Society for Testing and Materials (ASTM) high in carbonaceous matter, having less than 86 percent fixed carbon, and more than 14 percent volatile matter on a dry, mineral-matter-free basis and more than 10,500 Btu on a moist, mineral-matter-free basis. This class may be either agglomerating or nonagglomerating and is divisible into the high-volatile C, B, A; medium; and low-volatile bituminous coal groups on the basis of increasing heat content and fixed carbon and decreasing volatile matter. (See table 1.)

bone coal or **bone.**—Impure coal that contains much clay or other fine-grained detrital mineral matter (ASTM, 1981, D-2796, p. 344). See **impure coal**.

Discussion: The term *bone coal* has been erroneously used for cannel coal, canneloid coal, and well-cemented to metamorphosed coaly mudstone and (or) claystone. *Bone coal* has also been applied to carbonaceous partings. The term "impure coal" accompanied by adjective modifiers such as "silty,"

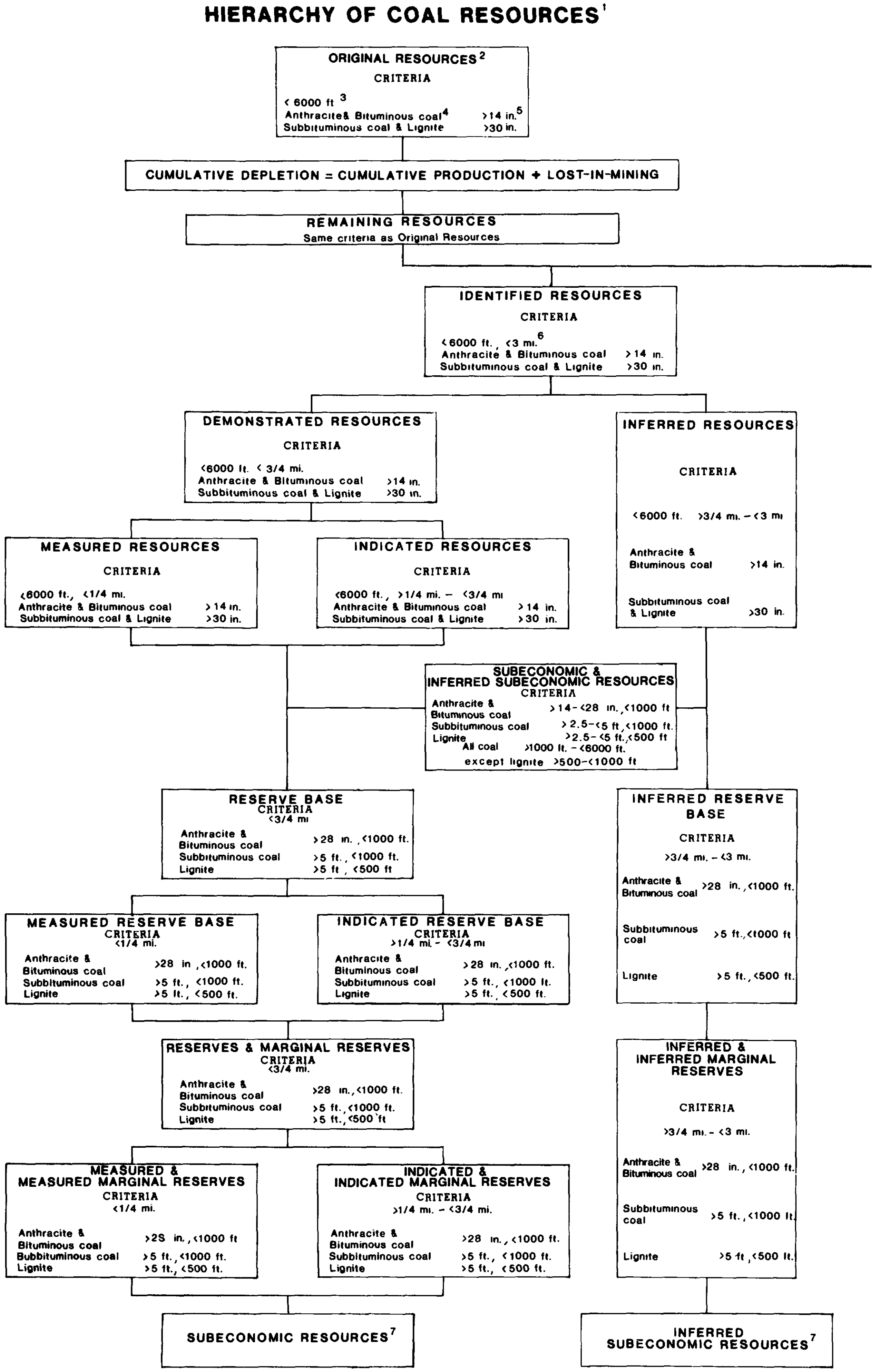
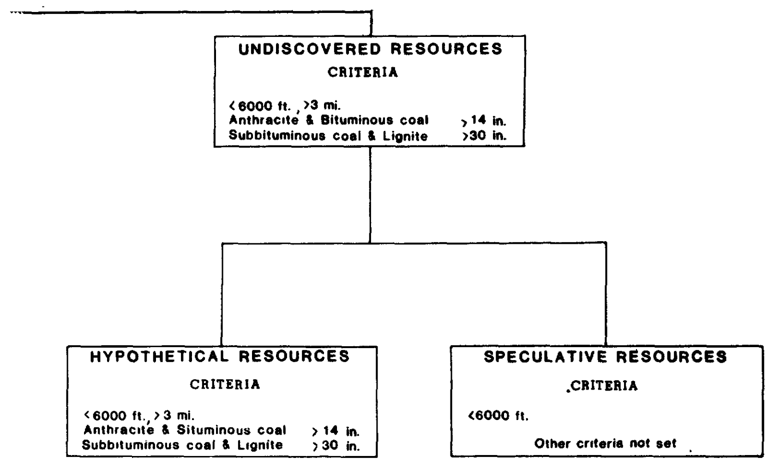


FIGURE 3.—Heirarchy of coal resources and



1 Coal resource terms are defined in glossary.
2. Resources before mining.
3. 500 ft., 1000 ft., and 6000 ft. Depth of burial or overburden thickness.
4. Anthracite, bituminous, subbituminous, and lignite are ranks of coal. See Table t.
5. 14 in., 26 in., 30 in., and 5 ft. are minimum thicknesses of coal.
6. 1/4 mi., 3/4 mi., and 3 mi. are distances from points of measurement of coal thickness.
7. Includes coal left in room and pillar mining, in property barriers, coal too thick to be recovered completely by conventional mining, and mine and preparation plant waste.

NOTE

OTHER OCCURRENCES

Includes coal:

a) less than minimum thickness at any depth

b) containing more than 33 weight percent ash on dry basis

c) buried at depths of more than 6,000 feet

Estimated tonnage, where calculated, is to be reported as "Other Occurrences" and not as resources, unless mined. Where mined, tonnage quantity is included in reserve base and reserve estimates.

criteria for distinguishing resource categories.

"shaly," or "sandy," is the preferred usage because the definition of *bone coal* does not specify the type or weight percentages of impurities.

British thermal unit (Btu).—The quantity of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit (°F) at, or near, its point of maximum density of 39.1° F (equivalent to 251.995 gram calories; 1,054.35 Joules; 1.05435 kilojoules; 0.25199 kilocalorie).

burn line.—The contact between burned and unburned coal in the subsurface. In the absence of definitive information, the subsurface position of a *burn line* is assumed to be vertically below the surface contact between unaltered and altered rocks. See **clinker**.

calorie (cal).—The quantity of heat required to raise 1 gram of water from 15° to 16° Celsius. A calorie is also termed gram calorie or small calorie (equivalent to 0.00396832 Btu; 4.184 Joules; 0.001 kilogram calorie).

clinker.—Baked or fused rock formed from the heat of a burning underlying coal bed.

coal.—A readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, including inherent moisture. It is formed from plant remains that have been compacted, indurated, chemically altered, and metamorphosed by heat and pressure during geologic time.

Discussion: Differences in the kinds of plant materials, in the degree of metamorphism (rank), and in the range of impurities are characteristic of *coal* and are used in coal classification. Impure coal/coaly material containing more than 33 weight percent ash is excluded from resources and reserve estimates unless the ash is largely in associated partings so that the *coal* is cleanable to less than 33 weight percent ash.

coal bed.—See **bed**.

coal field.—A discrete area underlain by strata containing one or more coal beds. (See figs. 5 and 6.)

coal measures.—Strata containing one or more coal beds.

coal province.—An area containing two or more coal regions. (See fig. 8.)

coal region.—An area containing one or more coal fields. (See fig. 7.)

coal reserves.—See **reserves**. (See also ***reserves***, p. 30.)

coal zone.—A series of laterally extensive and (or) lenticular coal beds and associated strata that arbitrarily can be viewed as a unit. Generally, the coal beds in a *coal zone* are assigned to the same geologic member or formation.

coke.—A gray, hard, porous, and coherent cellular-structured solid, primarily composed of amorphous carbon. *Coke* is combustible and is produced by destructive distillation or thermal decomposition of certain bituminous coal that passes through a plastic state in the absence of air.

concentration.—A greater than normal accumulation of substances such as (1) coal, (2) elements, (3) compounds, and (4) minerals. In coal resource terminology, *concentration* is used in two senses: (1) concentrations of coaly material into beds that are minable, and (2) concentrations of elements, compounds, and minerals that may add or detract from the value of the extracted coal. A *concentration* of a substance always exceeds the average content of that substance in the Earth's crust.

consolidated coal.—See **lignite**.

content.—The amount of ash, an element, an oxide, other types of compounds, or a mineral in a unit amount of coal, expressed in parts per million or percent. Also refers to the heat value of coal as expressed in Joules per kilogram (J/kg), kilojoules per kilogram (kJ/kg), British thermal units per pound (Btu/lb), or calories per gram (cal/g).

control point.—A **point of measurement**, a **point of observation**, or a sampling point.

correlate, correlation.—Demonstration of the apparent continuity of a coal bed between control, measurement, or sampling points by showing correspondence in character and stratigraphic position.

Discussion: Correlations of coal beds are based on a knowledge of the stratigraphy of the coal beds and of the enclosing rocks and of the unique characteristics of individual coal beds. Confidence in correlations increases as the knowledge and abundance of data increases. Where a coal bed is continuously exposed along an outcrop or strip-mine face, continuity of the coal bed becomes an established fact and not a *correlation*.

Where data indicate that correlation of a coal bed is possible or probable among data points within an area, an estimate of the resources of that coal bed can be made for the entire area. However, where a coal bed at single data point cannot be correlated with beds at other data points, or where there is only one data point, resources can be calculated for that coal bed using the single data point as the center of circles defining measured, indicated, and inferred.

cumulative depletion.—The sum in tons of coal extracted and lost-in-mining to a stated date for a specified area or a specified coal bed. (See ***cumulative depletion***, p. 25; and fig. 3.)

cumulative production.—The sum in tons of coal extracted to a stated date for a specified area or a specified coal bed. (See ***cumulative production***, p. 25; and figs. 1, 2, and 3.)

demonstrated.—A term commonly used for the sum of coal classified as measured and indicated resources. Used when not feasible or desirable to subdivide into **measured** and **indicated**. (See figs. 1, 2, and 3.)

demonstrated reserves.—Same as **reserves**. (See also, ***demonstrated reserves***, p. 25; and figs. 1, 2, and 3.)

demonstrated reserve base.—Same as **reserve base**. (See also ***demonstrated reserve base***, p. 25; and figs. 1, 2, and 3.)

demonstrated resources.—See **resources**. (See also, ***demonstrated resources***, p. 25; and figs. 1, 2, and 3.)

density.—Mass of coal per unit volume. Generally expressed in short tons/acre-foot or metric tons/hectare/square hectometer-meter of coal. See **specific gravity**.

depleted resources.—Resources that have been mined; includes coal recovered, coal lost-in-mining, and coal reclassified as subeconomic because of mining. See **cumulative depletion**. (See also ***cumulative depletion***, p. 25; and fig. 3.)

depth (overburden) categories.—Coal tonnage data are divided into classes by the thickness of overburden: 0–500 feet (0–150 m); 500–1,000 feet (150–300 m); 1,000–2,000 feet (300–600 m); 2,000–3,000 feet (600–900 m); and 3,000–6,000 feet (900–1,800 m). See **overburden**.

Discussion: The depth categories or overburden categories (see table 3, and specific instruction No. 2, p. 33) were decided after consultation among personnel from the U.S. Geological Survey, the Bureau of Mines, and various State Geological Surveys, mining companies, and agencies of foreign nations.

dry, mineral-matter-free basis.—A type of calculated analytical value of a coal sample expressed as if the total moisture and mineral matter had been removed. *Mineral-matter-free* is not the same as **ash-free**.

economic.—This term implies that profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.

economic assessment.—A critical analysis resulting in a judgment of the economic nature, significance, status, quantity, quality, market, demand, supply, costs, transportation, cash flow, capital, and processing of the coal resources of a mine, area, district, field, basin, region, province, county, state, or nation. See **assessment**.

estimate.—A determination as to the amount or tonnage of coal in an area. The term *estimate* indicates that the quantities of resources are known imprecisely. An *estimate* differs from an assessment, which is an analysis of all data concerning an area's coal resources and reserves with the objective of reaching a judgment about the geologic nature and economic potential of the coal resources and reserves of the area.

existing market conditions.—The relations between production, selling and transportation costs, supply, demand, and profit at any time.

extraction.—The process of removing coal from a deposit.

feasibility.—The possibility of extracting coal.

fixed carbon.—The solid residue, other than ash, obtained by destructive distillation of a coal, determined by definite prescribed methods (ASTM, 1981, p. 183).

floor.—Stratigraphically, the rock immediately underlying a coal bed. Where the bed is overturned, the stratigraphic *floor* is the mining roof.

gasification, underground (in situ).—A method of utilizing coal by burning in place and extracting the released gases, tars, and heat. See **in situ mining**.

geologic assessment.—A critical analysis resulting in a judgment of the geologic nature, significance, status, quality, and quantity of the coal resources of an area, district, basin, region, township, quadrangle, province, county, state or political province, nation, continent, or the world. See **assessment** and **economic assessment**.

geologic assurance.—State of sureness, confidence, or certainty of the existence of a quantity of resources based on the distance from points where coal is measured or sampled and on the abundance and quality of geologic data as related to thickness of overburden, rank, quality, thickness of coal, areal extent, geologic history, structure, and correlations of coal beds and enclosing rocks. The degree of assurance increases as the nearness to points of control, abundance, and quality of geologic data increases.

geologic evidence.—Information derived from geologic observations that can be used to substantiate the existence, size, depth, attitude, structure, tonnage, and physical and chemical characteristics of a body of coal.

geologic identification.—State of being identified as to location, areal extent or size, depth, volume, quantity, magnitude, and quality of coal resources.

grade.—A term indicating the nature of coal as mainly determined by the sulfur content and the amount and type of ash. This term is not recommended for usage in coal resource estimations; definitive statements as to the contents and types of sulfur and ash are preferable. Statements indicating high, medium, or low grade are inappropriate without documentation. See **quality**.

heat value or **heat of combustion.**—The amount of heat obtainable from coal expressed in British thermal units per pound, joules per kilogram, kilojoules or kilocalories per kilogram, or calories per gram. To convert Btu/lb to kcal/kg, divide by 1.8. To convert kcal/kg to Btu/lb, multiply by 1.8.

hectare (ha) or **square hectometer (hm^2).**—A metric unit of area equal to 10,000 square meters; 0.010 square kilometer; 2.4710538 acres; 107,639.10 square feet; 11,959.9 square yards; 0.003861 square mile.

high-ash coal.—Coal containing more than 15 percent total ash on an as-received basis. See **ash-content**, **medium-ash coal**, and **low-ash coal**.

high-sulfur coal.—Coal containing 3 percent or more total sulfur on an as-received basis. See **low-sulfur coal** and **medium-sulfur coal**.

high-volatile bituminous coal.—Three related rank groups of bituminous coal as defined by the American Society for Testing and Materials which collectively contain less than 69 percent fixed carbon on a dry, mineral-matter-free basis; more than 31 percent volatile matter on a dry, mineral-matter-free basis; and a heat value of more than 10,500 Btu per pound on a moist, mineral-matter-free basis. (See table 1.)

hypothetical.—A low degree of geologic assurance. Estimates of rank, thickness, and extent are based on assuming continuity beyond inferred. Estimates are made, not exceeding a specified depth beyond coal classed as inferred, by projection of thickness, sample, and geologic data from distant outcrops, trenches, workings, and drill holes. There are no measurement sites in areas of hypothetical coal. Used as a modifier to resource terms. See **resources** and **undiscovered**. (See also figs. 1, 2, and 3.)

hypothetical resources.—See Undiscovered Resources, p. 20; (See also ***hypothetical resources***, p. 25; and figs. 1, 2, and 3.)

identified resources.—See Identified Resources, p. 19; (See also ***identified resources***, p. 25; and figs. 1, 2, and 3.)

impure coal.—Coal having 25 weight percent or more, but less than 50 weight percent ash on the dry basis (ASTM, 1981, D-2796, p. 344). *Impure coal* having more than 33 weight percent ash is excluded from resource and reserve estimates unless the coal is cleanable to less than 33 weight percent ash. See **bone coal**.

indicated.—A moderate-degree of geologic assurance. Estimates of quantity, rank, thickness, and extent are computed by projection of thickness, sample, and geologic data from nearby outcrops, trenches, workings, and drill holes for a specified distance and depth beyond coal classed as measured. The assurance, although lower than for measured, is high enough to assume continuity between points of measurement. There are no sample and measurement sites in areas of indicated coal. However, a single measurement can be used to classify coal lying beyond measured as *indicated* and to assign such coal to resource and reserve base categories (fig. 4). Used as a modifier to resource terms.

indicated reserves and **indicated marginal reserves.**—See **reserves** and **indicated.** (See also ***indicated reserves*** and ***indicated marginal reserves***, p. 25; and figs. 1, 2, and 3.)

indicated reserves base and **indicated marginal reserve base.**—See **reserve base.** (See also ***indicated reserve base***, p. 26, and figs. 1, 2, and 3.)

indicated resources.—See Indicated Resources, p. 19. (See also ***indicated resources***, p. 26; and figs. 1, 2, and 3.)

inferred.—A low-degree of geologic assurance. Estimates of quantity, rank, thickness, and extent are based on inferred continuity beyond measured and indicated for which there is geologic evidence. Estimates are computed by projection of thickness, sample, and geologic data from distant outcrops, trenches, workings, and drill holes for a specified distance and depth beyond coal classed as indicated. There are no sample and measurement sites in areas of inferred coal. However, a single measurement can be used to classify coal lying beyond indicated as *inferred* and to assign such coal to inferred resource and inferred reserve base categories (fig. 4). Used as a modifier to resource terms.

inferred reserves and **inferred marginal reserves.**—See subdivisions of **reserves**. (See also ***inferred reserves***, p. 26, and ***inferred marginal reserves***, p. 26; and figs. 1, 2, and 3.)

inferred reserve base.—See **reserve base.** (See also ***inferred reserve base***, p. 26; and figs. 1, 2, and 3.)

inferred resources.—See Inferred Resources, p. 19. (See also ***inferred resources***, p. 26; and figs. 1, 2, and 3.)

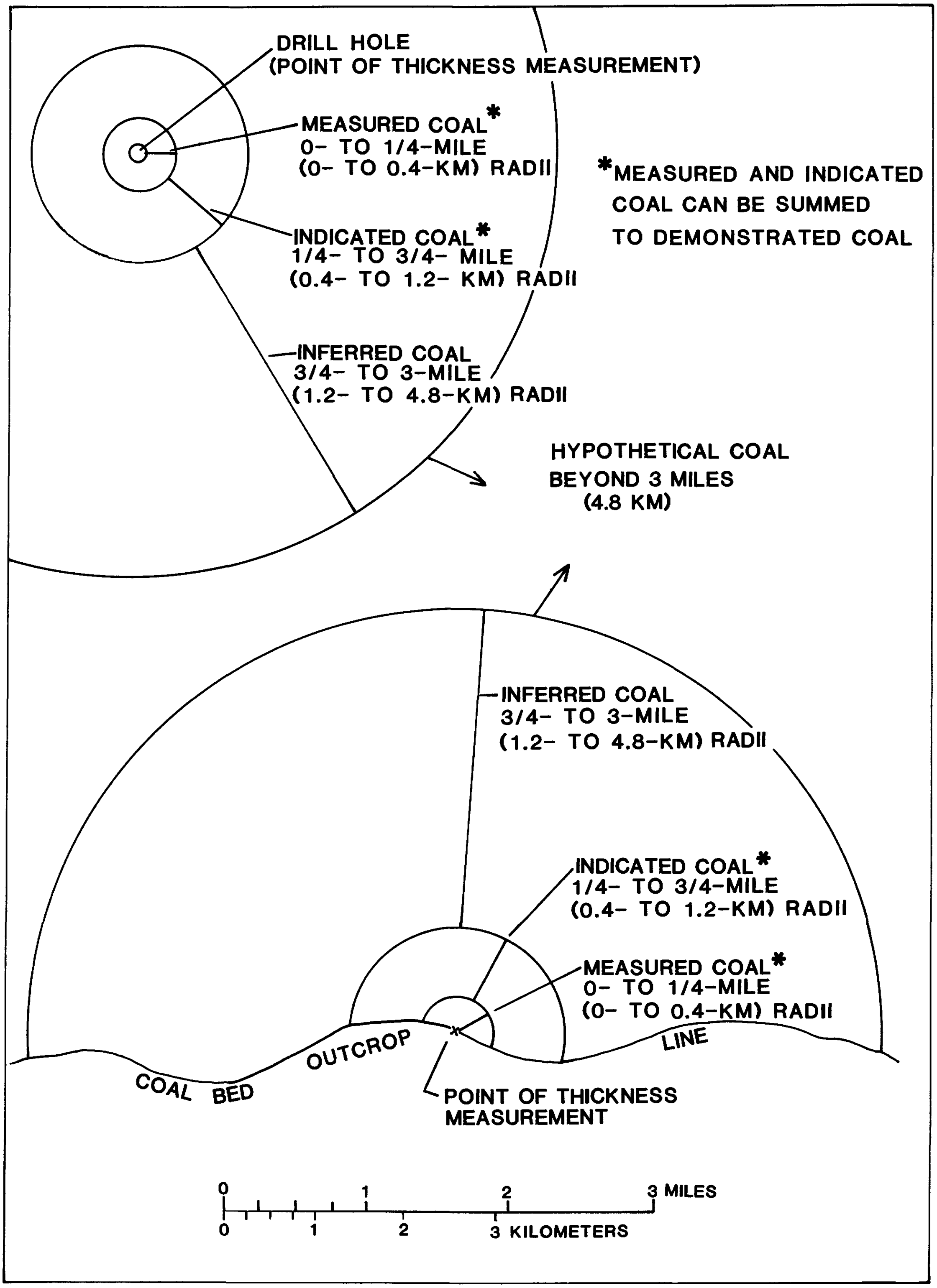


FIGURE 4.—Diagram showing reliability categories based solely on distance trom points of measurement.

inferred subeconomic resources.—See Inferred Subeconomic Resources, p. 20. (See also ***inferred subeconomic resources***, p. 31; and figs. 1, 2, and 3.)

in situ.—Refers to coal "in place" in the ground.

in situ mining.—Utilization of coal by burning in place and extracting the gases, tars, and heat.

joule (J).—The basic metric unit of work or energy equal to 1×10^7 ergs, 0.238662 gram calorie, 0.0002386 kilogram-calorie, or 0.0009471 Btu.

kilogram-calorie (kcal).—A metric unit of heat equal to 1,000 gram-calories; 3.9683207 Btu; 4,184 Joules; 4.184×10^{10} ergs; or 4,184 Watt seconds. Also known as "large calorie."

kilogram (kg).—The basic metric unit of weight measurement equal to 1,000 grams; 0.001 metric ton; 2.2046 pounds; 0.0011023 short ton; 0.0009842 long ton.

kilojoule (kJ).—A metric unit of work or energy equal to 1,000 joules; 0.948708 Btu; or 238.662 gram-calories.

known coal.—Coal whose existence has been perceived from measurements and observations at the outcrop, in mines, from drill holes, and from exploratory trenches. Data confirming existence may be projected for several miles (kilometers) if based upon reasonable geologic assumptions. See **identified resources**. Coal fields, basins, regions, provinces, and occurrences of coal in the United States are illustrated in figures 5, 6, 7, and 8.

lignite or **lignitic.**—A class of brownish-black, low-rank coal defined by the American Society for Testing and Materials as having less than 8,300 Btu on a moist, mineral-matter-free basis. (See table 1.) In the United States, *lignite* is separated into two groups: Lignite A (6,300 to 8,300 Btu) and lignite B (<6,300 Btu). *Lignite* is the preferred usage.

long ton.—A unit of weight in the U.S. Customary System and in the United Kingdom equal to 2,240 pounds (1.0160469 metric tons; 1.1200 short tons; 1,016.0469 kilograms). This term is not recommended for use in estimates of coal resources.

lost-in-mining.—Coal remaining in the ground after all extraction is completed. *Lost-in-mining* includes coal that is (1) left to support mine roofs, (2) too thin to mine, (3) unmined around oil, gas, water, and disposal wells, (4) unmined around shafts and electrical and water conduits, (5) unmined as barrier pillars adjacent to mine or property boundaries, (6) unmined adjacent to haulageways, tunnels, airways, and waterways, (7) unmined because of many other unspecified reasons, (8) the unrecovered or unrecoverable part of any coal bed in a mining property that has been or may be extracted, (9) all unrecoverable in beds that closely overlie a mined bed, (10) all unrecoverable in beds that closely underlie a mined bed, (11) unmined between mining properties.

Discussion: According to this system of classification, *lost-in-mining* equals reserve base minus reserves and marginal reserves. Thus, *lost-in-mining* includes all reserve base coal not economically recoverable at the time of classification or not bordering on being economically recoverable. Lost-in-mining coal is subtracted from the reserve base and is divisible into subeconomic coal or noneconomic coal according to its potential for being reclassified as economic. (See fig. 3.)

low-ash coal.—Coal containing less than 8 percent total ash on an as-received basis. See **ash content**, **high-ash coal**, and **medium-ash coal**.

low-sulfur coal.—Coal containing 1 percent or less total sulfur on an as-received basis. See **high-sulfur coal** and **medium-sulfur coal**.

low-volatile bituminous coal.—A rank group of bituminous coal as defined by the American Society for Testing and Materials containing more than 78 percent and less than 86 percent fixed carbon, and more than 14 percent and less than 22 percent volatile matter on a dry, mineral-matter-free basis. (See table 1.)

marginal reserves.—Borders on being economic. See **economic**; general guideline no. 8, p. 32; and subdivisions of **reserves**. (See also ***indicated marginal reserves*** and ***measured marginal reserves***, p. 25 and 27; and figs. 1, 2, and 3.)

measured.—The highest-degree of geologic assurance. Estimates of quantity are computed partly from dimensions revealed in outcrops, trenches, workings, and drill holes and partly by projection of thickness, sample, and geologic data not exceeding a specified distance and depth. Rank is calculated from the results of detailed sampling that may be located at some distance from this type of resource and may be on the same or other coal beds. The sites for thickness measurement are so closely spaced and the geologic character so well defined that the average thickness, areal extent, size, shape, and depth of coal beds are well established. However, a single measurement can be used to classify nearby coal as *measured* (fig. 4). Used as a modifier to resource terms.

measured reserves and **measured marginal reserves.**—See subdivisions of **reserves**. (See also ***measured reserves***, p. 27; ***measured marginal reserves***; p. 27; and figs. 1, 2, and 3.)

measured reserve base.—See **reserve base**. (See also ***measured reserve base***, p. 27; and figs. 2 and 3.)

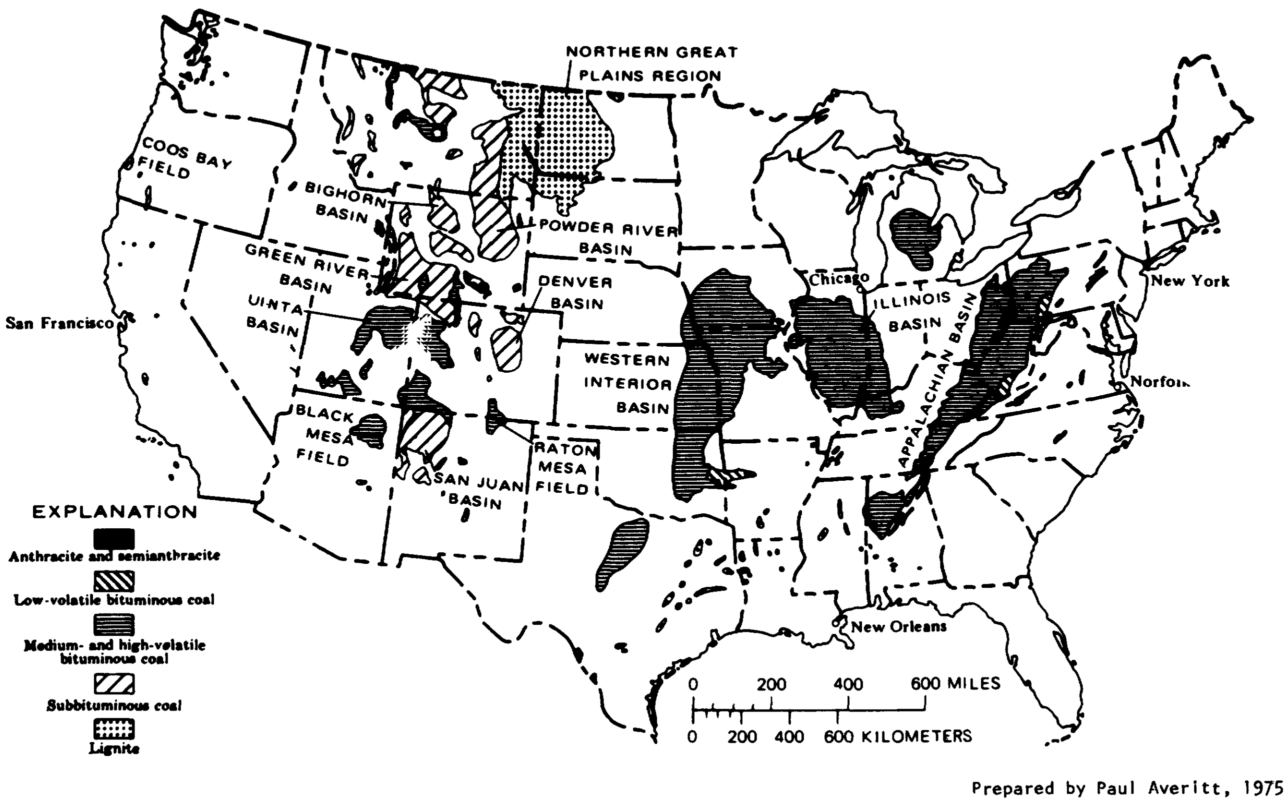


FIGURE 5.—Coal fields of the conterminous United States (from Averitt, 1975).

measured resources.—See Measured Resources, p. 19; (See also ***measured resources***, p. 27; and figs. 1, 2, and 3.)

medium-ash coal.—Coal containing 8 percent to 15 percent ash on an as-received basis. See **ash content**, **low-ash coal**, and **high-ash coal**.

medium-sulfur coal.—Coal containing more than 1 percent and less than 3 percent total sulfur on an as-received basis. See **high-sulfur coal** and **low-sulfur coal**.

medium-volatile bituminous coal.—A rank group of bituminous coal as defined by the American Society for Testing and Materials containing more than 69 percent and less than 78 percent fixed carbon and more than 22 percent and less than 31 percent volatile matter on a dry, mineral-matter-free basis. (See table 1.)

metallurgical coal.—An informally recognized name for bituminous coal that is suitable for making coke by industries that refine, smelt, and work with iron. Other uses are space heating, blacksmithing, smelting of base metals, and power generation. Generally, *metallurgical coal* has less than 1 percent sulfur and less than 8 percent ash on an as-received basis. Most premium *metallurgical coal* is low- to medium-volatile bituminous coal.

metric ton, megagram, tonne, or **millier.**—A metric unit of weight equal to 1,000 kilograms; 1.1023113 short tons; 0.98420653 long ton; 2,204.6226 pounds. The *metric ton* is the preferred usage.

minable.—Capable of being mined under current mining technology and environmental and legal restrictions, rules, and regulations.

mineral-matter.—The solid inorganic material in coal.

mineral-matter-free basis.—A theoretical analysis calculated from basic analytical data expressed as if the total mineral-matter had been removed. Used in determining the rank of a coal.

mining.—All methods of obtaining coal or its byproducts from the Earth's crust, including underground, surface, and in situ mining.

moist, mineral-matter-free basis.—A theoretical analysis calculated from basic analytical data and expressed as if the mineral-matter had been removed and the natural moisture retained. Used in determining the rank of coal.

moisture, bed.—The percentage of moisture or water in a bed or sample of coal before mining.

moisture content.—The percentage of moisture (water) in coal. Two types of moisture are found in

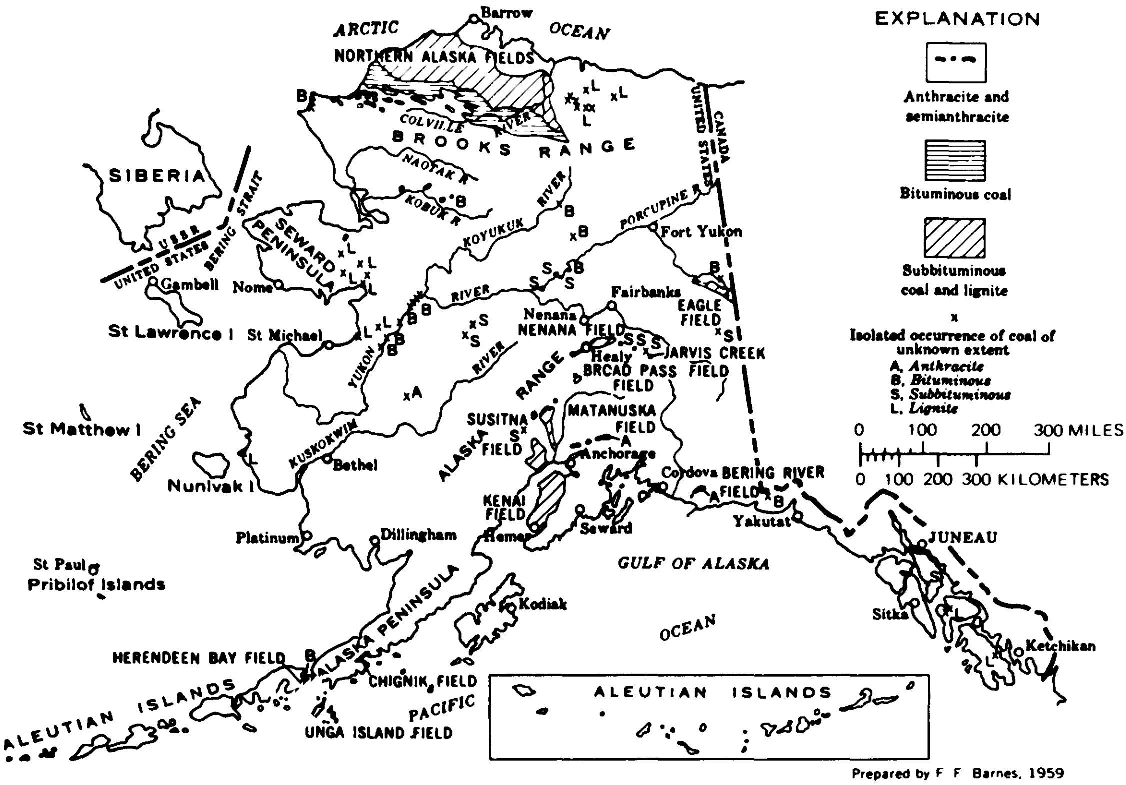


FIGURE 6.—Coal fields of Alaska (from Averitt, 1975).

coal, namely, free or surface moisture removed by exposure to air, and inherent moisture entrapped in the coal and removed by heating to 220°F.

noneconomic.—Not capable of profitable production or extraction. Coal classified as *noneconomic* may be reported in other occurrences. See ***other occurrences, noneconomic coal***, p. 27.

original.—The amount of coal resources in the ground before production.

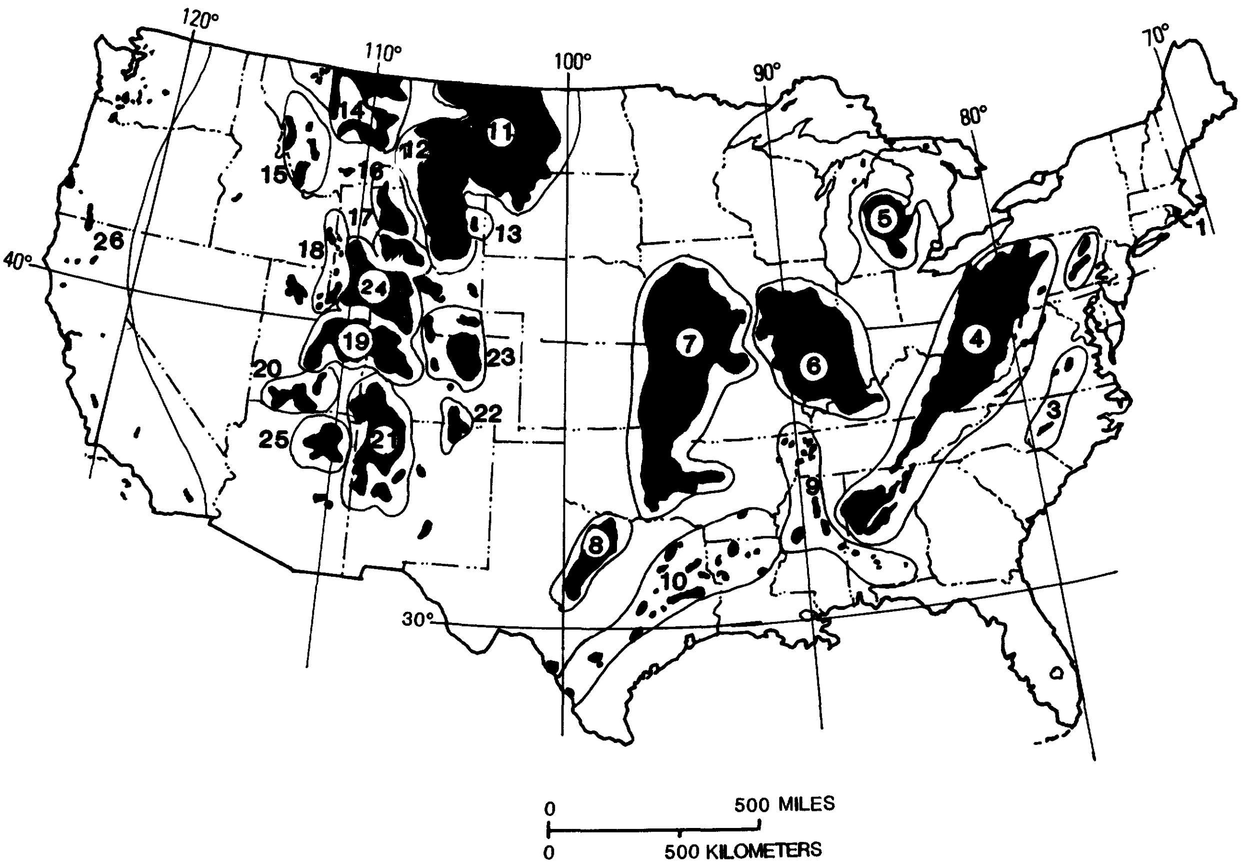
original resources.—See Original Resources, p. 19; and **original resources**. (See also ***original resources***, p. 27; and figs. 1, 2, and 3.)

other occurrences.—Coal in the ground that is excluded from classification as coal resources. Includes anthracite and bituminous coal less than 14 inches thick, subbituminous coal and lignite less than 30 inches thick, and any coal more than 6,000 feet deep unless it is currently being mined. May include coal that contains more than 33 percent ash. (See ***other occurrences, noneconomic coal***, p. 27; and figs. 1 and 2.)

overburden.—Rock including coal and (or) unconsolidated material that overlies a specified coal bed. *Overburden* is reported in feet and (or) meters and used to classify the depth to an underlying coal bed.

partial or incomplete measurement of coal thickness.—A determination of an incomplete coal thickness at a point of measurement.

Discussion: Measurements of coal thicknesses that are incomplete because of (1) near surface slumping of coal and overlying beds, (2) weathering, (3) a drill hole not penetrating the entire coal bed, (4) identified planar erosion of top part of coal bed, or (5) removal of most of a coal bed by a stream channel are to be treated as points of measurement from which circles of reliability are to be constructed. A geologist must decide whether each measurement is complete or incomplete. The thickness of coal at places where a measurement is deemed incomplete shall be located on the coal bed map by the number of feet and inches actually measured followed by a plus sign to indicate that only a part of the bed was measured. Thus, incomplete measurements define measured coal of a stated minimum thickness. If other thickness data are available to show by isopaching that a coal thickness is incomplete at a point of measurement, the isopached total thickness at the point of measurement should be used to determine the average thickness for the tonnage



EXPLANATION

1 Rhode Island Meta-anthracite	14 North Central
2 Pennsylvania Anthracite	15 Tertiary lake beds
3 Atlantic coast	16 Bighorn
4 Appalachian	17 Wind River
5 Northern	18 Hams Fork
6 Eastern Interior	19 Uinta
7 Western Interior	20 Southwestern Utah
8 Southwestern	21 San Juan River
9 Mississippi-Alabama	22 Raton Mesa
10 Texas-Louisiana	23 Denver
11 Fort Union	24 Green River
12 Powder River	25 Black Mesa
13 Black Hills	26 Pacific

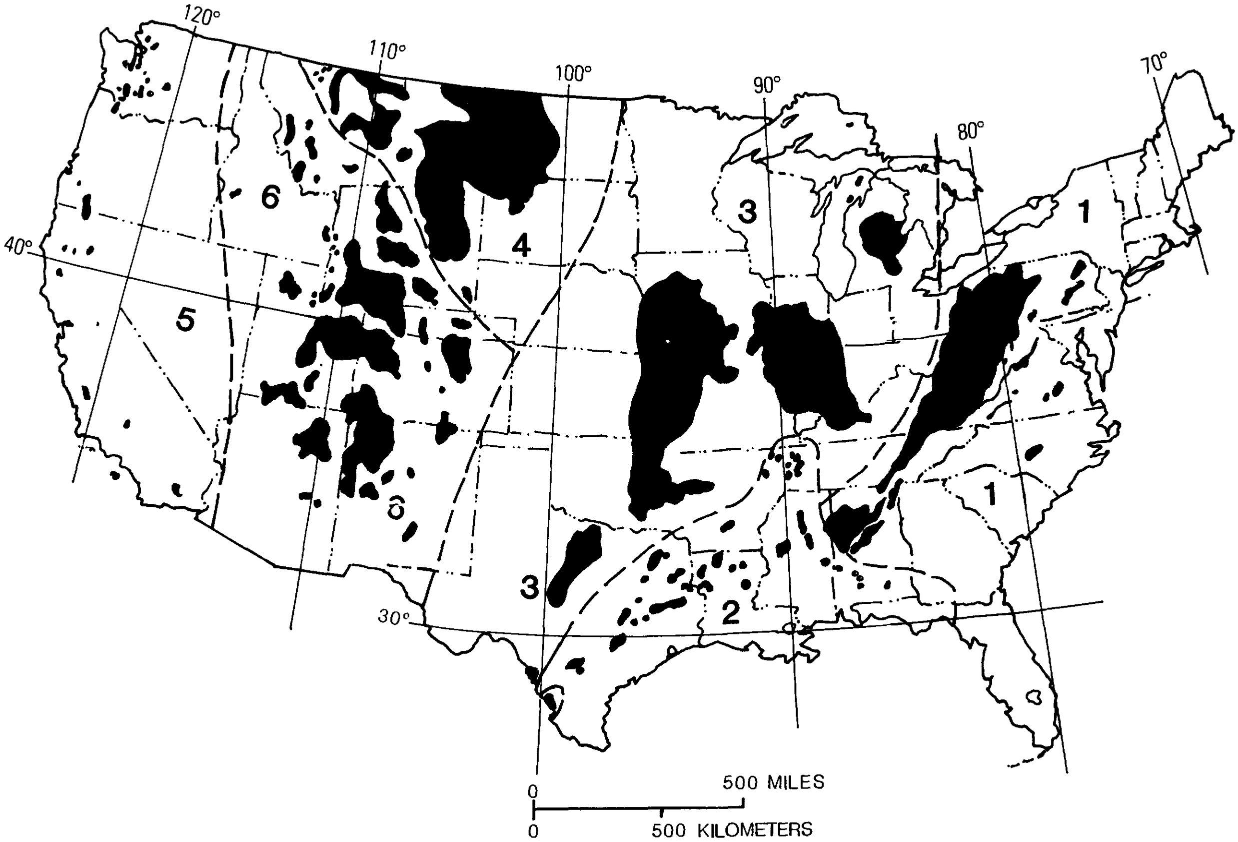
FIGURE 7.—Coal regions of the conterminous United States (modified from Trumbull, 1960.)

estimates of measured, indicated, and inferred categories. In those places where the coal bed cannot be isopached, the partial thickness of coal should be used as the thickness for estimating tonnages. See **point of measurement**.

parting.—A layer or stratum of non-coal material in a coal bed which does not exceed the thickness of coal in either the directly underlying or overlying benches. (See specific instruction No. 3, p. 34.)

parts per million (ppm).—A method of stating content of a substance in coal. One *ppm* equals 0.001 percent, or 0.000001.

point of measurement.—The exact location on an outcrop, in a trench, in mine workings, or in a drill hole



EXPLANATION

1 Eastern
2 Gulf
3 Interior
4 Northern Great Plains
5 Pacific Coast
6 Rocky Mountains

FIGURE 8.—Coal provinces of the conterminous United States (modified from Trumbull, 1960.)

where a coal bed is measured for thickness and (or) sampled for analysis. The surface position of a *point of measurement* must be located precisely on a map so that its geodetic position can be determined. The altitude of a subsurface *point of measurement* can be determined from cores, lithologic logs, mine workings, and also can be determined from a geophysical log of a drill hole or well if, in the opinion of a geologist or geophysist, the log is of good quality. See **partial or incomplete measurement of coal thickness**.

point of observation.—Place on an outcrop where a coal bed is visible or where evidence indicates that a coal bed could be measured or examined by trenching or digging a pit. Points of observation are used to verify the existence of a coal bed, and apparent similarity and (or) difference of a coal bed's thickness as to thickness at points of measurement. They also can be used to confirm the position of a coal outcrop on a geologic map and to support the measured, indicated, and inferred classification of a coal bed; however, these points cannot be used without actual measurements to classify a resource body.

production.—The coal that has been extracted from a mine for a specified period. *Production* may be reported for a mine or larger area such as a coal field, region, province, basin, township, quadrangle, state, nation, and (or) the world. Production in the United States is usually reported in short tons; most other nations report production in metric tons.

proximate analysis.—In coal, the determination by

TABLE 1.—*Classification of coals by rank* [A], [1]

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, percent Dry, Mineral-Matter-Free Basis		Calorific Value Limits BTU per pound (Moist,[B] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less	
I. Anthracite*	1. Meta-anthracite	98	-----	-----	2	-----------	--------	nonagglomerating
	2. Anthracite	92	98	2	8	-----------	--------	
	3. Semianthracite[C]	86	92	8	14	-----------	--------	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	-----------	--------	commonly agglomerating[E]
	2. Medium volatile bituminous coal	69	78	22	31	-----------	--------	
	3. High volatile *A* bituminous coal	-----	69	31	-----	14 000[D]	--------	
	4. High volatile *B* bituminous coal	-----	-----	-----	-----	13 000[D]	14 000	
	5. High volatile *C* bituminous coal	-----	-----	-----	-----	11 500	13 000	
		-----	-----	-----	-----	10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous *A* coal	-----	-----	-----	-----	10 500	11 500	nonagglomerating
	2. Subbituminous *B* coal	-----	-----	-----	-----	9 500	10 500	
	3. Subbituminous *C* coal	-----	-----	-----	-----	8 300	9 500	
IV. Lignite	1. Lignite *A*	-----	-----	-----	-----	6 300	8 300	
	2. Lignite *B*	-----	-----	-----	-----	-----------	6 300	

[A]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15 500 moist, mineral-matter-free British thermal units per pound.

[B]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[C]If agglomerating, classify in low-volatile group of the bituminous class.

[D]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[E]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in the high-volatile *C* bituminous group.

[1]ASTM, 1981, p. 215.

*Modified from ASTM, 1981.

prescribed methods of moisture, volatile matter, fixed carbon (by difference), and ash. Unless specified, proximate analyses do not include determinations of sulfur or phosphorous or any determinations other than those named. Proximate analyses are reported by percent and on as-received, moisture-free, and moisture- and ash-free bases.

quality.—An informal classification of coal relating to its suitability for use for a particular purpose.

Discussion: Most coal is used as a source of heat or energy, but coal is or will be used in making petrochemicals, metallurgical coke, synthetic gas, and synthetic liquid fuel. Factors considered in judging a coal's quality are based on, but not limited to, heat value; content of moisture, ash, fixed carbon, phosphate, silica, sulfur, major, minor and trace elements; coking and petrologic properties; and organic constituents considered both individually and in groups. The individual importance of these factors varies according to the intended use of the coal. Therefore, any designation of "high-quality coal," "moderate-quality coal," or "low-quality coal" should plainly indicate the intended or optimum use or uses and is inappropriate without such documentation.

quantity.—Refers to the amount or tonnage of coal. *Quantity* should be reported in short or metric tons.

rank.—The classification of coals according to their degree of metamorphism, progressive alteration, or coalification (maturation) in the natural series from lignite to anthracite.

Discussion: Classification is made on the basis of analysis of coal in accordance with table 1. The *rank* of coal can be used to infer the approximate dry, mineral-matter-free heat value, fixed carbon, and volatile matter in a coal, because the amounts of the constituents vary little within each coal rank. (See table 1; and ***rank calculation***, p. 28.)

rank calculation.—The determination of the rank of a coal. Such determination must use the instructions given under ***rank calculation***, p. 28.

recoverable coal.—The coal that is or can be extracted from a coal bed during mining. The term "recoverable" should be used in combination with "resources" and not with "reserves."

recovery percent.—The percentage of coal extracted from a bed where the total tonnage originally in the bed is equal to 100 percent.

recovery factor.—The estimated or actual percentage of coal that can be or was extracted from the coal originally in a bed or beds for an area, mine, district, field, basin, region, province, township, quadrangle, county, state, political province, nation, and (or) the world. See ***recovery factor method***, p. 28.

reliability categories.—Categories based on distance from points of measurement and (or) sampling. The measured, indicated, inferred, and hypothetical resource categories, as defined, indicate the relative reliability of tonnage estimates as related to distance from points of thickness control of particular parts of a coal deposit. The *reliability categories* are not indicative of the reliability of the basic data (that is, the accuracy of coal measurements, or the accuracy of location of the coal outcrop). It is assumed that all basic data used in resource estimation have been judged reliable by the estimator and that unreliable data have been discarded. (See fig. 4.)

reserves.—Virgin and (or) accessed parts of a coal reserve base which could be economically extracted or produced at the time of determination considering environmental, legal, and technologic constraints. The term *reserves* need not signify that extraction facilities are in place or operative. *Reserves* include only recoverable coal; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system. (See figs. 1 and 3; and ***reserves***, p. 30.)

Discussion: *Reserves* can be categorized as measured and indicated, as underground or surface minable, by thickness of overburden, by thickness of coal in the bed, and by various quality factors. The term "economic reserves" is not to be used because *reserves* by definition are economic. *Reserves*, which are derived from reserve base coal, exclude coal thinner or deeper than that classified as reserve base unless such coal is currently mined. See general guideline No. 7, p. 32.

MANDATORY SUBDIVISIONS:

A. Indicated Reserves and Indicated Marginal Reserves.—Categories of virgin reserves having a moderate degree of geologic assurance. See **indicated** and **marginal reserves**. (See also ***reserves***, p. 30; and figs. 1 and 3.)

B. Inferred Reserves and Inferred Marginal Reserves.—Categories of virgin reserves having a low degree of geologic assurance. See **inferred reserves** and **marginal reserves**. (See also ***reserves***; p. 30; and figs. 1 and 3.)

C. Measured Reserves and Measured Marginal Reserves.—Categories of accessed and virgin coal reserves having the highest degree of geologic assurance. See **measured reserves** and **marginal reserves**. (See also figs. 1 and 3.)

OPTIONAL SUBDIVISIONS:

A. Reserves and Marginal Reserves.—*Reserves* may be divided into subcategories other than those heretofore defined. These subcategories may be differentiated, for example, by ash and sulfur content, and heat value; by types or varieties of coal such as boghead or cannel coal; by usage such as metallurgical, petrochemical, and synthetic fuel types; by mineral ownership such as State, Federal, Indian, or private ownership; by Federal coal underlying private surface ownership; and by reserves and restricted reserves underlying State or national parks, monuments, forests, grasslands; military and naval reservations, alluvial valley floors, steep slopes, lakes and large rivers, and environmentally protected areas.

1. Restricted Reserves and Restricted Marginal Reserves.—Those parts of any reserve category that are restricted or prohibited by laws or regulations from extraction by underground and (or) surface mining.

   Discussion: For example, coal in a national park may meet all the physical, chemical and economic requirements of a reserve but is prohibited from extraction. The assignment to a restricted category may be either temporary or permanent; however, because laws and regulations can be repealed or changed, such coal should be separately distinguished, and tonnage estimates recorded as a restricted reserve. Locally, a specific regulation or law might prohibit one method of mining and allow or not specify other methods. In such a circumstance, the coal would be restricted from mining by the prohibited method and tonnage estimates would be so recorded. In other circumstances, other methods would be unrestricted, and tonnage estimates would be reported accordingly.

The separation of coal reserves into the many different subcategories listed above and other subcategories not listed in this text is desirable and encouraged. All subcategories not listed should be defined clearly and explicitly so that other resource specialists and the public will not be confused.

reserve base.—Those parts of the identified resources that meet specified minimum physical and chemical criteria related to current mining and production practices, including those for quality, depth, thickness, rank, and distance from points of measurement. (See **reliability categories**; and figs. 2 and 3.) The *reserve base* is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The *reserve base* may encompass those parts of a resource that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The *reserve base* includes those resources that are currently economic (reserves), marginally economic (marginal reserves), some of those that are currently subeconomic (subeconomic resources), and some of the resources that have been or will be lost-in-mining but whose attributes indicate possible future recovery. The term "geologic reserve" has been applied by others to the reserve base category, but it also may include the inferred reserve base category; it is not a part of this classification system. (See ***reserve base***, p. 29; and figs. 2 and 3.)

reserve base, inferred.—The in-place part of an identified resource from which inferred reserves and inferred marginal reserves are estimated. Quantitative estimates are based largely on knowledge of the geologic character of a coal deposit for which there are no samples or measurements. The estimates are based on an assumed continuity beyond the reserve base for which there is geologic evidence. (See figs. 2 and 3.)

resources.—Naturally occurring concentrations or deposits of coal in the Earth's crust, in such forms and amounts that economic extraction is currently or potentially feasible. (See ***resources***, p. 30; and figs. 1, 2, and 3.)

MANDATORY SUBDIVISIONS:

A. Hypothetical Resources.—See Undiscovered Resources (p. 20). (See also ***hypothetical resources***, p. 25; and figs. 1, 2, and 3.)

B. Identified Resources.—Resources whose location, rank, quality, and quantity are known or estimated from specific geologic evidence. (See ***identified resources***, p. 25). Identified coal resources include economic, marginally economic, and subeconomic components. To reflect varying distances from points of control or reliability, these subdivisions can be divided into demonstrated and inferred, or preferably into measured, indicated, and inferred. (See ***identified resources***, p. 25; and figs. 1, 2, and 3.)

Discussion: Identified resources may be accessed and (or) in bodies of virgin coal which are assigned to resource and reserve base subcategories on the basis of geologic evidence from maps, samples, drill holes, wells, mine records, and fieldwork. Specific evidence must include data on the location, thickness of overburden, distance from points of measurement or sampling, and extent and thicknesses of the resource bodies. Evidence about quality and rank may be determined from analyses of samples collected from the resource bodies or may be inferred by projection of analytical data obtained elsewhere in the body or from adjacent bodies. An identified resource body may contain reserves, marginal reserves, inferred reserves, inferred marginal reserves, reserve base, inferred reserve base, demonstrated resources, measured resources, indicated resources, inferred resources, subeconomic resources and inferred subeconomic resources. (See figs. 1, 2, and 3.)

C. Indicated Resources.—Identified bodies of virgin coal having a moderate degree of geologic assurance. See **indicated.** (See also ***indicated resources***, p. 26; and figs. 1, 2, and 3.)

D. Inferred Resources.—Identified bodies of virgin coal having a low degree of geologic assurance. See **inferred resources**. (See also ***inferred resources***, p. 26; and figs. 1, 2, and 3.)

E. Measured Resources.—Accessed and virgin demonstrated resources having a high degree of geologic assurance. (See ***measured resources***, p. 27; and figs. 1, 2, and 3.)

F. Original Resources.—The amount of coal in-place before production. Where mining has occurred, the total of *original resources* is the sum of the identified resources, undiscovered resources, coal produced, and coal lost-in-mining. (See ***original resources***, p. 27; and figs. 1, 2, and 3.)

G. Remaining Resources.—The resources in the ground in a mine, area, field, basin, region, province, county, state, and (or) nation after some mining. The term does not include coal lost-in-mining unless such coal can be considered potentially recoverable. *Remaining resources* may be divided into categories such as remaining economic, marginally economic, subeconomic, measured, indicated, inferred, identified, and undiscovered (hypothetical and speculative) resources or other types of resources. (See optional subdivisions, below; and figs. 1, 2, and 3.) The total remaining resources are the sum of the remaining identified and undiscovered resources as of the date of the estimate.

H. Subeconomic Resources.—That part of identified (demonstrated) resources that does not meet the economic criteria of reserves and marginal reserves. See **resources** and **economic**. (See also ***subeconomic resources***, p. 31; and figs. 1 and 2.)

I. Inferred Subeconomic Resources.—That part of identified (inferred) resources that does not meet the economic criteria of inferred reserves or inferred marginal reserves. See **resources** and **economic**. (See also ***subeconomic resources***, p. 31; and figs. 1 and 2.)

J. Speculative Resources.—See Undiscovered Resources (below). (See also ***speculative resources***, p. 30; and figs. 1, 2 and 3.)

K. Undiscovered Resources.—*Undiscovered resources*, the existence of which is only postulated, comprise deposits that are either separate from or are extensions of identified resources. *Undiscovered resources* may be postulated in deposits of such quality, rank, quantity, and physical location as to render them economic, marginally economic, or subeconomic. To reflect varying degrees of geologic certainty, *undiscovered resources* may be subdivided into two parts as follows. (See ***undiscovered resources***, p. 31.)

1. Hypothetical Resources.—A class of undiscovered resources that are either similar to known coal deposits which may be reasonably expected to exist in the same coal field or region under analagous geologic conditions or are an extension from inferred resources. In general, *hypothetical resources* are in the central parts of broad areas of coal fields where points of sampling and measurement and evidence for thickness and existence is from distant outcrops, mine workings, drill holes, and wells. If exploration confirms the existence of hypothetical resources and reveals enough information about their quality, quantity, and rank, they will be reclassified as identified resources.
2. Speculative Resources.—A class of undiscovered resources that may occur either in known types of deposits in favorable geologic settings where coal deposits have not been discovered or in types of deposits as yet unrecognized for their economic potential. If exploration confirms the existence of speculative resources and reveals enough information about their quality, quantity, and rank, they will be reclassified as identified resources.

OPTIONAL SUBDIVISONS:

Resources may be divided into subcategories, for example, on the basis of ash content, sulfur content, and heat value; type or variety of coal such as boghead or cannel coal; usage such as metallurgical, petrochemical, and synthetic fuel types; resources underlying specified lands owned by State governments, the Federal Government, or private interests; by restricted resources underlying State or national parks, monuments, forests, grasslands; military, naval, and Indian reservations; and alluvial valley floors, steep slopes, lakes and large rivers, and environmentally protected areas.

A. Restricted Resources.—Those parts of any resource category that are restricted or prohibited from extraction by laws or regulations.

Discussion: Restricted resources meet all requirements of coal classified as resources, except that they are restricted from extraction by law or regulation. The assignment to a restricted category may be either temporary or permanent, but, because laws and regulations can be repealed or changed, such coal should be separately distinguished and tonnage estimates recorded as restricted resources.

The division of coal resources into the many different categories described heretofore and into other categories not differentiated in the text is desirable and encouraged. Many requests for information about resources are received by coal resource specialists and are unanswerable because the scopes of the systems of classification used in the past were too limited. Persons and institutions classifying resources are, therefore, encouraged to use initiative in defining and developing additional classes of coal resources.

restricted reserves.—See optional subdivisions of **reserves.**

restricted resources.—See optional subdivisions of **resources.**

roof.—Stratigraphically, in underground mining the rock immediately overlying a coal bed. Where a bed is overturned, the stratigraphic *roof* is the mining floor.

sample.—A representative fraction of a coal bed collected by approved methods, guarded against contamination or adulteration, and analyzed to determine the nature; chemical, mineralogic, and (or) petrographic composition; percentage or ppm content of specified constituents; heat value; and possibly the reactivity of the coal or its constituents.

Discussion: Some samples are also collected so that fossil remains can be ascertained and physical, magnetic, or other geophysical properties can be determined, tested, observed, or analyzed. All samples should be accompanied by a description of the *sample*, including location, thickness of coal, and stratigraphic relationship to other rocks.

TYPES OF SAMPLES:

A. **as-received sample.**—A sample of coal as it is received at a laboratory.

B. **bed or channel sample.**—A sample of coal collected from a channel cut perpendicular to the stratification.

Discussion: This type of sample is used to ascertain the chemistry, rank of coal, mineralogy, petrography, and geophysical and physical properties of coal. Instructions for this type of sampling are contained in Geological Survey Circular 735 (Swanson and Huffman, 1976, p. 2).

C. **bench sample.**—A sample of a subdivision and (or) layer of a coal bed separated from other subdivisions by partings of non-coal rock.

Discussion: The term *bench sample* does not apply to coal lithotypes such as vitrinite and exinite as used by petrologists.

D. **blend pile sample.**—A sample of coal collected from the blend-pile of a processing plant or a utilization facility such as a powerplant or steel mill.

E. **breaker sample.**—A sample of coal broken or crushed in a breaker plant. A *breaker sample* is usually collected prior to cleaning of coal.

F. **cleaned coal sample.**—A sample of coal collected after use of a cleaning procedure.

G. **core sample.**—A sample of coal recovered from a core which was obtained at depth by a coring device in a drill hole.

H. **cutting sample.**—A sample of coal taken from the cuttings returned during drilling.

Discussion: Cutting samples are not recommended because many comparisons with properly or conventionally collected samples indicate they are rarely representative.

I. **delivered coal sample.**—A sample of coal collected from a shipment that is being or will be delivered to a user.

J. **grab sample.**—A sample, commonly a single piece, selected from a coal bed, tipple, preparation plant, blend pile, conveyor belt, or coal car.

Discussion: Grab samples are not recommended because many comparisons with properly collected samples indicate they are rarely representative.

K. **mine sample.**—A sample of coal collected from a mine, generally from an underground working face or from a strip-wall face.

L. **run of mine** or **mine run sample.**—Generally the same as a **tipple sample.**

M. **tipple sample.**—A sample of coal collected at a mine tipple.

seam.—A bed of coal lying between a roof and floor. This term is not to be used in place of "coal bed" in reports of the U.S. Geological Survey.

short ton.—A unit of weight equal to 2,000 pounds; 0.9071847 metric ton, tonne, or megagram; 0.8928571 long ton.

specific gravity of coal.—The ratio of the mass of a unit colume of coal to the mass of an equal volume of water at 4°C.

Discussion: The *specific gravity of coal* varies considerably with rank and with differences in ash content. The values shown in table 2 are close to the average specific gravities of unbroken or unmined coal in the ground (in situ) for the four major rank categories and are to be used in preparing U.S. Geological Survey estimates of coal resources and reserves.

Persons associated with individual mining operations sometimes use lower specific gravity factors to allow for anticipated losses in extraction. Such usage may be suitable for specific mine areas but is not recommended for use in general reports because the recoverability of coal varies greatly between areas, beds, mining methods, and mine operators.

speculative.—Lowest degree of geologic assurance. Estimates of rank, thickness, and extent are based on

TABLE 2.—*Average specific gravity and average weight of unbroken coal per unit volume of different ranks*

Rank	Specific gravity	Weight of unbroken coal per unit volume						
		Short tons per acre-foot	Short tons per acre-inch	Metric tons per acre-foot	Short tons per square mile-foot	Metric tons per square mile-foot	Metric tons per square hectometer-meter	Metric tons per square hectometer meter
Anthracite and semianthracite	1.47	2,000	166.6	1,814	1,280,000	1,160,960	14,700	1,470,000
Bituminous coal	1.32	1,800	150	1,633	1,152,000	1,045,120	13,200	1,320,000
Subbituminous coal	1.30	1,770	147.5	1,605	1,132,800	1,027,200	13,000	1,300,000
Lignite	1.29	1,750	145.8	1,588	1,120,000	1,016,320	12,900	1,290,000

assuming the existence of known types of coal deposits in favorable geologic settings or on assuming the existence of unknown types of deposits as yet unrecognized for their economic potentials. Tonnages are estimated by assuming thickness of coal, overburden, extent, and rank to a specified depth. There are geologic evidence sites but no measurement sites in areas of speculative coal. Used as a modifier to resource terms. See Hypothetical Resources, p. 20 ; Speculative Resources, p. 20; and Undiscovered Resources, p. 20. (See also figs. 1, 2, and 3.)

speculative resources.—See Speculative Resources, p. 20. (See also ***speculative resources***, p. 30; and figs. 1, 2, and 3.)

square hectometer-meter (hm^2–m).—A metric unit of the volume of coal that covers 1 square hectometer at a thickness of 1 meter; 10,000 cubic meters; 10 cubic dekameters; 0.010 square kilometer-meter; 13,079.51 cubic yards; 8.107132 acre-feet; 0.0126674 square mile-foot. The weight of coal in this volume varies according to rank. (See table 1.)

square kilometer.—1,000,000 square meters; 100 hectares; 247.10538 acres; 1,195,990 square yards; 10,763,910 square feet.

square kilometer-meter (km^2–m).—The volume of coal (1,000,000 cubic meters; 100 square hectare-meter-meters or 100 hectare-meters; 1,307,950.6 cubic yards; 35,314,667.0 cubic feet) that covers 1 square kilometer at a thickness of 1 meter. The weight of coal varies according to the rank. (See table 2.)

square mile.—27,878,400 square feet; 3,097,600 square yards; 2,589,988.1 square meters; 258.99881 hectares; 640 acres; 2.5899881 square kilometers.

square mile-foot.—The volume of coal (27,878,400 cubic feet; 789,428.38 cubic meters; 1,032,533.33 cubic yards) that covers 1 square mile to a thickness of 1 foot. The weight of coal varies according to the rank. (See table 2.)

strip or **stripping ratio.**—The amount of overburden that must be removed to gain access to a unit amount of coal.

Discussion: A *stripping ratio* may be expressed as (1) thickness of overburden to thickness of coal, (2) volume of overburden to volume coal, (3) weight of overburden to weight of coal, or (4) cubic yards of overburden to tons of coal. A *stripping ratio* commonly is used to express the maximum thickness, volume, or weight of overburden that can be profitably removed to obtain a unit amount of coal.

strip or **surface mining.**—The extraction of coal by using surface mining methods such as area strip mining, contour strip mining, or open-pit mining. The overburden covering the coal is removed and the coal extracted using power shovels, front end loaders, or similar heavy equipment.

subbituminous coal.—A rank class of nonagglomerating coals having a heat value content of more than 8,300 Btu's and less than 11,500 Btu's on a moist, mineral-matter-free basis. This class of coal is divisible on the basis of increasing heat value into the subbituminous C, B, and A coal groups. (See table 1.)

subeconomic resources.—See **resources** and **economic**. (See also ***subeconomic resources***, p. 31; and figs. 1, 2, and 3.)

sulfur content.—The quantity of sulfur in coal expressed in percent or parts per million. May be divided into the quantities occurring as inorganic (pyritic) sulfur, organic sulfur, and sulfate sulfur.

thickness categories.—The categories of thickness of coal beds employed in calculating, estimating, and reporting coal resources and reserves. (See ***thickness of coal for resource calculations***, p. 31; and specific instruction No. 3, p. 34.)

ultimate analysis.—In coal, the determination by prescribed methods of the ash, carbon, hydrogen, nitrogen, oxygen (by difference), and sulfur contents. Quantities of each analyzed substance are reported by percentage for the following conditions: as-received, dried at 105°C, and moisture-and ash-free.

Discussion: The principal reason for the ***ultimate analysis*** is the classification of coals by rank, although it is often used for commercial and industrial purposes when it is desirable to know the sulfur content. The *ultimate analysis* also is known as the "total analysis." This, however, is a misnomer because substances other than those noted above are not identified and quantified, such as trace elements, oxides, and rare gases.

underground mining.—The extraction of coal or its products from between enclosing rock strata by underground mining methods, such as room and pillar, longwall, and shortwall, or through in situ gasification.

undiscovered.—A category of virgin resources of coal having the lowest degree of geologic assurance. Category is divisible into the hypothetical and speculative categories. (See **hypothetical** and **speculative.**) Estimates are quantitative. There are no sample or measurement of coal thickness sites in areas of undiscovered coal. Used as a modifier to resources.

undiscovered resources.—See mandatory subdivisions of **resources.** (See also ***undiscovered resources***, p. 31; and figs. 1, 2, and 3.)

vein.—A bed of coal lying between a distinct roof and floor. Term is not to be used in place of "coal bed" in reports of the U.S. Geological Survey.

virgin coal.—Coal that has not been accessed by mining. See **accessed.**

volatile matter.—In coal, those products, exclusive of moisture, given off as gas and vapor, determined by definite prescribed methods (ASTM, 1981, p. 184, D2361-66, D3761-79, D3175-77, D3176-74, D3178-73, and D3179-73).

CRITERIA FOR COAL RESOURCE CLASSIFICATION

Although not specifically noted, coal resources are classified in figures 1, 2, and 3 according to geologic assurances of existence and to the economic feasibility of recovery.

The degree of geologic assurance in this system of coal classification is determined from the interrelations of (1) proximity to or closeness of spacing of points where a coal bed is measured or sampled (reliability); (2) concepts, ideas, and models of the depth, rank, quality, thickness of coal, areal extent, depositional patterns and correlations of coal beds and enclosing rocks; and (3) knowledge of associated structural features as they control the distribution, extent, thickness, depth of burial, and metamorphism of coal resources. An understanding of these elements as they relate to the three dimensional configurations of stratigraphic sequence is necessary to provide the highest degree of geologic assurance as to the existence and continuity or lack of continuity of specific coal beds.

The degree of economic feasibility is determined by interrelating the (1) thickness of coal (see specific instruction No. 3, p. 34); (2) thickness of overburden; (3) the rank and quality of coal as ascertained from analyses that may be from the same bed or adjacent beds and which may be projected on geologic evidence for several miles; (4) costs of mining, processing, labor, transportation, selling, interest, taxes, and demand and supply; (5) expected selling price; and (6) expected profits.

The thickness of overburden and the thickness of a coal bed are the primary factors controlling the feasibility of mining. Knowledge of the quantity of coal and rock that must be removed per unit of recovered coal, of the roof and floor conditions, and of the difficulty of separating coal from rock determine the mining method and the equipment chosen for the mining operation. The rank, purity, heat value, and selling price of the coal commonly dictate usage and marketability. Higher rank coals generally are judged more valuable than lower rank coals owing to greater heat values and chemical characteristics that are sought currently by the metallurgical and petrochemical industries. Economic variables that influence feasibility are price of coal, cost of equipment, mining, labor, processing, transportation, interest rates, and taxes. Supply and demand for coal also influence feasibility as do environmental laws, restrictions, judicial ratings, and political considerations. The relative value of coals may change markedly in the near future as the result of utilizing new techniques for converting coal to gas and or liquid fuels. Low-rank coals and coals containing pyrite that are currently of lower economic value may in the future be considered premium fuels for conversion processes.

The criteria for the principal classes of coal resources described hereafter are summarized in table 3 and are to be used in preparing all U.S. Geological Survey coal resource estimates from January 1, 1983, until further revised.

APPLICATIONS OF CRITERIA

The criteria are to be applied only to those deposits of coal that are currently or potentially feasible for economic extraction by underground mining, surface mining, and (or) in situ gasification methods. Coal beds that are thinner than 14 inches (35 cm; anthracite and

TABLE 3.—*Summary of coal resource criteria*

	Depth[1] Feet (Meters)	Thickness[1] Inches (Centimeters)
Identified and undiscovered resources:		
Anthracite and bituminous coal	≤6,000 (1,800)	≥14 (35)
Subbituminous coal and lignite	≤6,000 (1,800)	≥30 (75)
Reserve base and inferred reserve base:		
Anthracite and bituminous coal	≤1,000 (300)	≥28 (70)
Subbituminous coal	≤1,000 (300)	≥60 (150)
Lignite	≤ 500 (150)	≥60 (150)
Reserves[2], marginal reserves, and inferred reserves[2]: (Criteria same as reserve base and inferred reserved base but with factors based on engineering and economic analysis applied.)		
Subeconomic resources:		
Anthracite and bituminous coal	0-1,000 (300)	14 (35)-28 (70)
	1,000 (300)-6,000 (1,800)	≥14 (35)
Subbituminous coal	0-1,000 (300)	30 (75)-60 (150)
	1,000 (300)-6,000 (1,800)	≥30 (75)
Lignite	0-500 (150)	30 (75)-60 (150)
	500 (150)-6,000 (1,800)	≥30 (75)

[1]The metric thicknesses shown in parentheses are not exact equivalents of the thicknesses shown in feet; for convenience, they have been rounded to the amounts shown.

[2]Includes some beds that are thinner and (or) deeper than the general criteria permit, but that are being mined currently.

bituminous) and 30 inches (75 cm; lignite and subbituminous) generally are excluded from resource consideration unless currently being mined. All coal beds deeper than 6,000 feet (1,800 m) are excluded. These limits are imposed as the result of consultations with geologists and mining engineers throughout the international coal community. In the United States, beds that contain more than 33 percent ash also are excluded; because of a shortage of energy in some countries, however, coal containing more than 33 percent ash is being mined and is classified as reserves.

Coal beds thinner or more deeply buried than the imposed limits have been mined locally at several places in the United States and are mined in other parts of the world; however, their extraction in the United States has generally not proven economic. Where such mining is taking place, the coal should be classed as a reserve and recorded at the time of assessment in the coal resource figures. With the few exceptions owing to current mining and similar future exceptions, the imposed limits should be adhered to. See general guideline No. 7, p. 32.

SPECIFIC CRITERIA

Note.—Specific criteria and glossary terms are cross-referenced within this report. To aid the reader, specific criteria, beginning below, are printed in ***boldface italics***, and glossary items, beginning on p. 5, are printed in **boldface** type.

anthracite and bituminous coal reserves.—Tonnage estimates for these classes of coal are determined by summing the recoverable quantities of coal in the reserve base and are assigned to the following categories: (a) thickness of coal—28 to 42 inches (70 to 105 cm), 42 to 84 inches (105 to 215 cm), 84 to 168 inches (215 to 430 cm), more than 168 inches (>430 cm); and (b) thickness of overburden—0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 to 300 m). Tonnage estimates for the bituminous coal class may be divided into low-volatile, medium-volatile, high-volatile A, high-volatile B, and high-volatile C groups. Similarly, tonnage estimates for the anthracite class may be divided into meta-anthracite, anthracite, and semianthracite groups. Reserves assigned to these coal classes must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative. See specific instruction No. 3, p. 34.

anthracite and bituminous coal inferred reserves.—Tonnage estimates for these classes of coal are determined by summing the recoverable quantities of coal in the inferred reserve base and are assigned to the same coal thickness and overburden thickness categories as anthracite and bituminous coal reserves. Inferred reserves must be considered as economically producible at the time of classification. Facilities for extraction need not be in place and operative.

anthracite and bituminous coal marginal and inferred marginal reserves.—Tonnage estimates for these classes of coal are determined by summing the marginally recoverable quantities of coal in the reserve base and in the inferred reserve base and are assignable to the same categories of thickness of coal and overburden described for anthracite and bituminous coal reserves. These classes of coal may be divided into the same rank groups as described for anthracite and bituminous coal reserves. Marginal and inferred marginal reserves must be considered uncertain as to economic producibility at the time of classification. Facilities for extraction need not be in place and operative.

anthracite and bituminous coal reserve base and inferred coal reserve base.—See ***reserve base*** for thickness of coal and thickness of overburden criteria.

anthracite and bituminous coal resources.—Tonnage estimates for these classes of coals are determined by summing the estimates for anthracite and bituminous coal identified and undiscovered resources (fig. 3). They are assignable to the same thickness categories as for anthracite and bituminous coal reserves with the addition of a 14–28 inch (35–70 cm) category (see specific instruction No. 3, p. 34), and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). Tonnage estimates for the bituminous coal class may be divided into the low-volatile, medium-volatile, high-volatile A, high-volatile B, and high-volatile C groups, and tonnage estimates for the anthracite class may be divided into the meta anthracite, anthracite, and semianthracite groups.

cumulative depletion.—*Cumulative depletion* is summed from all coal extracted and lost-in-mining prior to the date of the estimate, which may be subdivided on the basis of rank and subrank (class and group) of coal, overburden class, thickness class, mining method, heat value, usage, time, cokeability, chemical constituents, and area of production.

cummulative production.—*Cummulative production* is summed from production from a mine, field, basin, region, province, state, or nation prior to the date of the estimate, which may be subdivided on the basis of rank and subrank (class and group) of coal, overburden class, thickness class, mining method, heat value, usage, time, cokeability, chemical constituents, and area of production.

demonstrated reserves and ***demonstrated marginal reserves.***—Tonnage estimates for these categories of coal are the sum of the estimates for measured and indicated reserves and marginal reserves, repectively, which are the preferred usages. See Reserves and Marginal Reserves, p. 18.

demonstrated reserve base.—Tonnage estimates for this category of coal are determined by summing the estimates for the measured and indicated reserves bases. The *demonstrated reserve base* is the same as the "reserve base," which is the preferred usage. See **reserve base**, p. 19).

demonstrated resources.—Tonnage estimates for this category are the sum of the estimates for the reserve base and subeconomic resources.

economic resources.—An informal term used by geologists to indicate their estimates of the coal resources that are potentially economic.

hypothetical resources.—Tonnage estimates for this category of resources are for (1) extensions of inferred resources (coal beyond a radius of 3 miles or 4.8 km from a point of measurement), and (2) regions where tonnage estimates are based on a knowledge of the geologic character of coal. *Hypothetical resources* include coal that is 14 inches (35 cm) or more thick (anthracite and bituminous coal) and 30 inches (70 cm) or more thick (subbituminous coal and lignite) to a depth of 6,000 feet (1,800 m). (See section on "Extrapolated Bed Map Method," p. 37; and "Extrapolated Coal Zone Method," p. 38; see also fig. 4.)

identified resources.—Tonnage estimates for this category of resource include all bituminous coal and anthracite 14 inches (35 cm) or more thick and all subbituminous coal and lignite 30 inches (75 cm) or more thick from the surface to a depth of 6,000 feet (1,800 m) whose location, rank, quality, and quantity have been determined within specified degrees of reliability as demonstrated, measured, indicated, and inferred.

indicated.—Virgin coal that lies between 1/4 mile (0.4 km) and 3/4 mile (1.2 km) from a point of thickness of coal measurement. (See fig. 4.)

indicated marginal reserves.—Tonnage estimates for this category of reserves include those parts of an indicated reserve base that at the time of determination border on being economically producible assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic profitability should be documented. (See **indicated**, p. 10; and fig. 4.)

indicated reserves.—*Indicated reserves* are estimated from an indicated reserve base by subtracting the assumed tonnage of coal that will be lost-in-mining and indicated marginal reserves. The remaining tonnage—the coal that is assumed will be extracted—is the *indicated reserves*, which must be considered as economically producible at the time of classification. However, facilities for extraction need not be in place and operative. (See **indicated**, p. 10; and fig. 4.)

indicated reserve base.—An *indicated reserve base* is determined by projection of thicknesses of coal and overburden, rank, and quality data from points of measurement and sampling on the basis of geologic evidence using the following criteria: (a) individual points of measurement are bounded by measured coal for 1/4 mile (0.4 km) suceeded by indicated coal from 1/4 mile (0.4 km) to 3/4 mile (1.2 km); and (b) *indicated reserve base* includes anthracite and bituminous coal 28 inches (70 cm) or more thick and subbituminous coal 60 inches (150 cm) or more thick to depths of 1,000 feet (300 m) and lignite 60 inches (150 cm) or more thick to depths of 500 feet (150 m). (See **indicated**, p. 10.)

indicated resources.—Tonnage estimates for *indicated resources* are computed by projection of thicknesses of coal and overburden, rank, and quality data from points of measurement and sampling on the basis of geologic evidence and are assigned to the following categories: (a) individual points of measurement are bounded by measured coal for 1/4 mile (0.4 km) succeeded by 1/2 mile (0.8 km) of indicated coal; and (b) *indicated resources* include anthracite and bituminous coal 14 inches (35 cm) or more thick and lignite and subbituminous coal 30 inches (75 cm) or more thick to a depth of 6,000 feet (1,800 m). The quantity of coal estimated as *indicated resources* is the same as the sum of the indicated reserve base, and indicated subeconomic resources. (See **indicated**, p. 10; and fig. 4.)

inferred.—Virgin coal that lies between 3/4 mile (1.2 km) and 3 miles (4.8 km) from a point of thickness of coal measurement. (See fig. 4.)

inferred marginal reserves.—Tonnage estimates for this category of reserves include those parts of an inferred reserve base that at the time of determination border on being economically producible assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic profitability should be documented. (See **inferred**, p. 10; and fig. 4.)

inferred reserve base.—An *inferred reserve base* is determined by projection of thicknesses of coal and overburden, rank, and quality data from points of measurement and sampling on the basis of geologic evidence using the following criteria: (a) individual points of measurement are bounded by measured and indicated coal for 3/4 mile (1.2 km) succeeded by inferred coal from 3/4 mile (1.2 km) to 3 miles (4.8 km); and (b) *inferred reserve base* includes anthracite and bituminous coal 28 inches (70 cm) or more thick, subbituminous coal 60 inches (150 cm) or more thick, all to depths of 1,000 feet (300 m), and lignite 60 inches (150 cm) or more in thickness to depths of 500 feet (150 m).

inferred reserves.—*Inferred reserves* are estimated from the inferred reserve base by subtracting the inferred marginal reserves and the coal that is estimated will be lost-in-mining. *Inferred reserves* must be considered as economically producible at the time of determination considering environmental, legal, and technologic constraints. Extraction facilities need not be in place and operative.

inferred resources.—*Inferred resources* are determined by projecting the thicknesses of coal and overburden, rank, and quality data from points of measurement and sampling on the basis of geologic knowledge and are assigned to the following categories: (a) individual points of measurement are bounded by measured and indicated coal for 3/4 mile (1.2 km) succeeded by 2-1/4 miles (3.6 km) of inferred coal; (b) *inferred resources* include anthracite and bituminous coals 14 inches (35 cm) or more thick and lignite and subbituminous coal 30 inches (75 cm) or more thick to depths of 6,000 feet (1,800 m). The quantity of coal estimated as an inferred resource is the same as the sum of the inferred reserve base and inferred subeconomic resources.

lignite reserves.—Tonnage estimates for this class of coal reserves are determined by summing the recoverable quantities of coal in the reserve base and are assigned to the following categories: (a) thickness of coal—5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3 to 6 m), 20 to 40 feet (6 to 12 m), and more than 40 feet (>12 m); and (b) thickness of overburden—0 to 500 feet (0 to 150 m). Tonnage estimates for *lignite reserves* may be divided into the lignite A and B groups. Reserves assigned to the lignite class must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative.

Discussion: Currently, there are few underground ground lignite mines in the United States. In addition, there are few, if any, lignite strip mines that are removing as much as 300 feet (100 m) of overburden. In order to provide for future technologic and surface mining advances, the maximum thickness of overburden for surface-minable *lignite reserves* and reserve base is set at 500 feet (150 m). It is deemed inexpedient to estimate underground-minable *lignite reserves* and reserve base at depths greater than 500 feet (150 m). (See specific instruction No. 3, p. 34.)

lignite marginal and inferred marginal reserves.—Tonnage estimates for these classes of coal reserves are determined by summing the marginally recoverable quantities of coal in the reserve base and inferred reserve base and are assignable to the same categories of thicknesses of coal and overburden described for lignite reserves; coal may be divided into the lignite A and B groups. *Lignite marginal and inferred marginal reserves* must be considered as uncertain as to their economic producibility at the time of classification. Facilities for extraction need not be in place and operative.

lignite inferred reserves.—Tonnage estimates for this class of reserves are determined by summing the recoverable quantities of coal in the inferred reserve base and are assignable to the same categories of thicknesses of coal and overburden described for lignite reserves. Also, this class of coal may be divided into the lignite A and B groups. Such inferred reserves must be considered economically producible at the time of classification; facilities for extraction need not be in place and operative.

lignite reserve base and inferred reserve base.—See *reserve base* for thickness of coal and thickness of overburden criteria.

lignite resources.—Tonnage estimates for this class of coal are determined by summing the estimates for lignite identified and undiscovered resources. The same thickness categories as for lignite reserves are to be used with the addition of a 30–60 inches (75–150 cm) category (see specific instruction No. 3, p. 34), and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). The tonnage estimates for this class of coal may be divided into lignite A and B groups.

measured.—Accessed and virgin coal that lies within a radius of 1/4 mile (0.4 km) of a point of thickness of coal measurement. (See fig. 4.)

measured marginal reserves.—Accessed and virgin coal that lies within a radius of 1/4 mile (0.4 km) of a point of thickness of coal measurement. Tonnage estimates for this category of reserves includes those parts of a measured reserve base that at the time of determination border on economic producibility assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic producibility should be documented. (See **measured**, p. 12; and fig. 4.)

measured reserves.—*Measured reserves* are estimated from a measured reserve base by subtracting the sum of the assumed tonnage of coal that will be lost-in-mining and measured marginal reserves. The remaining tonnage—the coal that is assumed will be extracted—is *measured reserves* which must be considered as economically producible at the time of classification; however, facilities for extraction need not be in place and operative.

measured reserve base.—A *measured reserve base* is determined by projection of thicknesses of coal and overburden, rank, and quality data from points of measurement and sampling on the basis of geologic evidence for a radius of 1/4 mile (0.4 km). A *measured reserve base* includes anthracite and bituminous coal 28 inches (70 cm) or more thick and subbituminous coal 60 inches (150 cm) or more thick to depths of 1,000 feet (300 m) and lignite 60 inches (150 cm) or more thick to depths of 500 feet (50 m).

measured resources.—Tonnage estimates for *measured resources* are computed by projection of thicknesses of coal and overburden, rank, and quality data for a radius of 1/4 mile (0.4 km) from a point of measurement. Measured resources include anthracite and bituminous coal 14 inches (35 cm) or more thick and lignite and subbituminous coal 30 inches (75 cm) or more thick to depths of 6,000 feet (1,800 m). The quantity of coal estimated as measured is the same as the sum of the measured reserve base and measured subeconomic resource.

original resources.—Tonnage estimates determined for coal in the ground prior to production. Where coal has been mined, estimates are made by summing remaining resources, cummulative production, and coal lost-in-mining. An estimate of total original resources is the sum of the original resources determined for many mines, fields, basins, regions, provinces, States, and the Nation. (See *resources* for thicknesses of coal and overburden; and **lost-in-mining**, p. 12.)

other occurrences, noneconomic coal.—Such coal, except where mined locally, consists of anthracite and bituminous coal beds less than 14 inches (35 cm) thick; lignite and subbituminous coal beds less than 30 inches (75 cm) thick; and all coal beds that are buried by more than 6,000 feet (1,800 m) of overburden; coal containing more than 33 percent ash; and that coal lost-in-mining that is considered noneconomic. Tonnage estimates are optional for such coal. However, if estimates are made, they should be reported as "other occurrences" and not as resources. However, where currently mined, coal that is considered too thin or too high in ash and would normally be classed as "other occurrences" is to be classed as reserves.

rank assignments.—The assignment of rank is a necessary part of classifying a coal; however, data for determining rank are commonly sparse or are far-removed from the localities where the data required for rank assignment is needed. In general, rank gradually changes laterally over many miles or stratigraphically over hundreds to thousands of feet. Because of the lack of data in some areas, conclusions concerning *rank assignments* commonly must be derived from analytic or petrographic determinations made on coal that lies some distance from where the rank assignment is desired. Conclusions concerning rank where analytic or petrographic data are sparse must be viewed as tentative. However, if a geologist's understanding of the setting of the area sampled is adequate, the rank assignment probably will be correct even though the rank data are sparse.

rank calculation.—The rank of coal is to be calculated by using the following instructions which are quoted from the standard specifications for classification of coals by rank (ASTM Standards, 1981, p. 212–216):

8. Calculation to Mineral-Matter-Free Basis

8.1 *Calculation of Fixed Carbon and Calorific Value:* For classification of coal according to rank, fixed carbon and calorific value shall be calculated to the mineral-matter-free basis in accordance with either the Parr formulas, Eqs 1, 2, and 3, or the approximation formulas, Eqs 4, 5, and 6, that follow. In case of litigation use the appropriate Parr Formula.

8.2 Calculation to Mm-free basis:

Parr Formulas:

$$\text{Dry, Mm-free FC} = \frac{(\text{FC} - 0.15\text{S})}{[100 - (\text{M} + 1.08\text{A} + 0.55\text{S})]} \times 100 \quad (1)$$

$$\text{Dry, Mm-free VM} = 100 - \text{Dry, Mm-free FC} \quad (2)$$

$$\text{Moist, Mm-free Btu} = \frac{(\text{Btu} - 50\text{S})}{[100 - (1.08\text{A} + 0.55\text{S})]} \times 100 \quad (3)$$

Note—The above formula for fixed carbon is derived from the Parr formula for volatile matter.

Approximation Formulas:

$$\text{Dry, Mm-free FC} = \frac{\text{FC}}{[100 - (\text{M} + 1.1\text{A} + 0.1\text{S}]} \times 100 \quad (4)$$

$$\text{Dry, Mm-free VM} = 100 - \text{Dry, Mm-free FC} \quad (5)$$

$$\text{Moist, Mm-free Btu} = \frac{\text{Btu}}{[100 - (1.1\text{A} + 0.1\text{S})]} \times 100 \quad (6)$$

where

Mm = Mineral matter,
Btu = British thermal units per pound (calorific value),
FC = percentage of fixed carbon,
VM = percentage of volatile matter,
M = percentage of moisture,
A = percentage of ash, and
S = percentage of sulfur.

Above quantities are all on the inherent moisture basis. This basis refers to coal containing its natural inherent or bed moisture but not including water adhering to the surface of the coal.

recovery factor method.—Only a part of the coal in any deposit can be extracted when mined. The coal not extracted during underground mining, strip mining, or auger mining; the coal that becomes a part of a underground or strip-mine waste pile; or the coal that is not removed adjacent to a strip-mine or underground-mine boundary is considered as lost-in-mining unless sufficient tonnages are left unextracted so that additional mining or recovery can be foreseen.

If it is not feasible or possible to calculate the reserves of an area using an economic analysis, a reasonable approximation of the reserves can be determined by using the *recovery factor method* described hereafter.

Each operating mine has a unique percentage of coal that is recovered. This percentage is termed the recovery factor of the mine and is obtained from the following formula:

$$RF = \frac{Y \times 100}{X}$$

where

RF = Recovery factor or percent coal estimated extractable during mining,
X = The total tonnage of coal estimated in the ground,
Y = The tonnage of coal estimated to be recoverable during mining.

A recovery factor can be applied to a reserve base to obtain an estimate of the reserves of an area. Such use of a recovery factor is appropriate when there is a paucity of geologic data for estimating the tonnage of potentially extractable coal.

It is difficult to estimate accurately the recoverable coal in a very large area such as a field, region, province, basin, State, or the Nation because it is impossible to determine how much coal in the area will not be mined for legal or environmental reasons, what method or methods of mining will be used, and what the average recovery factor will be for all mining methods.

A reserve base and reserves have been estimated by industry for most operating mines in the United States. Generally, data that can be used to compute recovery factors for individual mines are closely held by the operators; therefore, there is little publicly available information to guide estimators in determining local, regional, and national recovery factors. Commonly, estimators must extrapolate recovery factors from experience gained in a few mines by assuming that (1) geologic conditions controlling mining will be similar, and (2) success in the recovery of coal in unmined areas will be similar to that of mined areas utilizing the same mining method. Such extrapolation of recovery factors from a few well known mined areas to less well known or unknown areas requires experience regarding the geology, the mining method or methods to be employed, and an awareness of the difficulties, geologic and otherwise, that affect the estimation of reserves. Area, quadrangle, township, field, basin, province, county, State, and national recovery factors can be determined by using formulas after determining the mean recovery factor in percent for many mines, ascertaining the quantity of reserve base coal in the area of study, and ascertaining the total quantity of coal that is restricted from mining for any legal, environmental or technologic reason. These formulas are:

$$Z = 100 \frac{X}{Y}$$

$$NRF = W(100 - Z)$$

where

X = tonnage of coal restricted from extraction for any legal, environmental, or technologic reason,

Y = tonnage of coal included in the reserve base category of a large area,

Z = restricted coal (percent),

W = recovery factor percent obtained from local mines, and

NRF = National, State, or large area recovery factor in percent applied to all coal including restricted.

In the United States, recovery factors for underground mining as determined from mine maps of abandoned and operating mines generally range from about 35 to about 70 percent and average about 50 percent. Similarly, recovery factors for abandoned and operating surface mines range from about 70 to 95 percent and average about 80 percent. These local recovery factors are valid for individual mines but are not valid for large areas because they fail to consider the coal lost-in-mining such as (1) the coal that will not be mined between properties, and (2) coal in overlying and underlying beds rendered usuitable for future mining by past underground mining. Further, the local recovery factors do not consider the coal that is restricted or prohibited from mining, such as the coal underlying national parks and wild life sanctuaries; coal that is too deep and too thin to be mined because of excessive costs; and coal that cannot be mined because of unsolved technologic, geologic, or engineering problems.

The authors recommend applying a recovery factor of 50 percent to the reserve base when computing underground and surface mining reserves of large areas. However, if actual local recovery factors have been calculated, the procedure outlined with the two formulas should be implemented for smaller areas.

remaining resources.—The resources remaining in the ground after prior mining. These resources include identified and undiscovered resources and include coal lost-in-mining whose attributes indicate possible future recovery. See ***resources***, for thickness of coal and overburden criteria, and figure 3.

reserve base.—A tonnage estimate for this category of coal consists of the sum of the estimates for measured and indicated reserves, marginal reserves, and a part of the measured and indicated subeconomic resources (the coal that has or will be lost-in-mining). The *reserve base* is the same as the demonstrated reserve base. The term *reserve base* is preferred for reports of the U.S. Geological Survey. The criteria for the *reserve base* include bituminous coal and anthracite 28 inches (70 cm) or more thick, subbituminous coal 5 feet (1.5 m) or more thick that occurs at depths to 1,000 feet (300 m), and lignite 5 feet (1.5 m) or more thick that occurs at depths to 500 feet (150 m).

Discussion: Individual reserve bases, where needed and appropriate, are to be determined by categories of reliability, thicknesses of coal and overburden; rank, chemical constituents, ash content, heat value, and potential usage. Additionally, estimated individual reserve base estimates are to be summed into totals for each township, quadrangle, coal field, basin, region, province, township and range, county, State, and the Nation. Assignment of coal to a reserve base is controlled by physical and chemical criteria such as categories of reliability, thicknesses of coal and overburden, rank of coal, and knowledge of depositional patterns of coal beds and associated structural features. Changing economic, technologic, and environmental considerations do not control assignment of coal to a reserve base. In contrast, the discrimination of reserves is largely controlled by economic factors such as judgments of cost, profit, and supply of and demand for coal. Reserve discrimination is controlled secondarily by advances or differences in mining, preparation and transportation technologies, and by environmental regulations, laws, and judicial rulings.

The physical and chemical criteria used to assign coal to a reserve base category have been used already to evaluate many coal beds that are currently mined in the United States. These evaluations indicate coal assigned to a reserve that is derived from a physically-chemically defined *reserve base* can be expected to be economically minable with a high degree of confidence. In a few places, however, where the thickness of a coal bed or associated rock conditions are exceptionally variable or severe, the varying tonnages of coal classified as a reserve from a physically and chemically defined *reserve base* may or may not prove to be extractable at a profit.

Changes in environmental laws and regulations generally affect the tonnages of coal assigned to the various categories of the *reserve base*; however, assessments of these changes have not been made.

reserves.—Reserve tonnage estimates are to be determined by summing the recoverable quantities of coal in the reserve base for each rank of coal and are assigned to the following categories: (1) thickness of overburden—0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 m to 300 m); and (2) thickness of coal—28 to 42 inches (70 to 105 cm), 42 to 84 inches (105 to 215 cm), 84 to 168 inches (215 to 430 cm), and more than 168 inches (>430 cm) for anthracite and bituminous coal; and 5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3.0 to 6.0 m), 20 to 40 feet (6.0 to 12.0 m), and more than 40 feet (> 12.0 m) for subbituminous coal and lignite. (See specific instruction No. 3, p. 34.) *Reserves* must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative. In addition, categories based on potential mining methods (surface and underground); chemical constituents such as sulfur, phosphorous and ash content; heat value; and usage such as metallurgical, steam, petrochemical, gasification, and liquefaction are desirable. *Reserves* and marginal reserves are estimated by determining the amount of coal in each reserve base category that can be extracted at the time of classification (*reserves*), and the amount that borders on being extractable at a profit (marginal reserves). These two amounts and the amount that will be lost-in-mining, when summed, are equal to the reserve base. The estimates of each reserve category are to be totaled into quadrangle, township, field, basin, region, province, county, and State estimates, and into a national total, and then the various estimates for all categories are to be totaled similarly to reach an inclusive estimate of all *reserves*.

Reserves are derived from the reserve base, which includes bituminous coal and anthracite 28 inches (70 cm) or more thick, subbituminous coal 5 feet (1.5 m) or more thick that occurs at depths to 1,000 feet (300 m), and lignite 5 feet (1.5 m) or more thick that occurs at depths to 500 feet (150 m). *Reserves* also include thinner and (or) more deeply buried beds of these ranks of coal that are currently being mined.

resources.—Tonnage estimates for coal resources are determined by summing the estimates for identified and undiscovered deposits of coal that are 14 inches (35 cm) or more thick for anthracite and bituminous coal and under less than 6,000 feet (1,800 m) of overburden, and 30 inches (75 cm) or more thick for lignite and subbituminous coal and under less than 6,000 feet (1,800 m) of overburden.

speculative resources.—As of publication of this circular, there are no speculative resources of coal estimated for the United States. However, if it is desirable to make such estimates, the definition of Speculative Resources (p. 20) and the criteria for ***resources*** will be followed, and the geologic evidence supporting the estimates and methods of quantification will be made available publicly.

subbituminous coal inferred reserves.—Tonnage estimates for this class of coal are determined by summing the recoverable quantities of coal in the inferred reserve base and are assigned to the same categories of thickness of coal and overburden described for ***subbituminous coal reserves***. This class of coal may be divided into the same rank groups as described for ***subbituminous coal reserves***. Inferred reserves must be considered as economically producible at the time of classification. However, facilities for extraction need not be in place and operative.

subbituminous coal marginal and inferred marginal reserves.—Tonnage estimates for these classes of coal are determined by summing the marginally recoverable quantities of coal in the reserve base and inferred reserve base, respectively, and are assigned to the same categories of thicknesses of coal and overburden described for ***subbituminous coal reserves.*** These classes of coal may be divided into the same rank groups as described for ***subbituminous coal reserves.*** Marginal and inferred marginal reserves must be considered uncertain as to their economic producibility at the time of classification. Facilities for extraction need not be in place and operative.

subbituminous coal reserves.—Tonnage estimates for this class of coal are determined by summing the recoverable quantities of coal in the reserve base and are assigned to the following categories: (a) thickness of coal—5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3.0 to 6.0 m), 20 to 40 feet (6.0 to 12.0 m), and more than 40 feet (>12.0 m) (see specific instruction No. 3, p. 34); and (b) thickness of overburden—0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 to 300 m). Such reserve estimates may be divided into subbituminous A, B, and C rank groups. Reserves assigned to this coal class must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative.

subbituminous coal reserve base and inferred reserve base.—See ***reserve base*** for thickness of coal and thickness of overburden categories.

subbituminous coal resources.—Tonnage estimates for this class of coals are determined by summing the estimates for identified and undiscovered subbituminous coal resources. The same thickness categories as for subbituminous coal reserves are to be used with the addition of a 30 inches–5 feet (75 cm–1.5 m) category (see specific instruction No. 3, p. 34), and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). Such resource estimates may be divided into subbituminous coal A, B, and C rank groups.

subeconomic resources and inferred subeconomic resources.—Tonnage estimates for these classes of coal are determined by summing the estimates for measured, indicated, and inferred resources that do not meet the criteria for assignment to the reserve base or inferred reserve base because they are too thin to mine, are too deeply buried to mine, or are those parts of the reserve base or inferred reserve base that have been or will be lost-in-mining but whose attributes indicate future recovery may become feasible. Included are all measured, indicated, and inferred reliability categories of bituminous coal and anthracite beds 14 to 28 inches (35 to 70 cm) thick, all subbituminous coal beds 30 to 60 inches (75 to 150 cm) thick that are less than 1,000 feet (300 m) below the surface, and all lignite beds 30 to 60 inches (75 to 150 cm) thick that are less than 500 feet (<150 m) below the surface, unless the coal in these beds will be recovered in the process of extracting coal from thicker beds. Also included are all beds of bituminous coal and anthracite 14 inches (35 cm) or more thick and beds of subbituminous coal 30 inches (75 cm) or more thick that occur at depths between 1,000 and 6,000 feet (300 and 1,800 m) and lignite beds 30 inches (75 cm) or more thick and more than 500 feet (>150 m) below the surface.

thickness of coal for resource calculations.—The thickness of coal used for resource calculations is the net thickness of coal in a bed excluding all partings more than 3/8 inch (>1 cm) thick. Beds and parts of beds made up of alternating layers of thin coal and partings are omitted from calculations if the partings comprise more than one-half of the total thickness. Also, benches of anthracite and bituminous coal less than 14 inches (35 cm) thick and benches of subbituminous coal and lignite less than 30 inches (75 cm) thick are omitted from calculations if they lie above or below partings that may deter their mining. Coal and coaly material containing more than 33 percent ash is excluded from resource and reserve estimates unless the ash is largely in associated partings so that the coal is cleanable to less than 33 percent ash. (See **parting**, p. 15, and specific instruction No. 13, p. 36.)

undiscovered resources.—Tonnage estimates for this category of resources are based (1) on knowledge of the geologic character, habit, and pattern of a coal bed or coal zone in an area or region or (2) on speculative geologic data. Estimates are made by summing the tonnage estimates for coal assigned to the hypothetical and speculative resources reliability categories. Included are hypothetical and speculative resources of bituminous coal and anthracite in beds 14 inches (35 cm) or more thick and hypothetical and speculative resources of subbituminous coal and lignite in beds 30 inches (75 cm) or more thick presumed to occur in mapped areas and in unmapped or unexplored areas to depths of 6,000 feet (1,800 m).

GUIDELINES FOR ESTIMATING COAL RESOURCES

These guidelines were prepared so that coal-resource workers will have logical and uniform procedures to follow. They combine the best features of the procedures used in preparing many previously published estimates of State and national coal resources with additions and modifications from numerous conferences with experienced coal resource estimators.

These guidelines are aimed at producing a uniformity of procedures so that coal-resource estimates prepared by various individuals and groups can be compared and (or) combined into meaningful totals for a quadrangle, township and range, coal field, basin, region, province, county, state, nation, continent, and (or) the world.

Some statements in the guidelines obviously are not rigidly applicable to all coal beds or coal-bearing areas. Where such shortcomings are perceived, a logical procedure is to develop new guidelines to effect appropriate changes in methodology so that they can be studied, criticized, and accepted or rejected by others.

The following statements are to be strictly adhered to by all coal resource specialists in the U.S. Geological Survey: *(1) All tables of coal resource or reserve estimates must contain a date and appropriate authorship information; and (2) each table of coal resource or reserve estimates must show where supporting basic data were located at the time of estimation.*

GENERAL GUIDELINES FOR CLASSIFICATION OF COAL RESOURCES

These general guidelines are required for uniform classification and reporting of coal into the different resource categories. They are modeled after the guidelines in Circular 831 (U.S. Geological Survey, 1980, p. 3-4) for all minerals.

1. All naturally occurring concentrations of coal can be distributed into one or more of the classification categories.
2. Where the term "reserves" is used without a modifying adjective, for example, marginal, indicated, restricted, low-sulfur, or inferred, it is to be considered synonomous with the demonstrated-economic category.
3. Quantities and qualities of coal may be expressed in a variety of terms and units to suit different purposes but must be clearly stated and defined.
4. A reserve base is a resource category delineated only by physical and chemical criteria. A major purpose for the recognition and discrimination of a reserve base is to aid in long-range public and commercial planning. A reserve base estimate for specific rank, thicknesses of coal and overburden, quality, usage, geologic formation, age, depositional environment, and many other factors can be specified for any given deposit or area, or for the Nation. The position of the lower boundary of a reserve base is intended to extend into the subeconomic category. The intention of this extension is to define quantities of in-place material, parts of which may become economic depending on the extraction plan finally utilized. As a result of any given extraction plan, the reserve base can be subdivided into component parts—reserves, marginal reserves, and a remnant of subeconomic resources. For the purpose of Federal (USGS) assessment, criteria for the reserve base are listed on page 29 of this report.
5. Undiscovered resources should be subdivided in accordance with the definitions of hypothetical and speculative resources or they may be subdivided in terms of relative probability of occurrence (see figs. 1 and 2).
6. Inferred reserves and the inferred reserve base represent postulated extensions of reserves and the reserve base. They are identified resources but are quantified with a relatively low degree of certainty. Postulated quantities of resources based on geologic inference alone should be assigned to the undiscovered categories.
7. Locally, limited quantities of coal may be produced from beds that are of insufficient thickness or are too deeply buried to be classified as reserves. This situation arises when production facilities are already established or when favorable local circumstances, such as particular coal qualities or removal of overburden for other purposes, make it possible to produce coal that otherwise could not be extracted profitably. Where such production is occurring, the quantity of in-place coal (including coal for in situ gasification) shall be included in a reserve base and the quantity that is potentially producible shall be documented as reserves. The profitable production of such coal, however, should not be used as a rationale to assign a reserves classification to coal in other areas having similar overburden, thickness of coal, and qualities.
8. Coal resources classified as reserves must be considered as economically producible at the time of

classification. Conversely, coal not currently producible at a profit cannot be classified as reserves. However, there are situations in which mining plans are being made, lands are being acquired, or mines and plants are being constructed to produce coal that does not meet economic criteria for reserve classification under current costs and prices but that would do so under reasonable future projections and expectations. The marginal reserve category applies to such situations. When economic production appears certain, coal classified as marginal reserves will be reclassified as reserves. Marginal reserves also may include any other coal whose economic producibility borders on being profitable.

9. Tonnage of coal that is too impure, too thin, too deep, or for other reasons not considered to be potentially economic may be estimated, but is not to be classified as a resource. These tonnages may be classified in the box labeled "other occurrences" in figures 1, 2, and 3.
10. Rank classes of coal, for example, bituminous coal as distinct from lignite, should be separately quantified.
11. The amount of cumulative production is not a part of the remaining coal resources. However, an understanding of what has been produced in the past is important to resource understanding, both in terms of the amount of production and the amount of coal remaining in place. Separate accounting for cumulative production should be made for each report area, county, State, and the Nation.
12. By-passed coal in large blocks left in the ground during mining, or planned to be left in the ground during current or future extraction, should be recorded in an appropriate resource category depending upon its economic recovery potential. Coal lost-in-mining should also be recorded in an appropriate resource category if there is a potential for further recovery.
13. In classifying reserves and resources it may be necessary to recognize locally that some coal deposits derive their economic viability from coproduct or byproduct relationships with other commodities.
14. Factors other than economic and geologic considerations, including legal, regulatory, environmental, and political concerns, may restrict or prohibit the utilization of all or part of a coal deposit. Reserve and resource quantities known to be restricted should be recorded as such in an appropriate category.
15. This classification system allows for the presentation of more subdivisions than will commonly be reported or for which data are available. Where appropriate, subdivisions may be aggregated or omitted.
16. Data supporting resource estimates are to be documented and preserved.

SPECIFIC INSTRUCTIONS

1. RANK OF COAL

Where coal of more than one rank class or rank group is covered by an individual report, the resource data shall be reported separately for each major rank class and when possible for each rank group listed below:

Class	*Rank group*	*Abbreviation*
Anthracite	Meta-anthracite	ma
Do	Anthracite	an
Do	Semianthracite	sa
Bituminous coal	Low-volatile bituminous coal	lvb
Do	Medium-volatile bituminous coal	mvb
Do	High-volatile A bituminous coal	hvAb
Do	High-volatile B bituminous coal	hvBb
Do	High-volatile C bituminous coal	hvCb
Subbituminous coal	Subbituminous A coal	subA
Do	Subbituminous B coal	subB
Do	Subbituminous C coal	subC
Lignite	Lignite A	ligA
Do	Lignite B	ligB

Abbreviations can be used wherever appropriate in reports and tables.

2. OVERBURDEN

Tonnage estimates shall be reported according to thickness of overburden:

Mandatory underground mining categories:	*Mandatory and optional surface mining categories*[1]:
0 to 500 feet (0 to 150 m)	0 to 500 feet (0 to 150 m) mandatory use
500 to 1,000 feet (150 to 300 m)	0 to 100 feet (0 to 30 m) optional use
1,000 to 2,000 feet (300 to 600 m)	100 to 200 feet (30 to 60 m) optional use
2,000 to 3,000 feet (600 to 900 m)	0 to 200 feet (0 to 60 m) optional use
3,000 to 6,000 feet (900 to 1,800 m)	200 to 500 feet (60 to 150 m) optional use
Optional other occurrence category:	
>6,000 feet (>1,800 m)	

[1]Use of optional surface mining categories requires the complete coverage of the 0-500 feet (0-150 m) category. Other categories may be used if they are in increments of 100 feet (30 m) and do not exceed 500 feet (150 m).

Resources of currently and potentially strippable and underground minable coal beds and coal zones shall be computed for the 0–500 feet (0–150 m) overburden category. Use of the surface mining optional categories allows tonnage estimates to be related to overburden. When optional categories are used, the sum of their tonnage estimates must be equal to the tonnage estimate for the 0–500 feet (0–150 m) category.

In addition, other criteria such as the ratio of overburden to coal thickness or the ratio of cubic yards of overburden to tonnage of coal may be used to outline and evaluate strippable coal deposits. Such departures from the standard categories and criteria are advisable only where there is adequate data.

3. THICKNESS OF COAL CATEGORIES

Tonnage estimates shall be reported by rank and thickness of coal:

Anthracite and bituminous coal	*Subbituminous coal and lignite*
14 to 28 inches (35 to 70 cm)[1]	2.5 to 5 feet (75 to 150 cm)[1]
28 to 42 inches (70 to 105 cm)	5 to 10 feet (150 to 300 cm)
42 to 84 inches (105 to 210 cm)	10 to 20 feet (300 to 600 cm)
84 to 168 inches (210 to 420 cm)	20 to 40 feet (600 to 1,200 cm)
168 inches or thicker (420 cm +)	40 feet or thicker (1,200 cm +)

[1]Centimeter thicknesses may be reported in meters.

4. SIZE OF UNIT AREA

For future planning by Federal and State governments, industry, and the public, coal resources such as identified resources, reserve base, and reserves, are to be estimated for relatively small areas. Unit areas the size of townships, 7.5-minute quadrangles, and 15-minute quadrangles generally are satisfactory. For specific purposes such as tract assessment, evaluation, and management, however, it may be desirable and (or) necessary to report estimates for areas as small as an individual land section, or smaller.

In addition, there are many requirements for estimating the remaining tonnages and type of coal for each coal-bearing county, State, and the Nation. Although tonnage estimates for most currently known coal-bearing counties and States exist, many are inadequate and out of date. Numerous requests for information emphasize the need for modern reliable county and State estimates. Such modern estimates are to be prepared as information becomes available and can be assembled. The unit area for such re-evaluations is logically a completed county, the smallest unit universally employed by State and National agencies. Therefore, all resource estimates regardless of size of area (except for State and national estimates) must be reported by the county in which they occur.

5. MAJOR CATEGORIES OF RESOURCES

Estimates of the total coal tonnages in the following resource categories are required, where data are available, for adequate inventorying of county, State, and national coal resources: measured, indicated, inferred, and hypothetical resources; reserve base and inferred reserve base; and original resources and remaining resources. Additional divisions of total resource estimates are not required but are desirable to document more thoroughly the quantities of coal available for particular uses.

6. COAL BED MAPS

A map of each coal bed or coal zone known to contain coal resources must be prepared to document the estimate for coal resources. A coal bed map will show (1) the trace of a bed's outcrop; (2) all points where the thickness of coal was measured at outcrops and other surface exposures; (3) all wells, drill holes, and subsurface points where the thickness of coal was measured; (4) county, State, and national boundaries; (5) land lines (townships and ranges) and latitude and longitude coordinates; (6) boundaries of Federal and State Parks, forests, wildlife refuges, grasslands, military bases, and areas known to be environmentally or legally restricted from mining; (7) reliability categories; (8) isopachs of thicknesses of coal and overburden; (9) structure contours; (10) areas where coal is absent because of erosion or nondeposition; (11) structural features affecting coal, such as fold axes and traces of faults; and (12) boundaries of prior surface and subsurface mining. Information derived from proprietary data can be deleted where required by the author in preparing a bed map for publication. Such proprietary information may include, for example, points of thicknesses of coal beds and overburden, drill-hole locations, mine boundaries, and other data furnished by mining companies or land proprietors. Coal beds may be so numerous in some areas that only selected bed maps of the major deposits would be published, even though bed maps of all coal beds would be prepared in order to estimate the resources.

Figures 9 through 23 show how to prepare parts of a coal bed map. Tables 4 through 7 show listings of areas of reliability by thicknesses of coal and overburden categories derived from figures 9 through 23. The areal interrelations of data depicted on a coal bed map define a series of areas, each of which represent a separate coal resource category. The areal extent, average thickness of coal, and the depth, rank, and weight of coal per unit-volume in each area must be determined in order to estimate the tonnages of coal underlying each area.

7. THICKNESS OF COAL MEASUREMENTS

The stratigraphic thickness of coal is measured at outcrops, in trenches and prospect pits, at mine faces either underground or in surface pits, and in drill holes by direct measurement or geophysical logging. (See "Geophysical Logs* * *," p.46.) *Measurements may be made in inches or in feet and inches, in feet and tenths of feet, or in meters and centimeters*. Partings in a coal bed greater than 3/8 inch (1 cm) should be excluded from the thickness measurements of a coal bed when estimating coal resources (see ***thickness of coal for resource calculations***, p. 31, and specific instruction No. 3, p. 34) but should be recorded as stratigraphic information. *Field measurements of the thicknesses of coal beds should be made to the nearest 1 inch, tenth of a foot, or metric equivalent. Thicknesses determined from core and drill-hole logs and from geophysical logs should be reported to the smallest practical unit of measurement. The weighted average thickness of a coal bed based on field measurements in an area should be reported to the nearest inch, tenth of a foot, or metric equivalent.* An average thickness should be determined by using all measurements of coal, by the thickness gradients between measurements, and by isopaching. The thickness of coal at specific points should be recorded on coal bed maps, and then the bed should be isopached using the points of measurements and gradients between the points. An isopach should be drawn along each of the standard coal thickness category limits pertinent to the rank and thickness of coal in the area to be estimated. The weighted average thickness of an area of coal is calculated by estimating the size of each isopach unit according to the percent or proportion of the area covered by the unit. Where mining has been extensive, the thickness of coal in unmined areas can be extrapolated from data on thicknesses of coal obtained from mine maps and from adjacent mines.

8. DISTRIBUTION OF COAL BED THICKNESS MEASUREMENTS

The distribution of data points is exceedingly important in the estimation of coal resources because distribution (including spacing) is universally considered as the ultimate control governing the reliability, accuracy, and precision of any estimation. In most areas the coal resource worker must rely on existing outcrops, trenches, prospect holes, mine workings, and drill-hole data. If drilling is possible, a drilling pattern should be established, on the basis of geologic knowledge, to supplement the existing data so as to raise the assignment of coal resources to a higher degree of reliability.

9. MEASUREMENT OF AREAS

Coal-bearing areas, as determined from coal bed maps (see figs. 9–23) are to be measured to a precision of 2 percent or less. Such determinations may be made with a planimeter, with graph paper, with equally spaced dots, or with a computer. The most common instrument used for area determinations is the polar planimeter. In recent years the digital electronic planimeter has become increasingly popular. Prior to determining areas with a planimeter, a planimeter factor for acres or hectares, which depends upon the scale of the map used, must be ascertained. This is done according to instructions that accompany the planimeter. A similar factor must be determined if the graph paper technique of determining acreages is employed. After either factor is ascertained, the user is prepared to start measuring areas on the map and to convert the measurements using the appropriate planimeter or graph paper factor into acres or hectares.

On many 7.5-minute quadrangles, several dozen to several hundred areas must be measured that are based on the many parameters into which coal-bearing areas can be categorized. These parameters may include thicknesses of coal and overburden; distance from points of coal thickness measurements (reliability categories); quality; physical characteristics; rank, land ownership by Federal, State, Indian, and local governments, companies, individuals, and other nations; county, State, and townships and ranges of the land classification system; quadrangle, coal field, basin, region, and province; legally and environmentally restricted areas, and others as desired.

As the areas are measured, mean results ascertained by averaging the planimeter or graph paper readings are recorded so that each area's acreage can be computed.

A planimeter is accurate in measuring map areas ranging from several square inches to 20–30 square inches. Generally, planimetric measurements are repeated several times and then averaged. However, if readings are in disagreement by more than 2 percent, they should be repeated until an agreement of 2 percent, or less, is achieved. Map areas of less than 1 square inch commonly are not as precisely measureable with a planimeter as are larger map areas and must be remeasured and the planimeter vernier read many times to obtain an agreement within a 2-percent error. Repetition of planimetric measurements with only two vernier readings, one at the beginning and one at the end, can be accomplished by continuously tracing the borders of the area being measured a predetermined number of times in a manner similar to the repetitive turning of angles with a transit by a surveyor. The difference between the two readings should be divided by the number of times the borders are traced; the answer multiplied by the planimeter factor is the size of the area. This repetitive measurement of an area is a good method of obtaining precise planimetric readings.

10. WEIGHT OF COAL PER UNIT VOLUME

A tonnage estimate for any coal deposit can be made if the thickness of coal, areal extent, and weight of coal per unit volume are known. The weight of coal per unit volume (density) or specific gravity varies with rank, ash content, and the amount of each macerals group (such as vitrinite, inertinite, and exinite) in the coal. Ideally the density of coal in a deposit should be determined from numerous specific gravity determinations on unbroken coal, but there are rarely sufficient determinations to characterize a deposit. Therefore, it is recommended that tonnage calculations be based either on the average specific gravity or the average weight of unbroken coal per unit volume of the different ranks shown in table 2.

11. CALCULATION OF COAL RESOURCES

After the area underlain by coal, the average thickness of coal, and the weight of coal per unit volume for each category shown on a coal bed map have been determined, the tonnage can be estimated. The tonnage is estimated by the following formula:

$A \times B \times C$ = tonnage of coal where

A = weighted average thickness of coal in inches, feet, centimeters, or meters,

B = weight of coal per appropriate unit volume in short or metric tons, and

C = area underlain by coal in acres or hectares.

12. ROUNDING OF TONNAGE ESTIMATES

The rounding of tonnage figures shall be done only after all calculations have been completed using data for areas (acres or hectares), coal thicknesses, and weight of coal per unit volume and summed for each coal category. The tonnage estimates for each coal category are then rounded to significant numbers so as to not eliminate tonnage estimates for small areas of measured and indicated coal. For example, the tonnage estimates for small areas such as A, B, C, F, G, H, K, M, O, P, Q, and R in figure 17 and A, B, C, D, E, F, G, H, L, Q, W, Y, AA, HH, and OO in figure 19 are not rounded out of the totals and are included in the summing of the total coal resources for all areas in figures 17 and 19. After summing, the resultant total coal resources estimates for a whole map area (a quadrangle, county, or basin) are not rounded because their component parts have been rounded.

13. ESTIMATION OF RESOURCES IN THE VICINITY OF WHERE A COAL BED BIFURCATES INTO TWO OR MORE TONGUES

Resource estimation is difficult in those localities where a coal bed bifurcates or splits into tongues, each of which exceeds the minimum thickness for resource estimation. The difficulty is caused by the necessity to delineate a boundary between the area where the resources of the main coal bed are estimated and the areas where the resources of the tongues are individually estimated.

As stated in the glossary, a **parting** is "a layer or stratum of non-coal material in a coal bed which does not exceed the thickness of coal in either the underlying or overlying benches" of coal. Where the non-coal material exceeds the thickness of either the underlying or overlying parts of the coal bed, the coal bed is considered for the purpose of resource estimation to have split into two coal beds (each of which is depositionally a tongue from a thicker main coal bed).

In estimating resources in such a geologic situation, it is necessary to delineate on a coal bed map the areas where resources will be separately calculated; to do so, a line is used to connect all points where one of the tongues becomes thinner than the intervening parting. It is also necessary to locate on the coal bed map all points where the thickness of the main coal bed and the tongues were measured. Measured, indicated, and inferred reliability circles should be drawn on the bed map from each point of thickness of coal measurement on the main bed and the tongues. The circles should be drawn, according to the appropriate distance for each reliability category, across the boundary line for resource estimation. After the circles are drawn, the thickness variations of the main coal bed and each tongue (bed) are to be isopached separately. Tonnage estimates should then be calculated for each tongue (bed) and the main bed using procedures outlined elsewhere in this report for separate coal beds.

ESTIMATION OF HYPOTHETICAL RESOURCES

The estimation of hypothetical coal resources in areas where geologic, thickness, rank, and areal size data are sparse or absent is necessary to promote exploration for poorly known and undiscovered coal areas. Currently about 2.24 trillion short tons of the Nation's 3.68 trillion tons of remaining coal resource inventory are classified as undiscovered (hypothetical) (Averitt, 1975). Much additional unknown coal may be concealed in the central parts of basins and is not as yet included in the Nation's coal inventory. This additional unknown coal must be identified, as must the 2.24 trillion tons currently remaining in the inventory, because knowledge of the quantity, quality, and rank of the unknown and hypothetical coal could influence the Nation's energy usage plans. Therefore, a question commonly asked by government and industry estimators responsible for inventorying coal resources is: How do you estimate resources where there are no nearby thickness, depth, and rank data? Another way of stating this question is: How do you estimate the resources of central parts of poorly explored or unexplored basins?

The problem of estimating hypothetical resources in the central parts of basins and elsewhere has been approached by (1) not attempting to calculate them; (2) assuming that the centers of the basins or coal-bearing areas where control is lacking are barren of coal; (3) assuming that the better known marginal areas of coal-bearing basins are representative of the average quantity of coal per square mile in the central parts of the basins; (4) assuming an average thickness of coal and applying this factor to the volume of coal-bearing rocks in an area; and (5) making an outright guess. None of these solutions are satisfactory. A sixth solution has been to extrapolate measurement data from surrounding areas into the unknown area. This approach is better than the others but commonly is inadequate because it does not consider geologic factors that would control unsystematic distribution of coal in an unknown area.

The following discussion describes two methods, based on geologic principles, for estimating hypothetical resources. Both are acceptable if the supporting basic geologic and measurement data are documented and presented for evaluation. These alternative approaches can be termed the "extrapolated bed map method" and the "extrapolated coal zone method." Both methods are based on the extrapolation of geologic knowledge and measurement data into an area of unknown coal resources. In some problem areas, a mix of the two methods may be desirable.

Much of the data called for in the descriptions of the extrapolated bed map and extrapolated coal zone methods will not be available in many areas where hypothetical resources must be estimated. The descriptions of the methods are written for the ideal amount of control adjacent to an unknown area; thus, the methods will have to be modified on the basis of the type, availability, and amount of control data.

EXTRAPOLATED BED MAP METHOD

Step 1.—Assemble all available geologic data in the areas adjacent to the unknown area for the coal bed whose resources are to be estimated.

Step 2.—Assemble and plot on a base map all pertinent data on thicknesses of coal and overburden, quality of coal, reports of coal in drill holes and wells, and rank of coal.

Step 3.—Analyze all data collected in steps 1 and 2 to ascertain trends of coal deposition by (a) constructing isopach maps of the coal bed in known areas; (b) constructing isopleth maps of heat values, ash contents, and contents of trace elements that may be related to sources of sediment; and (c) identifying trends of persistent thick or thin coal, or other parameters of coal.

Step 4.—Identify depositional and erosional trends and features in the known areas of rocks adjacent to the coal bed and in the coal bed itself that may indicate ancestorial through-flowing rivers in swamps, coastal environments, unconformities, directions of delta building, paleogeomorphic locations of swamps on a coastal plain or delta, and directions and distances to sediment sources. Plot all pertinent data on a map.

Step 5.—Extend stratigraphy from known areas into and across the unknown area by utilizing all surface and subsurface information. Collect surface stratigraphic data and existing petroleum and water well information. Evaluate and analyze all data and determine best correlations so that coal bed extensions and correlations can be made. Determine from available data probable geologic model of deposition. Plot all data on the map of step 4.

Step 6.—Construct structure sections across the unknown area so that changes in the thickness of overburden and rank of the coal bed can be considered and (or) postulated.

Step 7.—Construct a structure contour map of the coal bed in the unknown area.

Step 8.—Combine all pertinent data from steps 2, 3, 4, 5, and 7 onto a single coal bed map.

Step 9.—Fill in the unknown area by projecting pertinent coal and other data across or through the unknown area. This projection should include isopachs for thicknesses of coal and overburden, isopleths for rank and (or) heat values, predicted erosional channels cutting through the coal, and other stratigraphic, depositional, or structural features affecting the coal bed.

Step 10.—Place land lines and boundaries of political subdivisions on the map.

Step 11.—Define areas of hypothetical coal by plotting the outer limits of inferred coal as determined from points of thickness control in the known areas. Determine acreages of hypothetical coal for the following resource categories: thicknesses of coal and overburden; rank; quadrangle; townships and ranges; counties; and State.

Step 12.—Determine the average coal bed thickness for each acreage unit in each category.

Step 13.—Calculate and sum estimated tonnages for each category, round estimated tonnages to significant figures as per specific instruction No. 12, p. 36, and sum into a final hypothetical tonnage. These estimated tonnages and the total summed tonnage probably represent the best information that can be estimated for a bed that extends from a known area into an unknown area where control points are absent or sparse.

EXTRAPOLATED COAL ZONE METHOD

If the procedure for an extrapolated bed map analysis of hypothetical coal resources is impractical because of time limitations or sparsity of data it is suggested that the approach to estimating hypothetical resources be by an extrapolated coal zone method.

Step 1.—Determine if a coal zone exists by analyzing the available data.

Step 2.—Assemble and plot on a base map all available geologic data in areas adjacent to the unknown area.

Step 3.—Construct an isopach map of the cummulative thicknesses of all coal beds in the coal zone (less partings) that exceed 14 inches for anthracite and bituminous coal beds and 30 inches for lignite and subbituminous coal beds in known areas.

Step 4.—Identify trends and geologic features in the rocks of the coal zone in the known area that may indicate persistent ancient through-going rivers, coastal environments, unconformities, directions of sediment transport, intertonguing sediments and coal beds, regressions and transgressions, and so on. Plot pertinent data on a map.

Step 5.—Extend stratigraphy of the coal zone and related rocks into and across the unknown area on the map of step 4 by utilizing all surface and subsurface data. Determine geologic model of deposition of the coal zone. Construct stratigraphic diagram of the coal zone and fit diagrammatic data to the map.

Step 6.—Construct structure sections across the unknown area so that thickness of overburden and rank changes of coal zone can be considered and (or) postulated.

Step 7.—Construct a structure contour map of the coal zone in the unknown area.

Step 8.—Combine all pertinent data from steps 2, 3, 4, 5, and 7 onto a single coal zone map.

Step 9.—Fill in unknown area by projecting pertinent coal zone and other data across or through unknown area.

Step 10.—Place land lines and boundaries of political subdivisions on map.

Step 11.—Define areas of hypothetical coal by plotting an outer limit of inferred coal as determined from points of thickness control in the known areas. Determine acreages of hypothetical coal for the following categories: thicknesses of overburden, cummulative thicknesses of coal, rank, quadrangle, townships and ranges, counties, and State.

Step 12.—Calculate and sum tonnages for each category after determining a cummulative thickness of coal for each acreage unit in each category and calculating tonnage. Round tonnages to significant figures as per specific instruction No. 12, p. 36, and sum into a total hypothetical tonnage amount.

The extrapolated coal zone solution for hypothetical coal eliminates the estimation of tonnages for many individual beds and, in the view of some workers, provides a more valid estimate than the bed-by-bed approach. Despite this view, the bed-by-bed method is herein recommended for use where practicable and (or) feasible.

EXAMPLES ILLUSTRATING THE BASIC GEOMETRIC PRINCIPLES OF CONSTRUCTING COAL RESOURCE BED MAPS

Coal resource estimation systems on a worldwide basis generally lack illustrations amplifying written instructions as to how to calculate coal resources.

The following illustrations are intended to bridge this gap and to show how coal resources data are utilized to construct bed maps. Many more illustrations could be prepared, but the accompanying figures are believed to be representative.

Figure 9 illustrates how to determine areas of reliability (areas based on distance of from points of thickness measurements—measured, indicated, inferred, and hypothetical coal) where a coal bed has been mapped on the surface and the thickness of coal has been measured

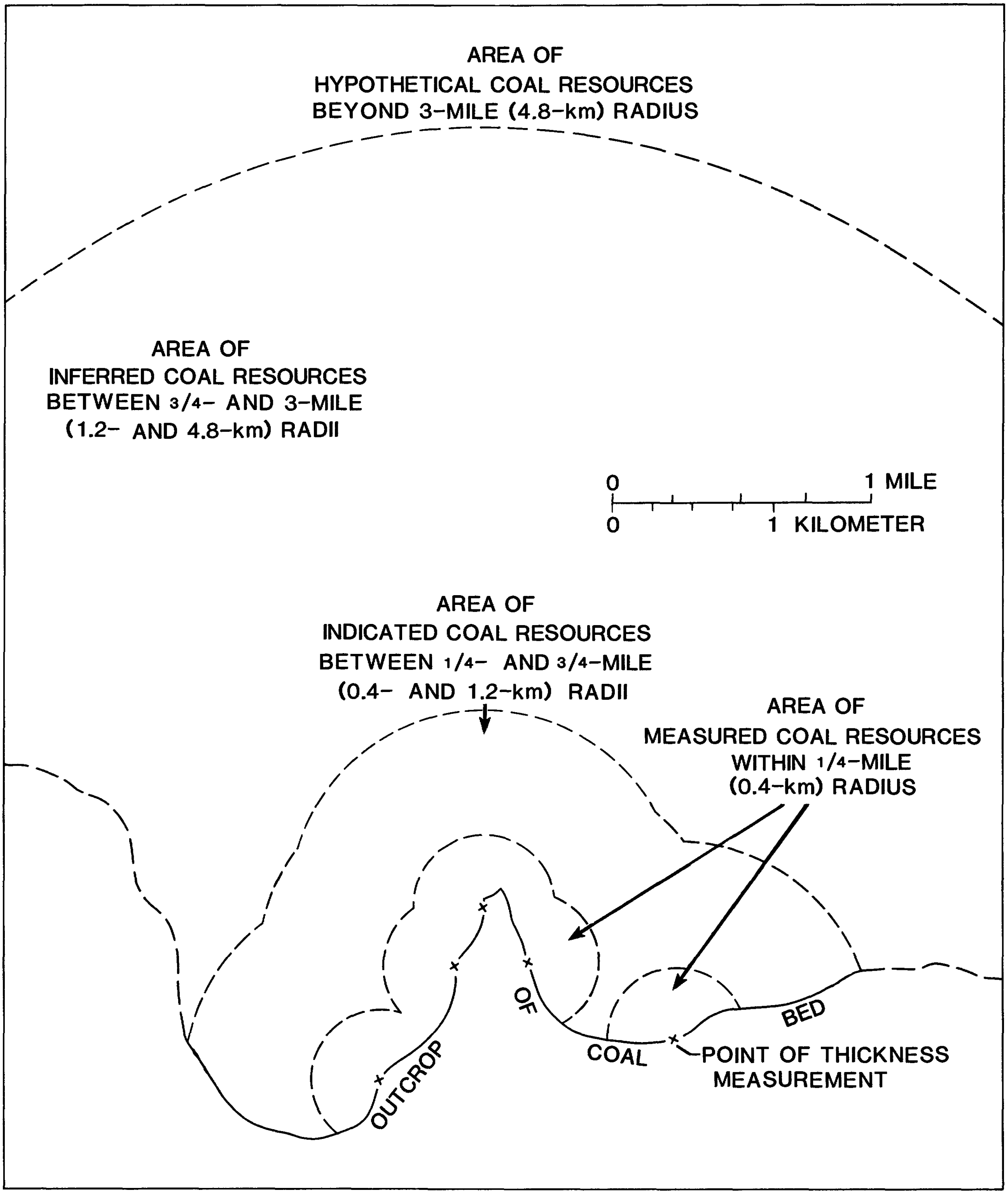


FIGURE 9.—Determination of areas of reliability using coal thickness data only at points of measurement along outcrop line. Radii origins are at points of thickness measurement.

at five points. The solid outcrop line indicates where the bed has been mapped with assurance as to its intersection with the ground surface; the dashed line indicates uncertainty as to the exact location. Utilizing radii originating at the points of thickness measurements, arcs are constructed at appropriate distances according to the criteria for the measured, indicated, inferred, and hypothetical reliability categories. The arcs enclose areas theoretically underlain by coal for each reliability category.

Figure 10 uses the same coal bed outcrop as figure 9 and shows the effect of additional thickness information from drill-hole measurements and a small mine. A comparison of figures 9 and 10 illustrates how the additional data derived from drill-holes and mining expand the areas designated in figure 10 as measured and indicated and modify the inferred and hypothetical areas.

The objective of figure 11 is to show how drill-hole data combined with outcrop data on a continuously exposed strip-mined coal bed result in the coalescing of measured and indicated coal and in an expansion of the area of the inferred reliability category. It also shows how a single point of thickness of coal measurement defines an area of measured, indicated, and inferred coal.

The primary objective of figure 12 is to show how to construct a minimum thickness-of-coal isopach (14 inches) based solely on outcrop data. A secondary objective is to illustrate how to locate a coal outcrop and boundaries such as county lines on a bed map from a geologic map. Generally, as a bed thins along an outcrop, it is increasingly more difficult to trace. Figure 12 illustrates a simple, nearly straight coal bed outcrop with three thickness-of-coal measurements. The three measurements are all thicker than the 14-inch minimum thickness of coal considered when calculating anthracite and bituminous coal resources. The thickness gradients between the 26-inch and each of the 20-inch points of measurement of coal are extrapolated along the crop line to the east and west of the 20-inch measurements to points *A* and *B* where the coal gradients predict coal thicknesses of 14 inches. A straight line is then drawn between the predicted 14-inch points *A* and *B* on the crop line and subsequently is bisected at mid-point *O*. An arc *AB* is drawn between the predicted 14-inch points using either *AO* or *BO* as a radius. The arc *AB* locates the 14-inch isopach according to the available data on thickness and length of outcrop.

Figure 13 displays areas of reliability, thickness-of-overburden contours, political subdivisions, and a completed coal bed map ready for determinations of acreages and weighted average thickness of coal in each area. Areas *A* to *P* are ready for planimetry of acreages, for calculation of coal tonnages after weighted average thickness of coal for the areas are determined, and for subsequent entry on tonnage tables according to their assignment to a thickness of coal, thickness of overburden, reliability category, and to a county. Table 4 lists the areas of reliability by thickness of overburden category, by a single thickness of coal category, and by counties. To avoid confusion, figure 13 and table 4 were constructed with only one thickness of coal category, 14 to 28 inches. Subsequent figures are more complicated because more thickness categories are introduced.

Figures 14 and 15 show a diagram of a ridge underlain by coal; they also show the geometric method of determining the 14-inch minimum thickness of bituminous coal isopach and the areas of reliability constructed from the points of thickness of coal measurement. The 28- and 42-inch coal isopach lines were constructed by using the gradients between the various thicknesses of coal measurements. This method of determining the area of coal under a ridge is commonly necessary when thickness measurements are sparse and an estimation of coal resources beneath a ridge is required. Table 5 ennumerates the areas assigned to the varous thicknesses of coal and overburden and reliability categories.

Figures 16 and 17 and table 6 show how to construct the 14-inch minimum thickness limit of anthracite or bituminous coal resources, other coal isopachs, and the areas of reliability and overburden isopachs for a simple valley reentrant in a coal bed outcrop. Figures 16 and 17 and table 6 are important because they show how to treat a valley reentrant in a coal outcrop characterized by minimal thickness data.

Figures 18 and 19 and table 7 show how to determine the location of the minimum coal isopach (14 inches for bituminous coal) in a valley and ridge underlain by a coal bed that is locally less than the minimum thickness. Figure 19 also illustrates the areas of reliability, overburden categories, and coal isopachs. The location of the minimum coal isopach (14 inches) on a ridge which has thickness data on only one side is a common problem facing geologists estimating coal resources.

One of the most difficult problems in estimating resources of coal is where the beds are moderately to steeply dipping or are highly deformed. A simplified problem is illustrated in figures 20*A*, *B*, and *C* by a bed that dips uniformly 30° into the subsurface. The problem as illustrated can be solved by two methods. The first method is to estimate all areal resource tonnages in the plane of the coal bed and then to project all pertinent areal categories to the ground surface. For example, the measured, indicated, inferred, and hypothetical reliability circles, coal isopachs, overburden contours,

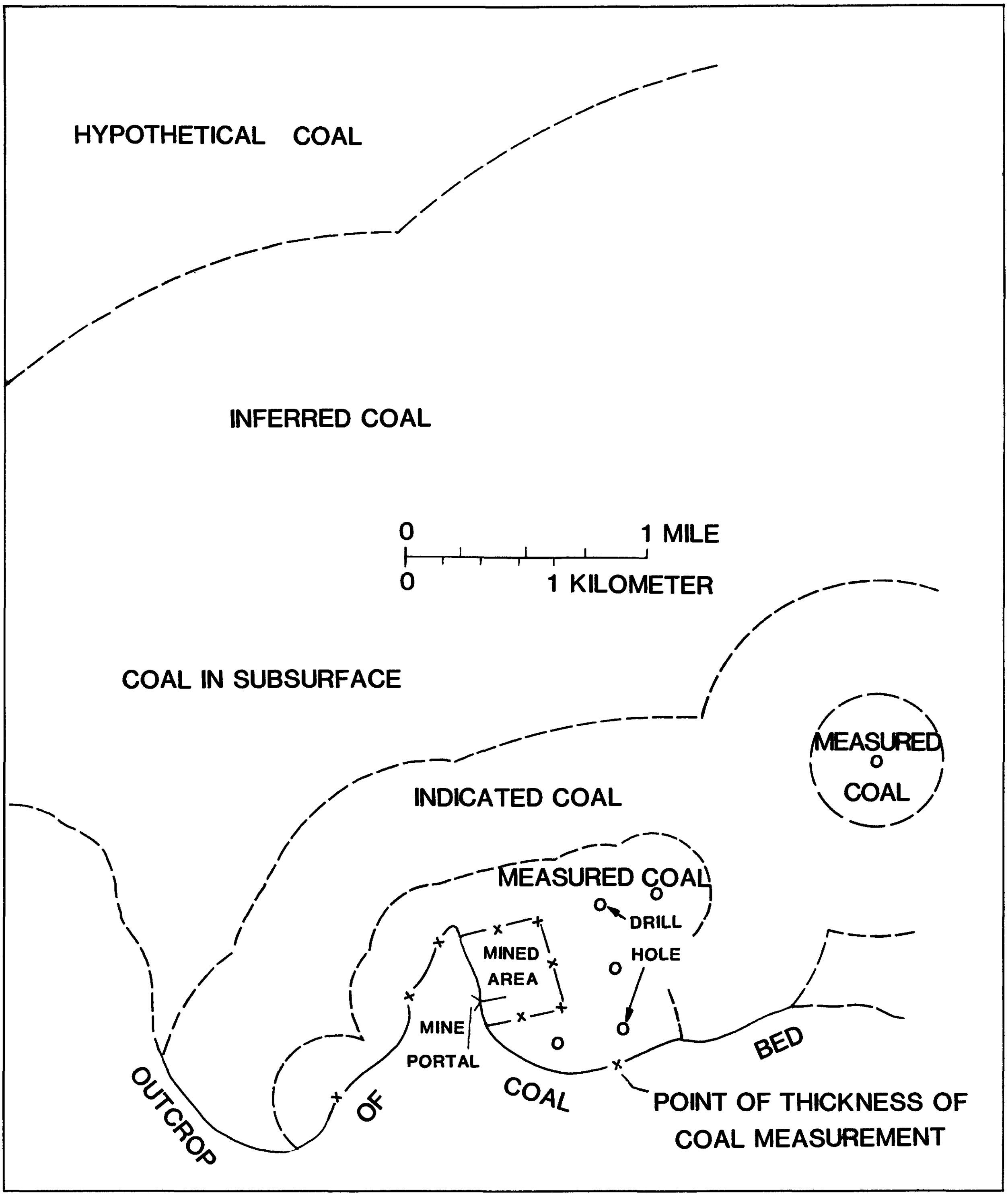


FIGURE 10.—Determination of areas of reliability from points of measurement on the outcrop line, supplemented by mine and drill-hole data.

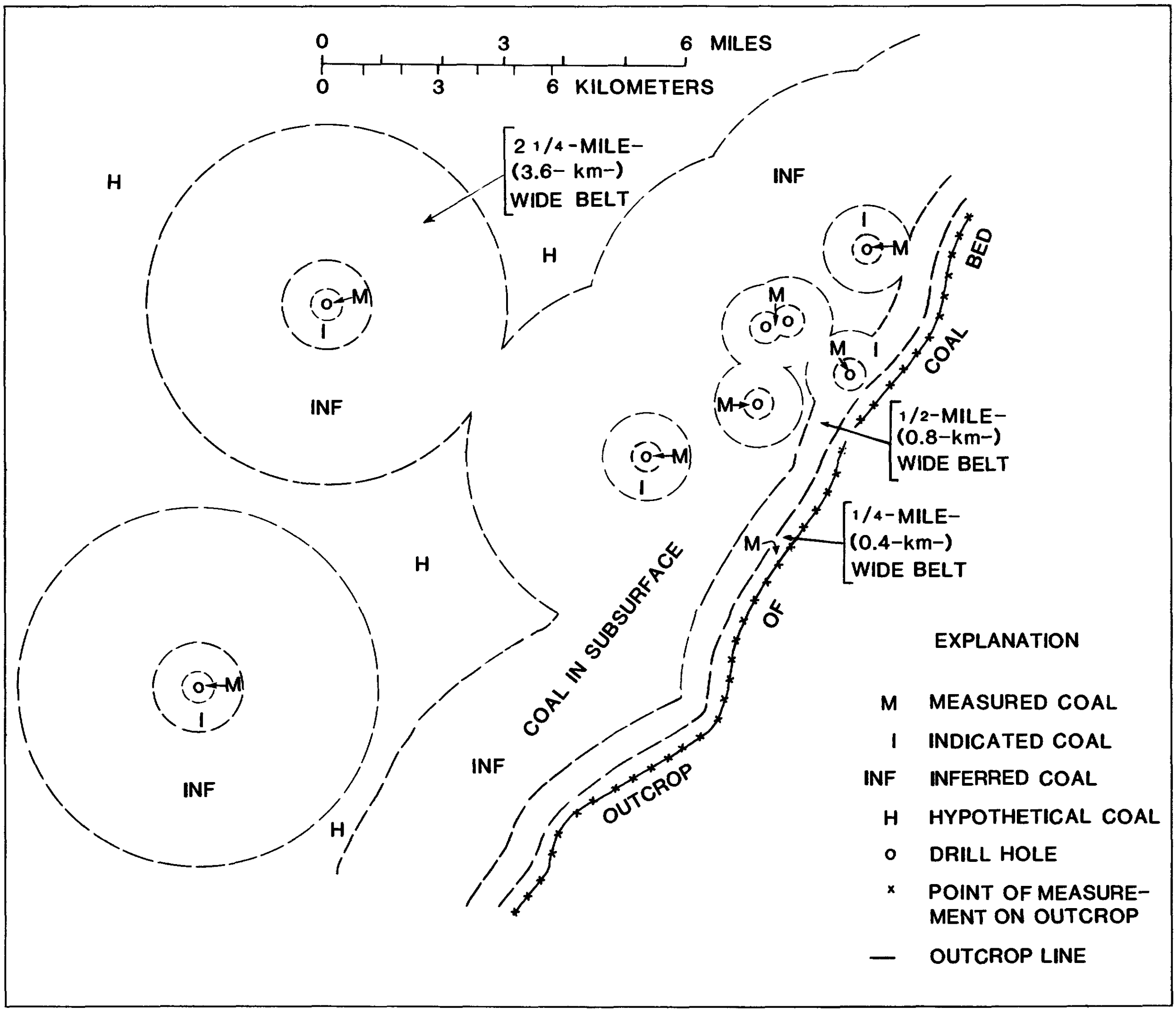


FIGURE 11.—Determination of areas of reliability using coal thickness measurements taken along a continuously exposed, strip-mined bed, supplemented by drill-hole data.

and structure contours should be drawn in the plane of the coal bed (fig. 20*A*). Then the areas of each of these categories are planimetered and coal tonnages estimated. This procedure provides an adequate estimate of coal tonnages for all values of dip. However, it is difficult to project the areas from the plane of the coal bed to the surface area overlying any particular category (fig. 20*B*). Although this method gives an adequate tonnage estimate, it distorts the ground surface depiction of areal categories (fig. 20*C*).

The second method is to draw the areal boundaries of the various categories on a surface map, measure the areas underlain by the various categories, and estimate the coal tonnages for each category. After estimation of the resources as if they were flat-lying, the estimates are divided by the cosine of the dip. The resultant answer is the tonnage in the plane of the bed. This method will provide correct tonnage estimates in each resource category underlying the surface but will horizontally exaggerate the areas of measured, indicated, and inferred coal and should be used only where the dip is more than 10° and less than 30°. For dips above 30°, it is recommended that resource estimates be made by the first method. For dips less than 10°, all estimation of resources should be done as if the bed was flat-lying.

The authors suggest that geologists involved with estimating the coal resources of highly deformed areas consult with coal geologists who have worked on similar areas and estimation problems. Currently, resource problems in highly deformed areas have not been solved

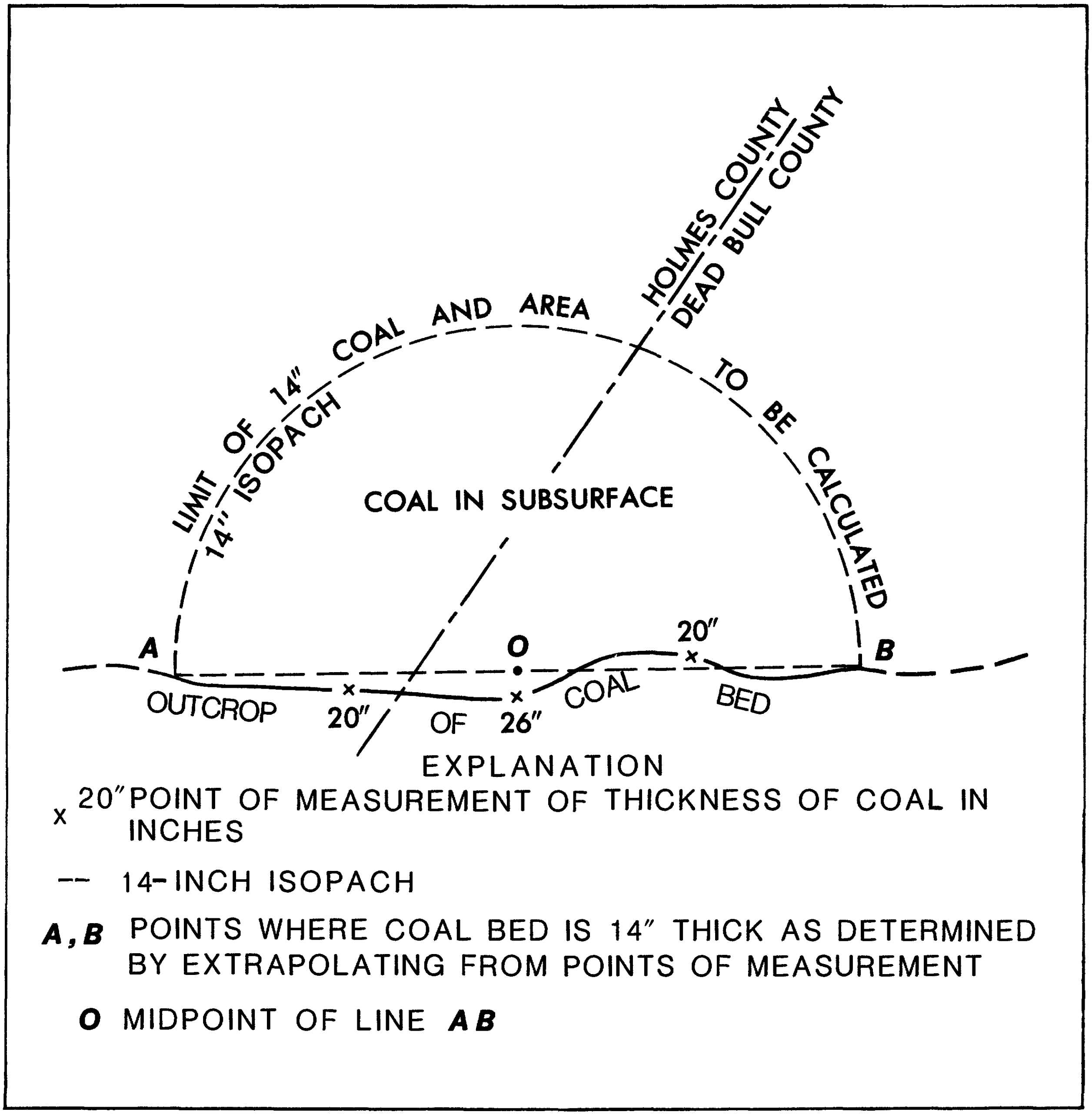


FIGURE 12.—Determination of minimum thickness isoline of 14-inch thick anthracite or bituminous coal using data from a nearly straight outcrop line. *A* and *B* are located on the outcrop line where the coal thickness as extrapolated from the points of measurement are predicted to be 14 inches. Line *AB* connecting the points of predicted 14-inch coal is bisected at *O*. The radius *AO* or *BO* is then used to construct arc *AB*, the 14-inch isopach or predicted limit of 14-inch-thick coal. This figure also shows the location of the outcrop line and a county boundary on a coal bed map as derived from a geologic map.

escept locally for small areas. Although methods have been developed, they are generally very time consuming and as yet unproven by mining.

Figure 21 illustrates a coal bed that has been mined from shafts at some distance from outcrops. All data are derived from the mines or drill holes. The figure shows measured, indicated, inferred, and hypothetical coal; county lines; thickness of coal measurements; coal thickness categories; and the 0–200 feet, 200–300 feet, and the 300–500 feet overburden categories. It also shows a

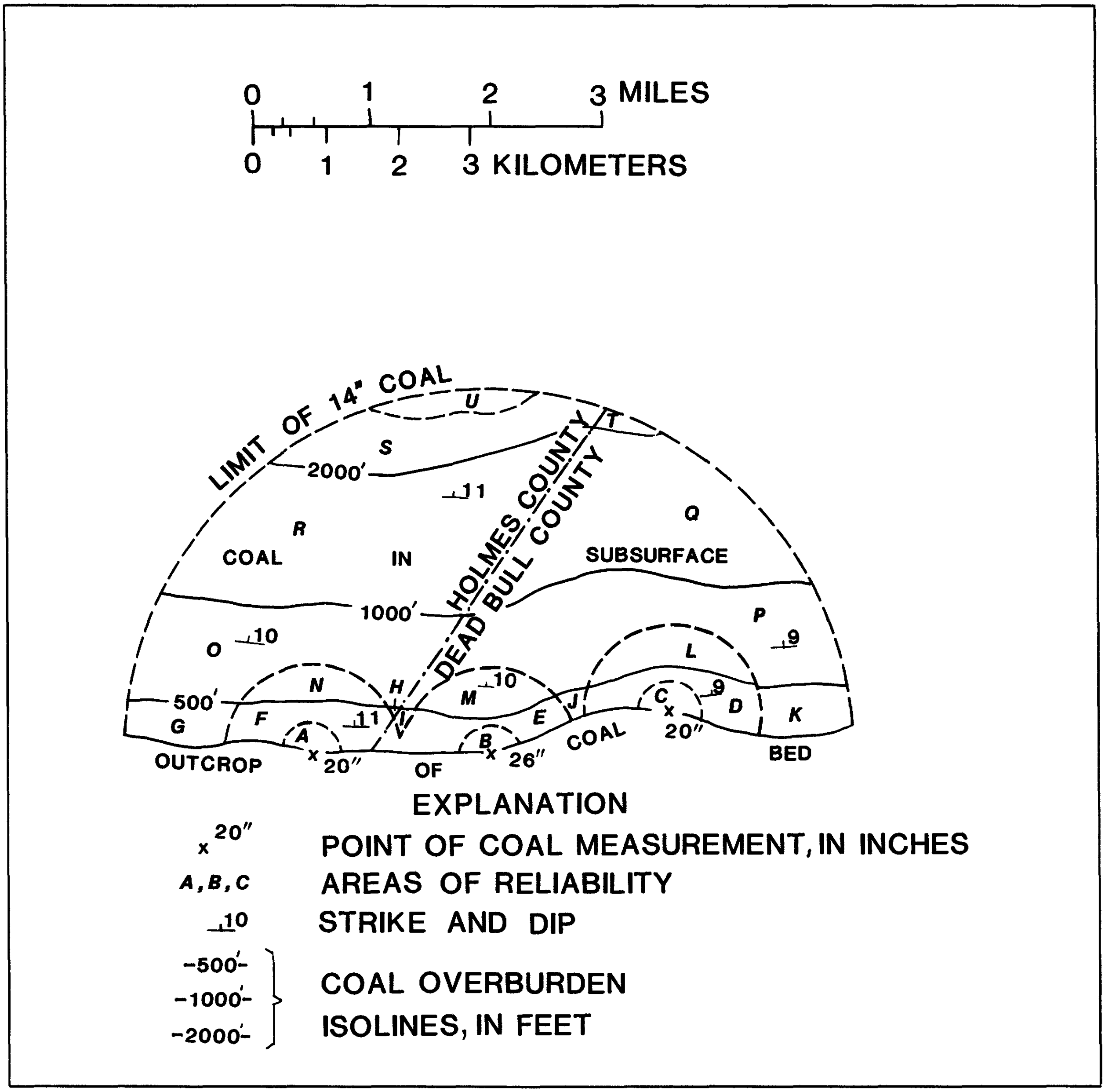


FIGURE 13.—Same basic diagram as figure 12. Shows determination of areas of reliability and 500–, 1,000– and 2,000–foot overburden contours which were obtained by subtracting elevations of bed from surface elevations. Bed elevations were obtained from a topographic map, from the outcrop of a coal bed, and from structure sections utilizing dips. Areas of reliability determined by using 1/4-mile radius (measured), 3/4-mile radius (indicated), 3-mile radius (inferred), and more-than-3-mi' radius (hypothetical) from measurement points. Individual areas of reliability are identified by letters *A* through *U*.

national park, a national bird refuge, a State park, and a large lake, all of which merit assignment of the underlying coal in those areas to restricted categories.

Figure 22 demonstrates a small coal basin where many resource classification categories are distinguished, including two large areas of hypothetical coal. The figure also shows two coal beds that intertongue with an intervening linear sandstone body. The coal beds have been strip-mined at six localities and underground mined at three localities. The coal beds have been tested by 15 drill holes which revealed the existence of two coal beds separated by sandstone. Numerous surface measurements of coal thickness support the widespread extent of at least one bed, and three measurements revealed the relations of two coal beds with the sandstone body. A bed map of the basin revealed two

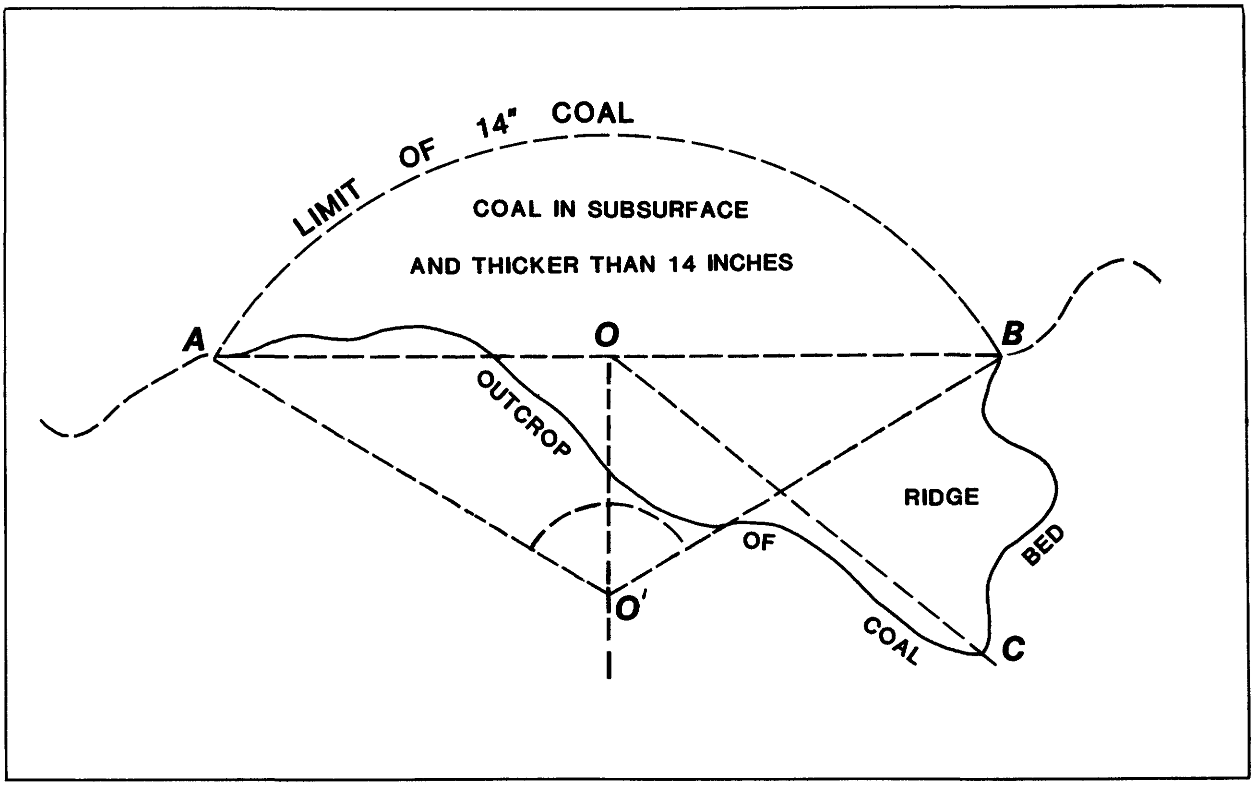


FIGURE 14.—A ridge showing construction of accepted 14-inch minimum thickness limit of a bituminous coal bed. Point *C* is the most distant point of outcrop on the ridge from end points *A* and *B*. Accepted 14-inch thickness of coal limit comprises an arc *AB*. Construction of arc *AB* is as follows: from midpoint *O* of line *AB*, draw line *OC* to furthest point on outcrop. Swing arcs from *A* and *B* with a radius of *OC*. The intersection of the arcs is point *O'*. From *O'* draw arc *AB* using either *AO'* or *BO'* as the radius.

TABLE 4.—*Areas of reliability from figure 13 listed by overburden and coal thickness categories, and by counties*

[Tonnage estimated for each area could be determined (1) by planimetering each area for acreage, and (2) by multiplying acreage by proper weight of coal per acre-inch by the average thickness of coal in the area. Average thickness of coal would be obtained by isopaching coal thickness as shown on figure 13]

Geologic assurance category	Coal thickness	
	14 to 28 inches	28 to 42 inches
	0 to 500 feet overburden:	
Measured	*A, B, C*	None
Indicated	*D, E, F*	Do.
Inferred	*G, H, I, J, K*	Do.
	500 to 1,000 feet overburden:	
Indicated	*L, M, N*	None
Inferred	*O, P*	Do.
	1,000 to 2,000 feet overburden:	
Inferred	*Q, R*	None
	2,000 to 3,000 feet overburden:	
Inferred	*S, T*	None
Hypothetical	*U*	Do.

Political division	
Holmes County	Dead Bull County
A, F, G, H, N, O, R, S, U	*B, C, D, E, I, J, K, L, M, P, Q, T*

coal-bearing areas separated stratigraphically and areally by an intervening sandstone body. The completed bed map in figure 22 allows the segregation and subsequent estimation of the resources of the two coal beds into a large number of categories enumerated in the caption for the figure. The two coal beds are subdivided by their heat values on a moist, mineral-matter-free basis into lignite and subbituminous coal. The 8,300-Btu isolines that represent the boundary between subbituminous coal and lignite are drawn so that tonnage estimates can be made for proper rank classification.

Figure 23 depicts a large but simple subbituminous coal and lignite basin that contains predominantly hypothetical resources traversed by three synclines and two anticlines. The total thickness of coal at each point of surface measurement and in each drill hole penetrating the coal zone is obtained by summing the thicknesses of all coal beds that are thick enough to be considered as resources (2.5 feet, or 75 cm). These thicknesses are isopached at 40-foot thick increments, and the overburden, heat value, and reliability categories are plotted

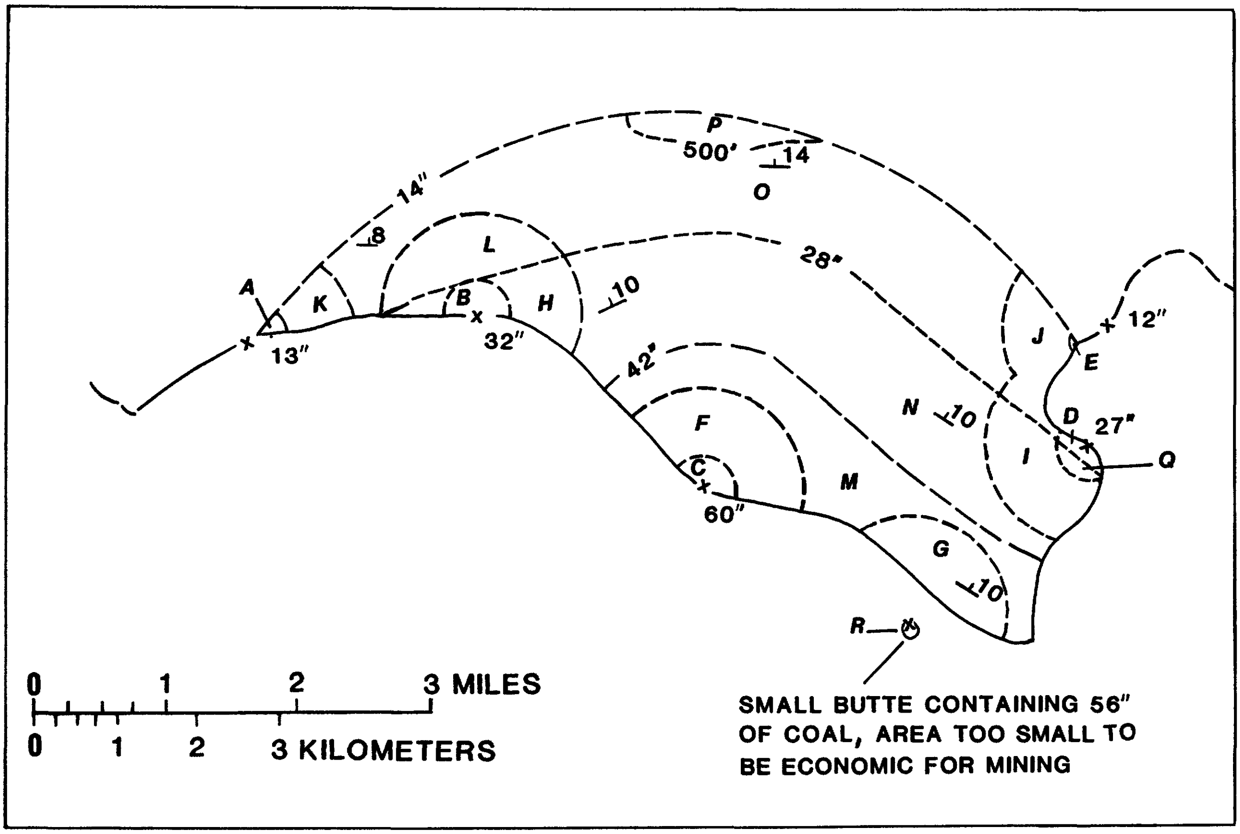


FIGURE 15.—Same ridge shown in figure 14 with the addition of an isolated butte containing bituminous coal. Shows determination of areas of reliability; 14-, 28-, and 42-inch coal isopachs, and 500-foot overburden contour. Categories defined by intersections of lines separating areas of reliability, thickness of coal, and thickness of overburden are labelled *A* through *R*. Overburden contour was computed from dips and by subtracting bed elevations from surface topographic elevations.

on the map. Estimates of coal tonnage should be calculated for each rank category. The total tonnage estimate for hypothetical resources in the example is the sum of each of these estimates. Generally, the size of the thickness of coal increments is left to the geologist to determine. Figure 23 is appropriate to an analysis based on a coal-zone approach to estimation of hypothetical resources as outlined on p. 37-38.

Figures 24 and 25 show suggested forms for recording coal resource data. These forms, or similar forms, are necessary for recording coal bed names; overburden and thickness of coal categories; planimeter readings; calculated areas; and weighted average thickness of coal for the area being calculated. The forms also provide columns for tabulating tonnage estimates in the measured, indicated, and inferred reliability categories, by coal thickness categories, and miscellaneous information such as planimeter factor, persons responsible for steps of work, and total tonnages by thickness and overburden categories. The data recorded on such forms and the calculations made therefrom represent the culmination of coal resource work starting in the field and continuing through the preparation of bed maps such as those in figures 9 through 23. The forms for data entry and calculation should be designed with care so the data entered on the forms from accompanying bed maps contain the necessary information for estimating all types of coal resources and reserves. This information can be combined with other information such as pertinent data on costs, transportation, and marketing to provide a documented analysis of the coal resources/reserves in a coal bed, field, region, basin, province, county, State, and (or) the Nation.

GEOPHYSICAL LOGS AS A SOURCE OF COAL BED DATA

Geophysical well logs have been invaluable in the search for oil and gas because they provide rapid, economical, and detailed information on the thickness, lithologic characteristics, fluid content, correlation,

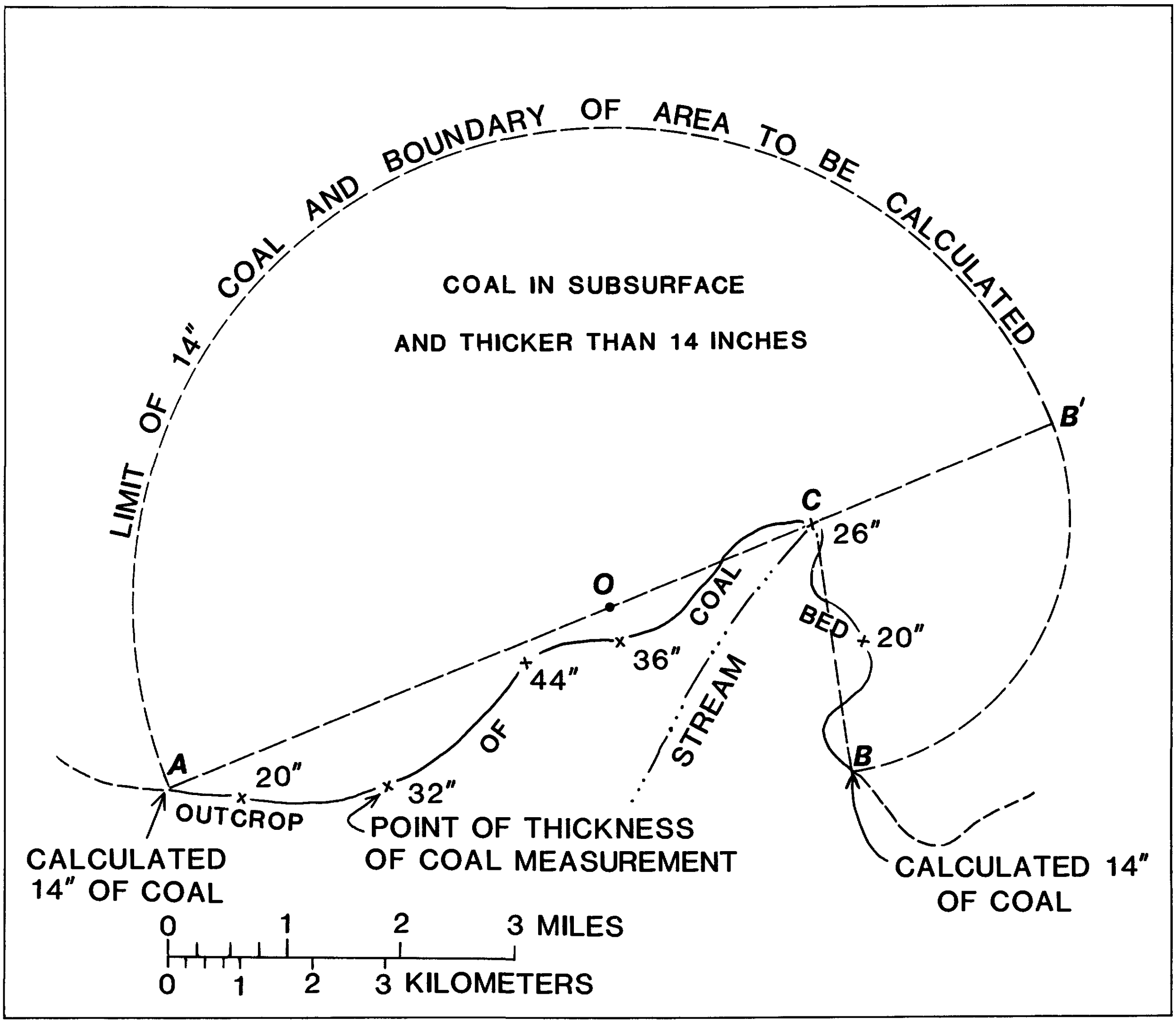


FIGURE 16.—A simple valley reentrant in a bituminous coal bed outcrop. Shows determination of 14-inch coal isopach and limit of area to be planimetered for underlying coal. The 14-inch coal thickness points were obtained by extrapolating data from points of measurement along outcrop line. Projected limits of coal resource isopach (14-inch coal) and area to be calculated are determined by constructing: (1) an arc BB' with origin at C drawn from B to the extension at B' of line AC and CB; and (2) final segment of arc AB' is drawn with origin at midpoint O of line AB'.

TABLE 5.—*Areas of reliability from figure 15 listed in proper overburden and coal thickness categories*

Geologic assurance category	Coal thickness 14 to 28 inches	28 to 42 inches	42 to 84 inches
	0 to 500 feet overburden:		
Measured ----	*A, D, E* -----	*B, Q* --------	*C, R*
Indicated -----	*J, K, L* -----	*I, H* --------	*G, D*
Inferred ------	*O* ----------	*N* ----------	*M*
	500 to 1,000 feet overburden:		
Inferred ------	*P* ----------	None -------	None

structure, and depth of strata penetrated by a well. Such logs have been run in many thousands of oil and gas exploratory, discovery, and producing wells that have penetrated coal-bearing strata in many regions of the country.

Geophysical logs can be used to identify coal beds and to quantify their resources because coal has several unique physical properties including low natural radioactivity, low density, and high resistance to electrical currents; these properties contrast with those of most

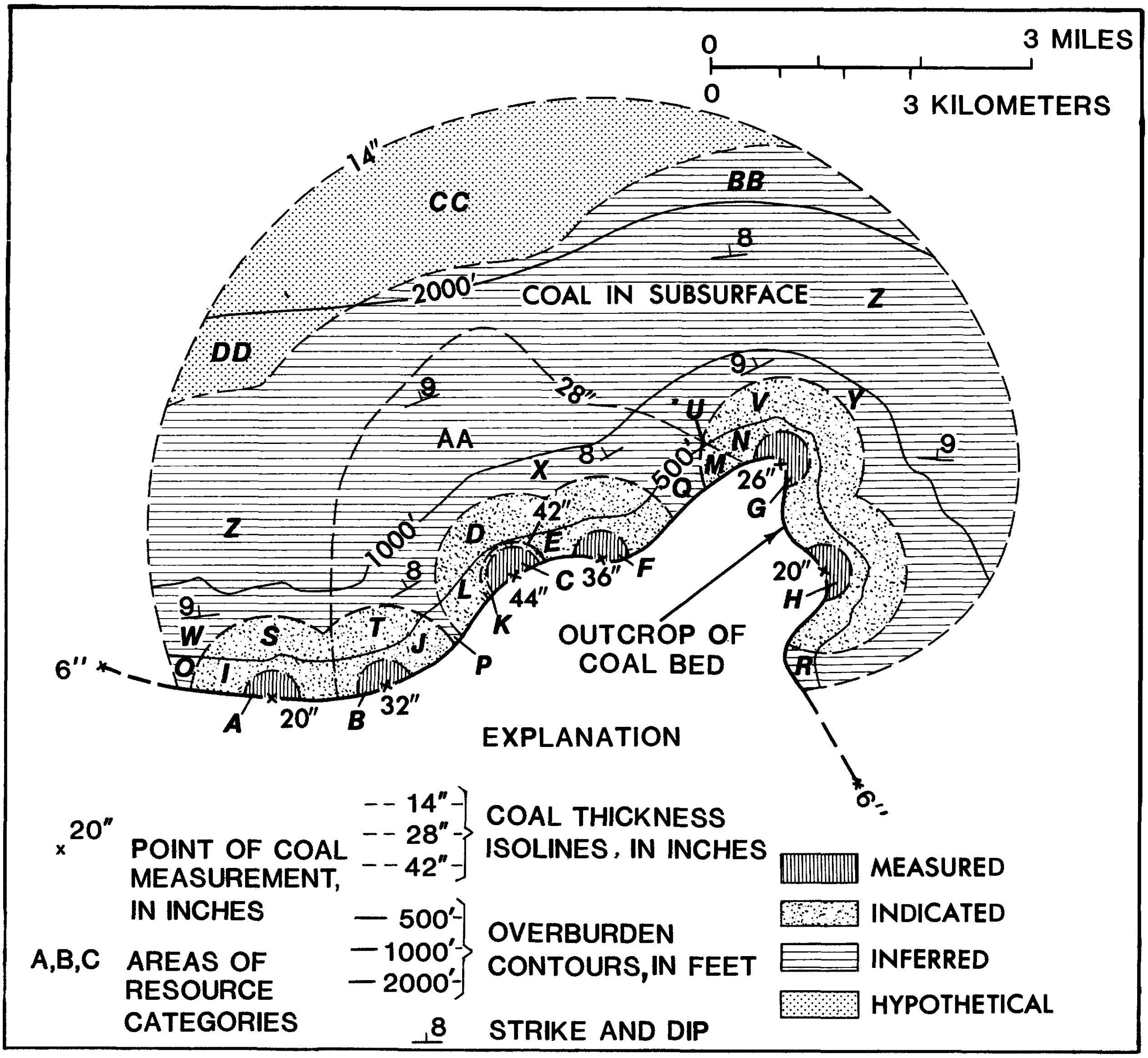


FIGURE 17.—Same diagram as figure 16. Shows determination of areas of reliability; 500-, 1,000-, and 2,000-foot overburden contours; and 14-inch, 28-inch, and 42-inch coal isopachs. Overburden contours were determined from surface elevations on a topographic map and by subtracting bed elevations utilizing structure sections, and dips. Coal isopachs were determined from points of coal thickness measurement and 14-inch limit of coal. Areas of reliability were determined by using 1/4-mile radius (measured), 3/4-mile radius (indicated), 3-mile radius (inferred), and more-than-3-mile radius (hypothetical) from points of thickness of coal measurement. Individual areas of resource categories are identified by letters *A* through *DD*.

other rocks in the coal-bearing sequence. Thus, geophysical logs can provide information on the existence, continuity, thickness, and correlation of shallow to deeply buried coal beds in known coal-bearing areas that have not yet been fully explored and in the future may provide information in areas not previously thought to contain coal. Most of these logs are available to the public through commercial companies and may be studied at State geological surveys or at similar agency offices in some States.

Caution should be used in evaluating and interpreting the existence, thickness, and correlation of coal beds from the geophysical logs of oil and gas exploratory and production wells for two reasons. First, if only one type of log is available, other rock types may be misidentified as coal, for example, highly resistive limestone on a resistivity log or pure quartz sandstone on a natural radioactivity log. However, this problem can be mitigated by a thorough knowledge of the coal-bearing strata in the area under investigation and by an under-

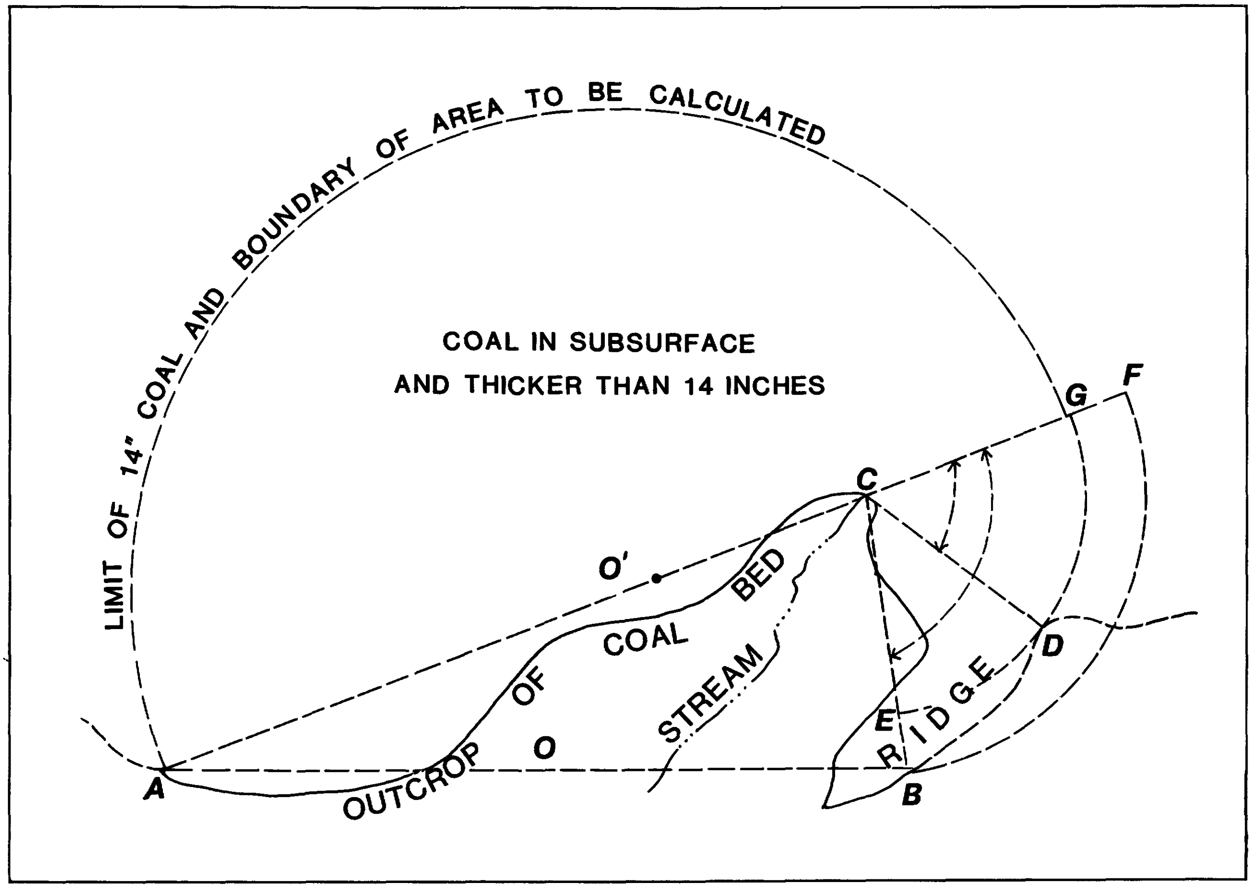


FIGURE 18.—A valley and ridge with part of coal bed less than minimum thickness but within determined 14-inch limit as illustrated in figure 16. Determined limit comprises the outcrop line from *A* to *B* and from *B* to *D* along the arc *B* through *D* to intersect projection of line *AC* at *G*. Radius *CD* is obtained from distance to nearest point of outcrop line, *D*, below minimum thickness. Arc *BF* using radius from line *BC* includes coal on outcrop line below minimum thickness and therefore is not acceptable. Arc *AG* is drawn from midpoint *O'* of line *AG*. Arc *EDG* is drawn from *C* to extend arc *AG*.

TABLE 6.—*Areas of resource categories from figure 17 listed in proper reliability and thickness of coal and overburden categories*

[Tonnage estimate for each area could be determined (1) by planimetering each area for acreage, and (2) by multiplying acreage by proper weight of coal per acre-inch by the average thickness of coal in the area. Thickness of coal for each area is obtained by referring to coal thickness isopachs]

Geologic assurance category	Coal thickness		
	14 to 28 inches	28 to 42 inches	42 to 84 inches
	0 to 500 feet overburden:		
Measured	*A, G, H*	*B, F*	*C*
Indicated	*I, N*	*E, J, L, M*	*K*
Inferred	*O, R*	*P, Q*	None
	500 to 1,000 feet overburden:		
Indicated	*S, V*	*T, D, U*	None
Inferred	*W, Y*	*X*	Do.
	1,000 to 2,000 feet overburden:		
Inferred	*Z*	*AA*	None
Hypothetical	*DD*	None	Do.
	2,000 to 3,000 feet overburden:		
Inferred	*BB*	None	None
Hypothetical	*CC*	do.	Do.

standing of how these strata are recorded on a log. For example, if limestone beds are not present in the coal-bearing sequence and if all sandstone beds are more radioactive than the coal beds, problems of lithologic identification are nonexistent. If several log types are available, the coal generally can be identified with confidence despite other strata with similar log characteristics in the sequence. Second, some oil and gas logs are not suitable for identifying coal beds for reasons that are not always clear because they give readings that either mask coal beds, indicate coal beds where none are present, or are ambiguous. Here again, a knowledge of the stratigraphic positions of coal beds in coal-bearing sequences will aid identificaiton of unsuitable logs. Because coal thicknesses interpreted from geophysical logs are considered as points of measurement for calculating coal resources, it is advisable to use only those coal thicknesses that are determined with confidence.

The geophysical log types generally used in coal bed recognition and stratigraphic identification and rank,

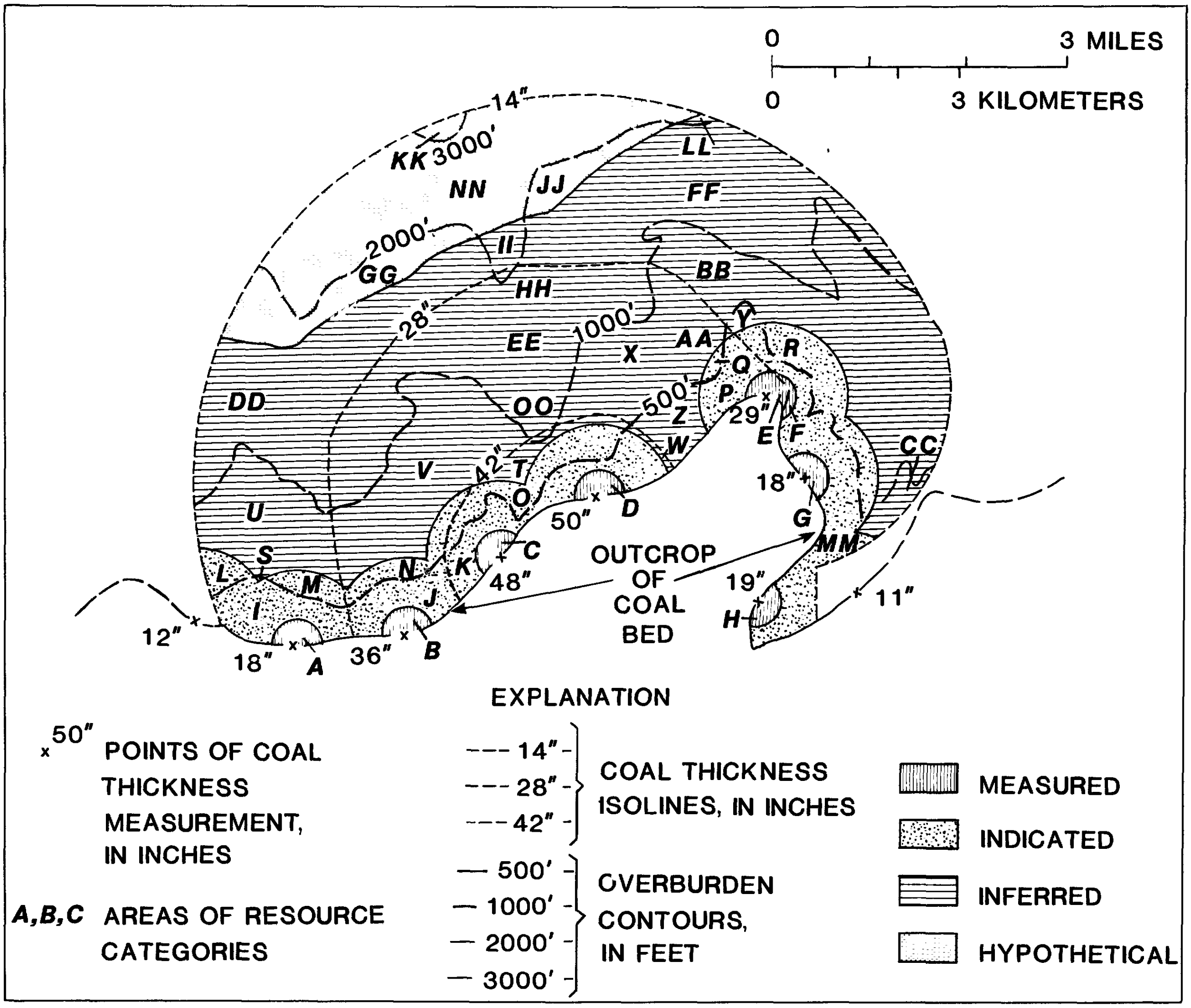


FIGURE 19.—Same diagram as figure 18. Shows determination of areas of reliability; 500-foot, 1,000-foot, 2,000-foot, and 3,000-foot overburden contours; and 14-inch, 28-inch, and 42-inch bituminous coal isopachs. Overburden contours are determined by subtracting bed elevations from surface topographic map elevations. Bed elevations are determined by utilizing structure sections and dips. Coal isopachs are obtained from points of coal thickness measurement and 14-inch limit of coal. Areas of reliability determined by using 1/4-mile radius (measured), 3/4-mile radius (indicated), 3-mile radius (inferred), and more-than-3-miles radius (hypothetical) from points of coal thickness measurement. Areas of resource categories are identified by letters *A* through *OO*.

quality, and thickness evaluations are the electrical, gamma ray, density, neutron, and acoustic velocity. The following discussion of log types is concerned principally with geophysical logs of oil and gas exploratory wells. It should be noted that coal exploration programs increasingly have become reliant on coal-oriented geophysical logs, which provide important data on thickness, depth, and correlation of coal beds, and locally on the composition of coal. A carefully chosen suite of coal-oriented logs can provide positive recognition of coal, identification of specific coal beds, and precise coal thickness measurements (Vaninetti and Thompson, 1982). Such suites are used currently to supplement information obtained from core holes, driller's logs, and examination of drill cuttings. They are useful especially where core or sample recovery of coal was incomplete. The ease and accuracy of recognizing, identifying, and evaluating coal beds with coal-oriented logs strongly contrasts with the difficulty of performing the same interpretations using the higher speed and less accurate geophysical logs of oil and gas wells, which generally are run at different instrument settings and with different equipment. Most oil and gas geophysical logs are recorded at a scale of 1 inch equals 50 feet, with selected sections recorded at the larger scale of 1 inch equals 20 feet, which is reduced for commercial sale to 1 inch equals 100 feet and 1 inch equals 40 feet, respectively.

ELECTRIC LOGS

By far the most common geophysical logs run in oil and gas exploratory wells are electric logs. Prior to the 1950's, conventional electrical logging surveys consisted of one measurement of the spontaneous potential (SP) and three measurements of apparent electrical resistivity of the rocks adjacent to the bore hole (fig. 26). These rock properties were measured only in the uncased part of a well that was filled with water or a water-based mud. The diameter of the well and the effect of adjacent rocks combined to give confusing curves on older electric logs. In solving this problem, a new family of resistivity curves, the focusing-electrode and the induction logs, came into use in the late 1950's. These logs provide better resolution of the coal beds than the older conventional logs and permit more accurate coal thickness measurements.

SP LOG

The spontaneous potential (SP) log measures the difference in electrical potential between rock types, and the resulting curve is recorded on the left-hand side of the log as a single trace. This curve generally reflects the invasion of drilling fluid into the rocks, so a permeable sandstone bed tends to record as a large deflection to the left of the log response for shale (figs. 27 and 28). There are many exceptions to this generalization as shown by the deflections caused by high-porosity coal beds (see fig. 29, SP curve). There are also many wells where the SP curve is nearly featureless in a coal-bearing section and the porosity is recorded the same as shale (fig. 28*A* and *B*).

NORMAL AND LATERAL LOGS

Three types of resistivity curves are recorded on the right side of a geophysical log. These are the 16-inch normal (short normal); the 64-inch normal (long normal); and the 18-foot, 8-inch or 24-foot lateral (lateral); the names referring respectively to the spacing and to the configuration of the electrodes in the probe. These curves record the resistance of rock types to the flow of an electric current. Because most coal beds are highly resistant to the flow of an electric current compared with most adjacent rocks, resistivity curves generally show a large deflection opposite a coal bed. In the short and long (16-inch and 64-inch, respectively) normal curves, however, coal beds thinner than the electrode spacing show a "reverse" (low resistivity) curve bounded by two small peaks (fig. 28*A* and *B*, No. 6 coal). The lateral curve shows a large deflection opposite thin coal beds and a low deflection below the bed. The lateral curve is of little value in the measurement of the thickness of coal beds because it is asymmetric and generally offset from the coal bed. Nevertheless, this curve can be useful in correlating coal beds (fig. 28*A* and *B*).

TABLE 7.—*Areas of resource categories from figure 19 listed in proper reliability and thickness of coal and overburden categories*

[Average thickness of coal in each area can be determined by utilizing coal isopachs]

Geologic assurance category	Coal thickness: 14 to 28 inches	28 to 42 inches	42 to 84 inches
	0 to 500 feet overburden:		
Measured	*A, F, G, H*	*B, E*	*C, D*
Indicated	*I, MM*	*I, J, P*	*K*
Inferred	*CC, Y, S*	*AA, Z*	*W*
	500 to 1,000 feet overburden:		
Indicated	*L, R, M*	*N, Q*	*O*
Inferred	*U, BB*	*V, X*	*T*
	1,000 to 2,000 feet overburden:		
Inferred	*DD, FF*	*EE*	None
Hypothetical	*GG, JJ*	None	Do.
	2,000 to 3,000 feet overburden:		
Inferred	*LL, II*	*HH*	*OO*
Hypothetical	*NN*	None	None
	3,000 to 6,000 feet overburden:		
Hypothetical	*KK*	None	None

FOCUSING-ELECTRODE AND INDUCTION LOGS

Focusing-electrode logs (for example, lateral logs) use special electrodes to send a narrow focused electric current horizontally into adjacent rocks. This results in a resistivity curve that has good resolution of thin resistive beds such as coal (figs. 29 and 30). These focusing and lateral logs measure the conductivity (inverse of resistivity) and the resistivity of rocks by means of induced alternating currents. Commonly, an induction log is run in conjunction with a SP and 16-inch normal log (fig. 27). The induction log is recorded simultaneously as two curves, conductivity and resistivity. The conductivity curve is hyperbolic, which compresses the parts of the curve characterized by low conductivity.

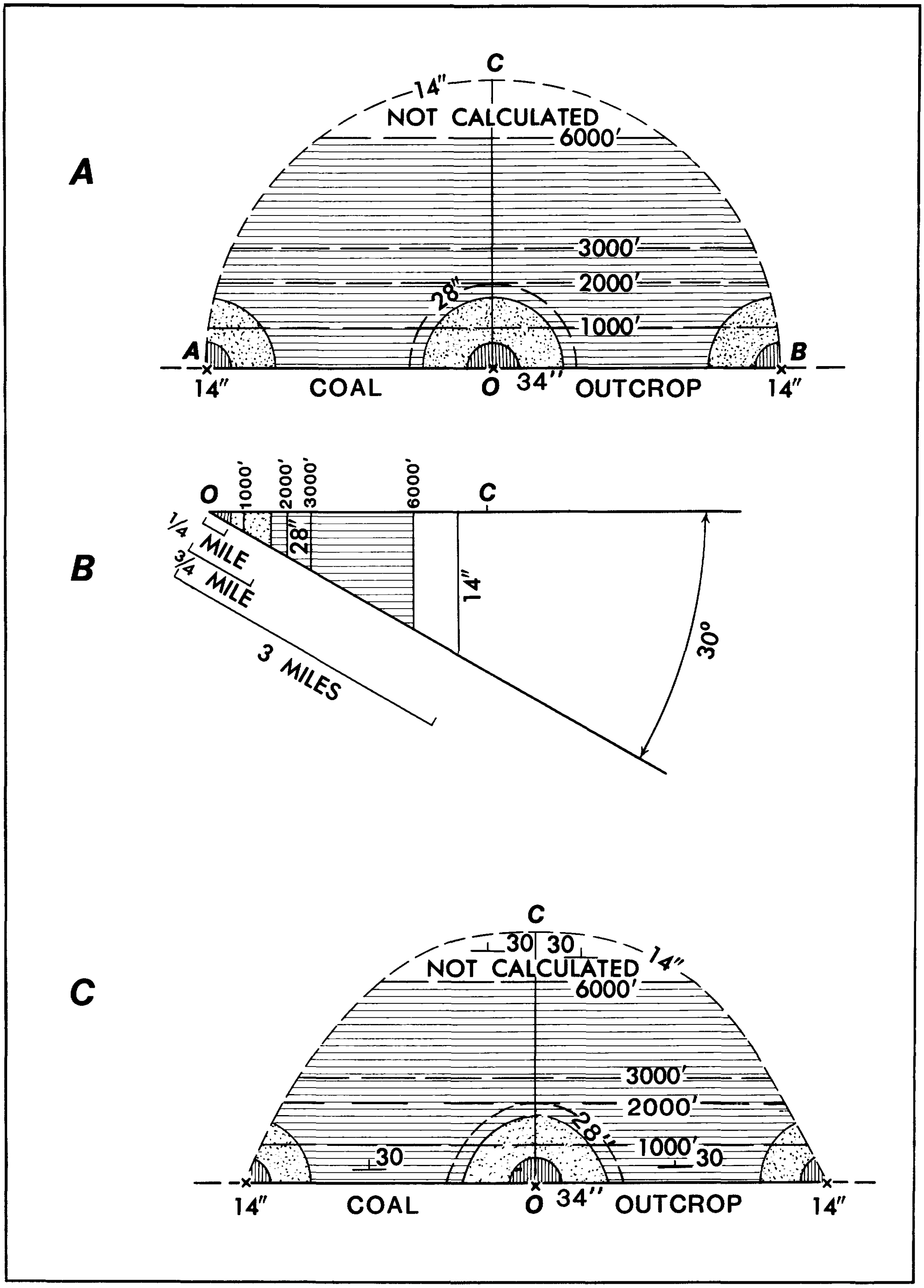


FIGURE 20.—Diagrams showing *A*, Coal categories in plane of coal bed. *B*, Structure section *OC* showing relations between features measured in plane of bed and ground surface when bed dips 30°. *C*, Coal categories as viewed projected to the ground surface from plane of coal bed. Note contraction of category areas towards the outcrop as compared to plane of coal bed; contraction is due to dip.

The resistivity curve, however, is not compressed, so it can be compared directly to the short normal curve and can be used for measurement of the thickness of a coal bed. Combinations of induction and focusing-electrode logs are also common.

DISCUSSION OF ELECTRIC LOGS

With the exception of some high-moisture-content lignites, most coal beds are responsible for high-resistivity deflections on resistivity curves. However, some other rock types such as limestone or resistive sandstones also show high-resistivity deflections and may be mistaken for coal. Limestone is indistinguishable from coal on most electric logs. Fortunately, limestone beds are absent in many regions. In the Midcontinent region, however, limestone is abundant in the coal-bearing sequence and generally can be differentiated from coal only by use of supplementary logs (see fig. 31) or by examination of closely spaced samples of drill cuttings.

Resistive sandstone beds that are permeable generally can be differentiated from coal beds because of their large deflections on a SP log (figs. 26, 27, and 28). Where a SP log is featureless or ambiguous, a knowledge of the lithology of a coal-bearing sequence can help differentiate coal from sandstone. For example, in the Powder River basin of Montana and Wyoming, many sandstone beds are gradational with adjacent low resistivity shale beds, whereas the shale beds are in sharp contrast with adjacent high-resistivity coal beds. As a result, the resistivity curves delineating coal beds are more nearly parallel than the curves representing the contacts of sandstone beds.

GAMMA RAY LOG

The gamma ray log records the natural gamma radiation from rocks adjacent to a drill hole. Coal generally has low natural radioactivity as compared with other rocks, particularly shale, in a coal-bearing sequence (figs. 29, 30, and 31). In some coal-bearing regions, limestone and sandstone may have similar low natural radioactivity (for example, Midcontinent or Appalachian regions) so that in those regions supplemental logs such as density or acoustic velocity are needed to identify coal. In other regions, gamma ray logs alone are sufficient to identify coal beds as, for example, in the Fruitland Formation (Fassett and Hinds, 1971) and in the Northern Great Plains where no other rock types in the Tertiary coal-bearing sequence, including limestone, are known to have as low a natural radioactivity as coal. Even in areas where a gamma ray log is diagnostic of coal, a few oil and gas well gamma ray logs are useless because their time constant is so long and their sensitivity is so low that a coal bed either cannot be detected or its boundaries are obscured. Locally some coal beds are uraniferous; consequently, a high radioactivity is recorded on gamma ray logs. These uranium-bearing coal beds usually can be identified by using other logging methods.

A gamma ray log is the most versatile of the geophysical logs for the following reasons: (1) it does not require fluid in the hole; (2) it is not sensitive to small variations in hole diameter; and (3) it can be used to detect coal beds through well casing. In fact, near-surface gamma ray logs of cased oil and gas wells are a prime source of data for identifying and measuring the thickness of shallow coal beds in the Northern Great Plains region.

The gamma ray logs can detect shale partings in a coal bed, but generally the thickness of thin partings is exaggerated. In the Powder River basin of Montana, there is an example where the gamma ray log records a 0.3-foot shale parting at the same thickness as a 2-foot parting.

DENSITY LOG

A gamma-gamma density log records the bulk density of rocks adjacent to a drill hole by measuring the induced gamma rays emitted by the rocks after bombardment by a gamma ray source encased in a probe and lowered into the drill hole. The denser the adjacent rocks, the more gamma rays are absorbed and not returned to a detector in the probe where they are measured in grams/cm^3. Most ranks of coal are low in density (about 0.7 to 1.8 grams/cm^3) compared to adjacent rocks; therefore, a density log is an excellent tool for coal-bed evaluation. The density log is capable of identifying detailed variations in the density of rocks. Density logs from oil and gas wells are commonly run at 30 feet per minute, are recorded at 1 inch equals 20 feet, and then are reduced to 1 inch equals 100 feet. At this scale and speed, thin coal beds and partings can be detected and their thicknesses accurately measured (fig. 30). Unfortunately, density logs must be run in uncased holes and are strongly affected by differences in hole diameter; thus, the curve recorded for a caved or enlarged part of a well may simulate the curve of a coal bed. A caliper log, which measures the diameter of a well, is generally run in conjunction with these logs so that the proper interpretation and correction can be made.

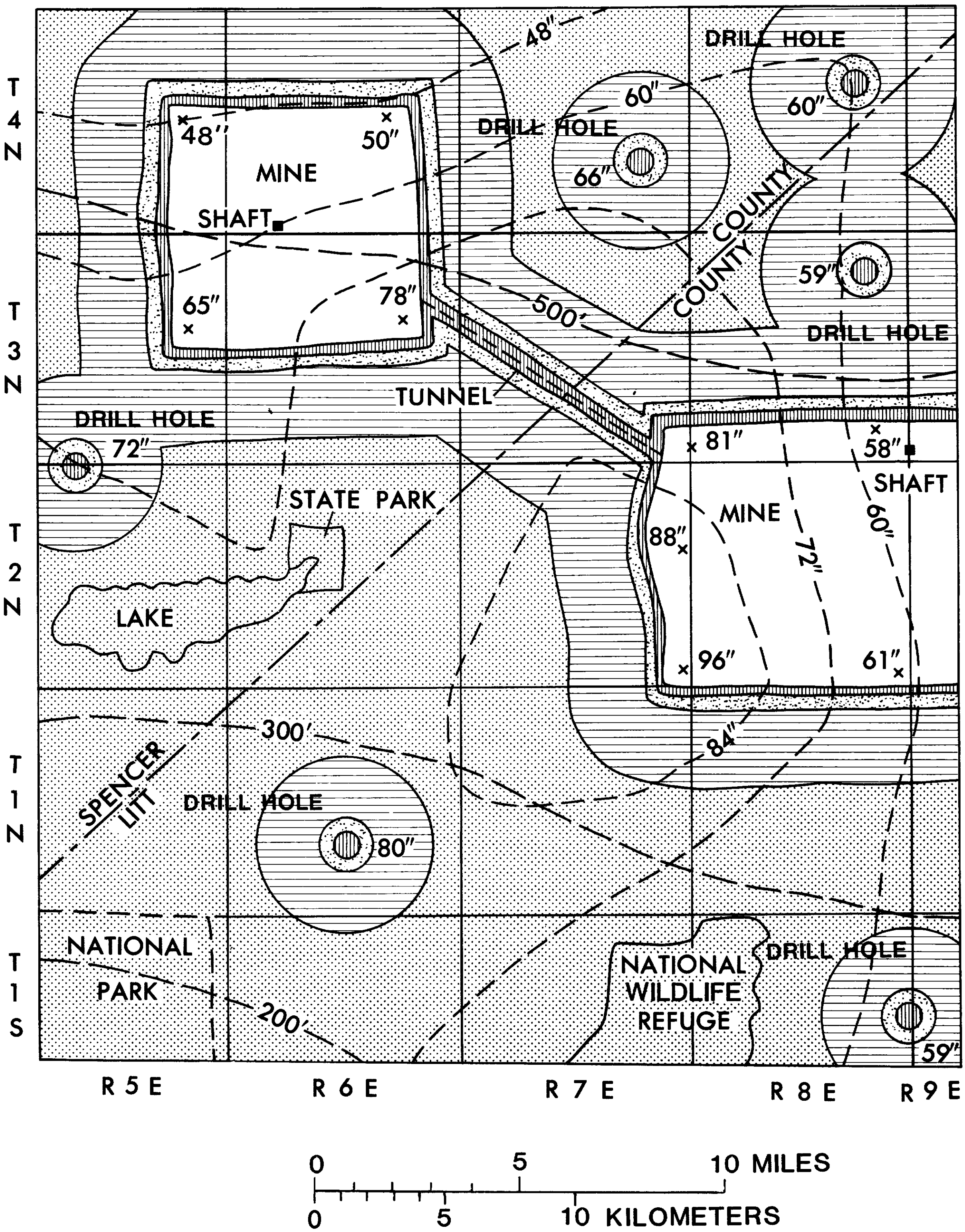


FIGURE 21.—Flat-lying bituminous coal bed with data only from underground mined areas and drill holes. Note pattern areas of reliability around each drill hole and paralleling the boundaries of mined areas and the tunnel that connects the mines. Numerous thickness of coal measurements along tunnel and mine boundaries are not shown. Coal tonnages and acreages should be reported separately for each resource category, as determined by areas of reliability; the 0–200 foot, 200–300 foot, 300–500 foot, and >500-ft

Density logs should be used in conjunction with other logs to avoid mistaking spurious low-density readings for coal. These logs are generally recorded simultaneously with a gamma ray log, which resolves most uncertainties of rock identification.

NEUTRON LOG

The neutron log, which is similar to the density log, records the varying intensity of gamma rays resulting from inducing neutrons into rocks adjacent to a drill hole by a probe containing a radioactive source. In general, the number of gamma rays and neutrons detected as they return to a detector in the probe are inversely proportional to the hydrogen ion content of a particular rock type. The curve recorded by the detector of returning gamma rays and neutrons can be interpreted to indicate the relative fluid content of the rocks and therefore their porosity and permeability. This log is commonly called the porosity index. The curve of the neutron log records high readings adjacent to permeable fluid-filled rocks because of their high hydrogen contents, but it also records high adjacent to a coal bed because of its high carbon content (fig. 31). A clay with high-moisture content will also record high reading on this curve. Therefore, a high-moisture clay adjacent to a coal bed can obscure the contact between the clay and coal and record a spurious thickness of coal. Other types of logs such as the density or gamma ray will allow a more accurate measurement of the thickness of coal. Neutron logs are also strongly affected by caved or oversized diameter holes; therefore, neutron logs should be used in conjunction with caliper logs.

ACOUSTIC VELOCITY LOG

Acoustic velocity logs record the velocity of pulsed sonic waves generated in a probe, transmitted into rocks surrounding the probe in a drill hole, and reflected to receivers in the probe. The results are recorded as the inverse of velocity—that is, the time in microseconds for the waves to travel 1 foot (interval transit time). The velocity of the sonic wave depends both upon the lithology and the porosity of the rock type being penetrated. If the rock type is known, therefore, the acoustic velocity log can be used as a measure of porosity. A decrease in velocity (increase in interval transit time) can be interpreted to be the result of an increase in porosity. Coal generally has a longer interval transit time (lower velocity) than adjacent rocks. Because an acoustic velocity log can record velocity changes in great detail, it is commonly recorded on an expanded scale (1 inch = 20 feet) along with a gamma ray and caliper log. However, its value as a tool for identifying coal beds is dependent on the nature of the coal-bearing sequence. An acoustic velocity log is an excellent tool in deeply buried rocks such as the Tertiary rocks of southwest Wyoming. Acoustic velocity logs can be used to delineate coal beds with precision (see fig. 29). They are of lesser value where the same rocks are near the surface, are poorly consolidated, or are fractured because the many spurious low-velocity deflections are recorded. Such logs are everywhere useful in distinguishing coal from limestone, which has a much shorter interval transit time.

MEASUREMENT OF THE COAL BED THICKNESS

The measurement of thickness of coal beds on geophysical logs requires the identification of the top and base of the coal beds by either of the following methods: (1) point of inflection method (the points where curves change direction), or (2) midpoints of inflection method (arbitrary points located midway between the points of inflection). The points of inflection method is used for measuring the thickness of coal on gamma ray logs, on resistivity logs, and for thin beds on density, neutron, and acoustic velocity logs. It is important to understand that the thickness of coal measured on the short normal and long normal resistivity curves is less than the true thickness of the coal bed by the amount of the electrode spacing; that is, 16 inches less for the short normal curve, and 64 inches less for the long normal curve. The midpoints of inflection method is used to identify the top and base of thick coal beds on the density, neutron, and acoustic velocity logs (see figs. 26, 27 29, and 30 for examples). In general, the SP, long normal resistivity, lateral resistivity, and induction curves are not suitable for accurate measurement of the thickness of coal beds.

The precision and accuracy of coal bed thickness measurements on geophysical logs are dependent on several factors, such as the speed of logging, the scale at

overburden categories; counties; areas underlying the lake; State and national parks and the National Wildlife Refuge; and each township and range. The 200–, 300–, and 500–foot overburden contour lines and the coal isopachs were constructed to define depth of burial and average thickness of coal in each areal category. Explanation for patterns of resource categories is in figure 19.

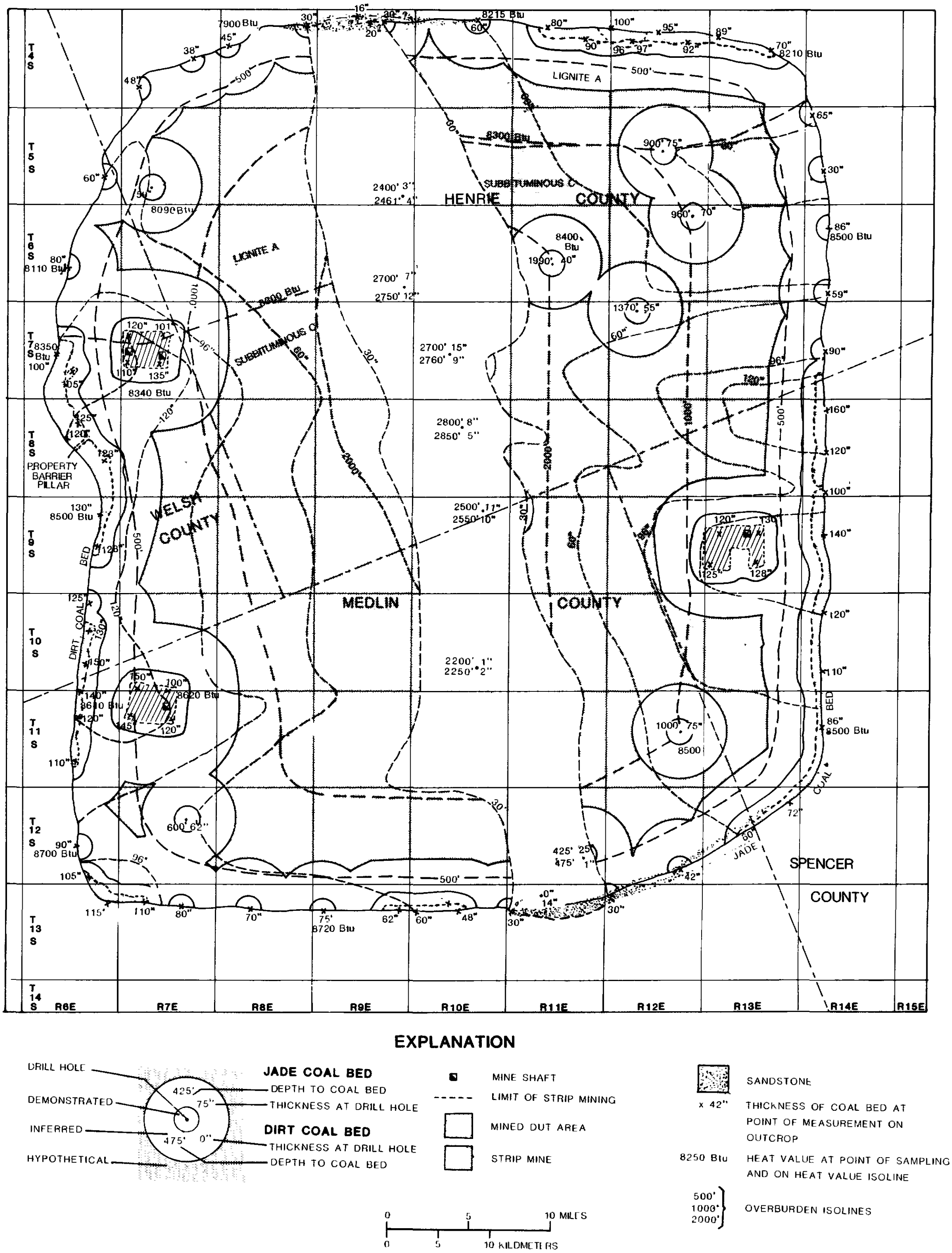


FIGURE 22.—A small coal basin containing two coal beds that thin out into sandstone by intertonguing. Area of intertonguing sandstone and coal beds trends slightly west of north and is marked by absence of coal beds or by coal too thin to mine. Note 8,300 Btu isolines trending about east-west. Isolines mark approximate areal boundaries between lignite A and subbituminous C coal as defined by heat value on a moist, mineral-matter-free basis. Coal tonnages should be computed as follows: by demonstrated, inferred, and hypothetical categories; by mined out (underground and strip); by 0–500 feet

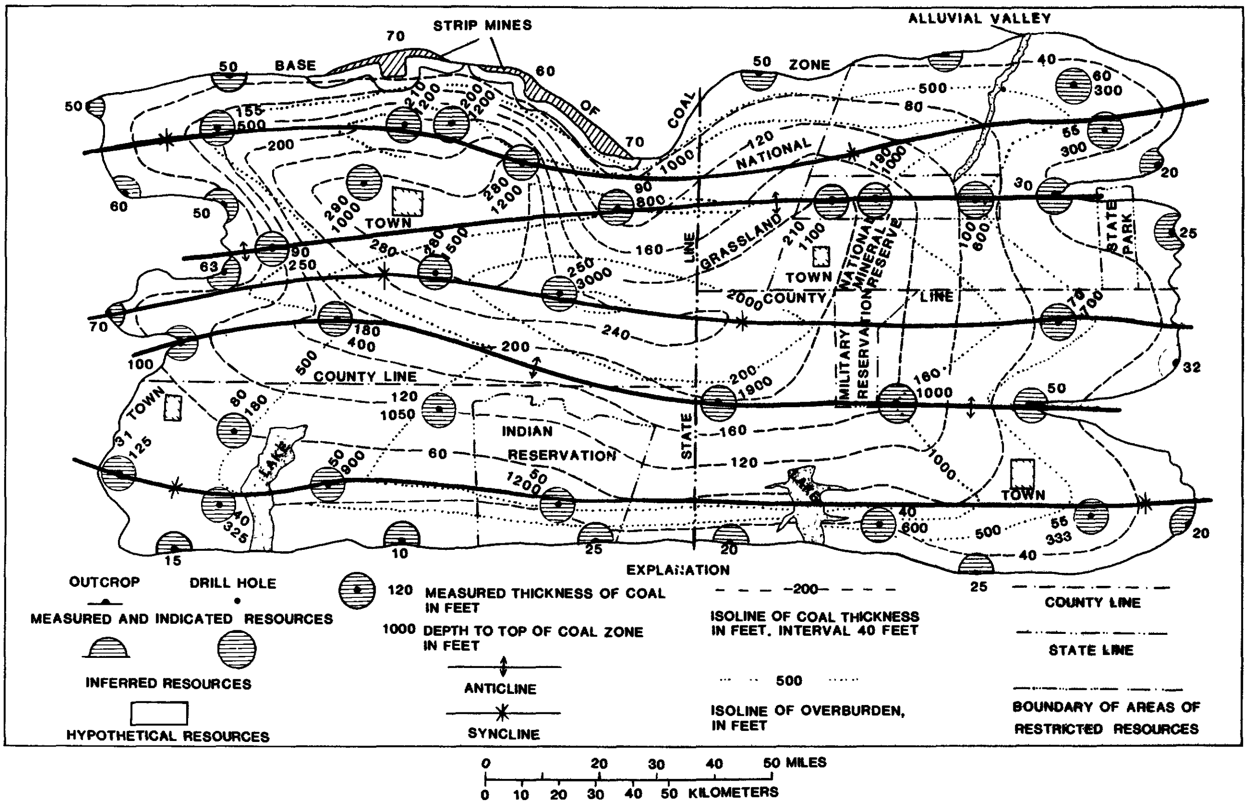


FIGURE 23.—A large, simple coal basin containing a large quantity of subbituminous coal and lignite. Coal occurs in a zone as thick as 500 feet. Information on coal zone is derived from two strip mines, 20 exposed localities where coal-bearing rocks can be measured, described, and correlated, and numerous oil and gas wells for which there are drill cuttings, cores, and (or) geophysical logs. Demonstrated, inferred, and hypothetical areas of reliability are based on points of control from the surface exposures and wells. Townships and ranges and rank differences are not shown on map because of density of detail. Coal should be categorized and tonnages estimated by States; counties; townships and ranges; rank; demonstrated, inferred, and hypothetical areas of reliability; 0–500 feet (0–150 m), 500–1,000 feet (150–300 m), 1,000–2,000 feet (300–600 m), 2,000–3,000 feet (600–900 m), and 3,000–6,000 feet (900–1,800 m) categories of overburden; thickness of coal in coal zone; and coal underlying Indian reservations, military reservations, national grasslands, national mineral reservations, and State park categories. Coal beneath Indian reservations, towns, lakes, and alluvial valleys could be tabulated separately from other coal resources and those that are restricted so labeled. Cumulative total thickness of coal at a point of surface measurement or well is the summing of all coal in beds greater than 2.5 feet thick.

which the log is recorded, the type of log, the type of equipment, and the instrument settings as well as the ability of the user to pick the correct top and base of a coal bed.

Density, neutron, gamma ray, and acoustic velocity logs in oil and gas wells are recorded at speeds of 30 to 60 feet per minute and at a scale of 1 inch equals 20 feet. Such logs generally permit the measurement of the thickness of coal beds within an error of ±1 foot and allow identification of coal beds as thin as about 2 feet. A suite of logs run in a coal exploratory drill hole at slow speeds of 15 feet or less per minute and recorded at 1 inch equals 10 feet or less, with a standard mineral probe and recording instruments set for coal identification, can measure coal beds as thin as ±0.5 foot. The use of special equipment and slower logging speeds can improve the precision of thickness measurements.

Resistivity logs of oil and gas wells generally are run at higher speeds of about 100 feet per minute and are recorded at 1 inch equals 50 feet, with the result that coal beds thinner than about 2 feet cannot be identified or measured as to thickness. Some of the focusing electrode logs recorded at 1 inch equals 20 feet may permit greater precision. In contrast with oil and gas logs, logs

(0–150 m), 500–1,000 feet (150–300 m), 1,000–2,000 feet (300–600 m), and 2,000–3,000 feet (600–900 m) overburden categories; by 30–60 inches (75–160 cm), 60–96 inches (150–240 cm), 96–120 inches (240–300 cm), and 120–240 inches (300–600 cm) thickness of coal categories; by rank of coal (lignite A and subbituminous C), and by townships and ranges, counties, coal field, basin, and State.

Coal reserves or
resources of ___________ Township, Range ________, Quadrangle _______, Field _______, County, State of ___________

Formation______, Member _______, Rank of Coal________, Sulfur Content______, Ash Content______, Heat Value (Btu Cal)____

Name of Bed	Overburden Range (feet)	Planimeter Reading	Area (Acres)	Weighted Average Thickness (inches)	Remaining or Original Tonnage (millions of short tons)[1]											
					Measured (inches)				Indicated (inches)				Inferred (inches)			
					14-28	28-42	42-84	84-168	14-28	28-42	42-84	84-168	14-28	28-42	42-84	84-168
				Column total												

Planimeter factor ________________

Short or metric tons
per acre-inch ___________________ Total Measured ___________ Total Indicated ________ Total Inferred _______

Planimetered by ________ Total 14-28"________ Total 28-42"__________ Total 42-84"__________ Total 84"+__________

Calculated by __________________ Total 0-500'_____________ Total 500-1,000'_________ Total 1,000-2,000'_____

Checked by ____________________ Total 2,000-3,000'________ Total 3,000-6,000________
Grand Total ____________

[1]Categories for hypothetical and speculative coal may be added.

FIGURE 24.—Suggested type of form for recording data and computed tonnages for a mine, area, coal bed, quadrangle, township and range, coal field, basin, region, province, county, State or political province, and the Nation.

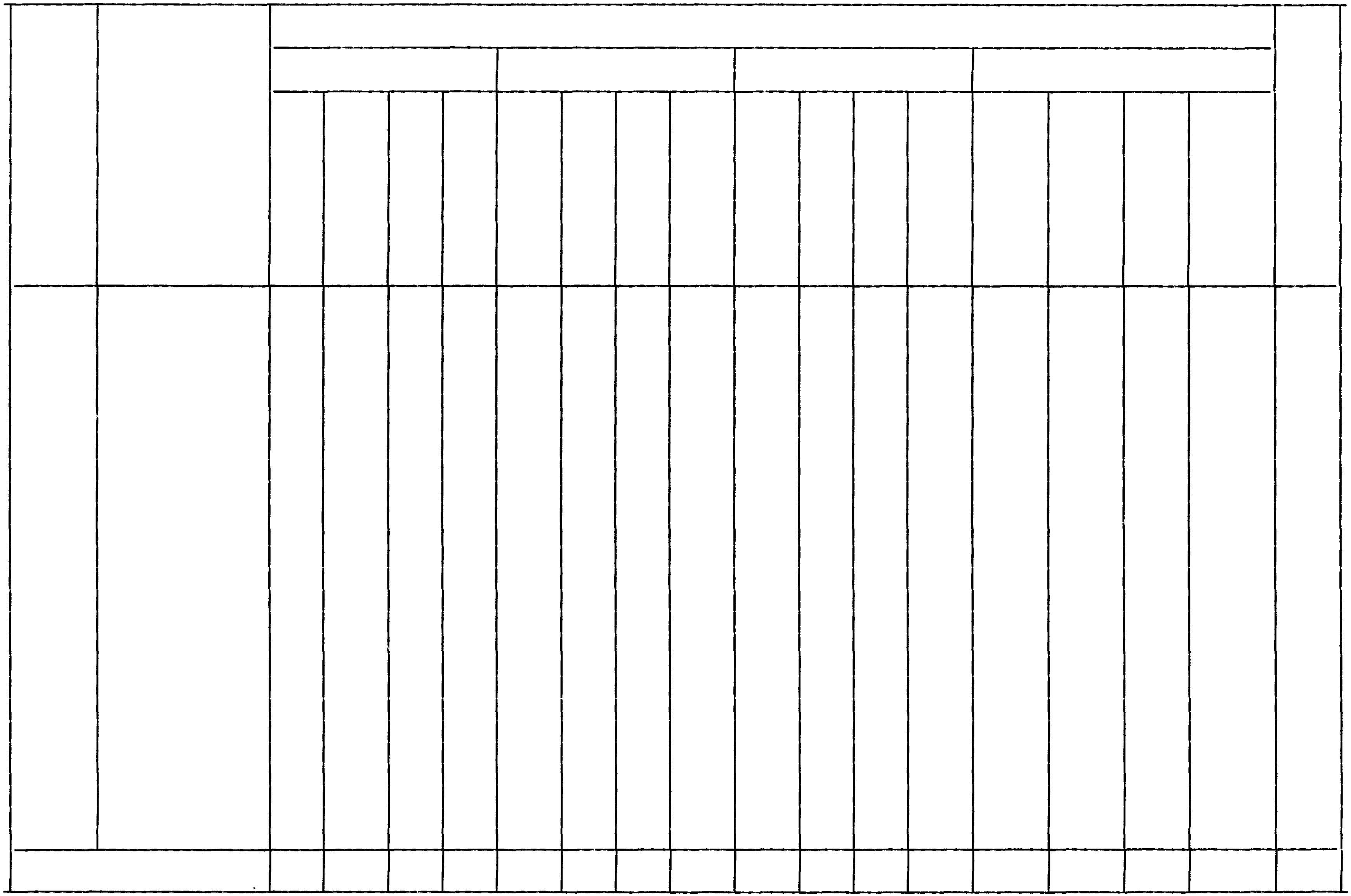


FIGURE 25.—Suggested format for tabulating data and calculating tonnages with headings left to judgment of estimator.

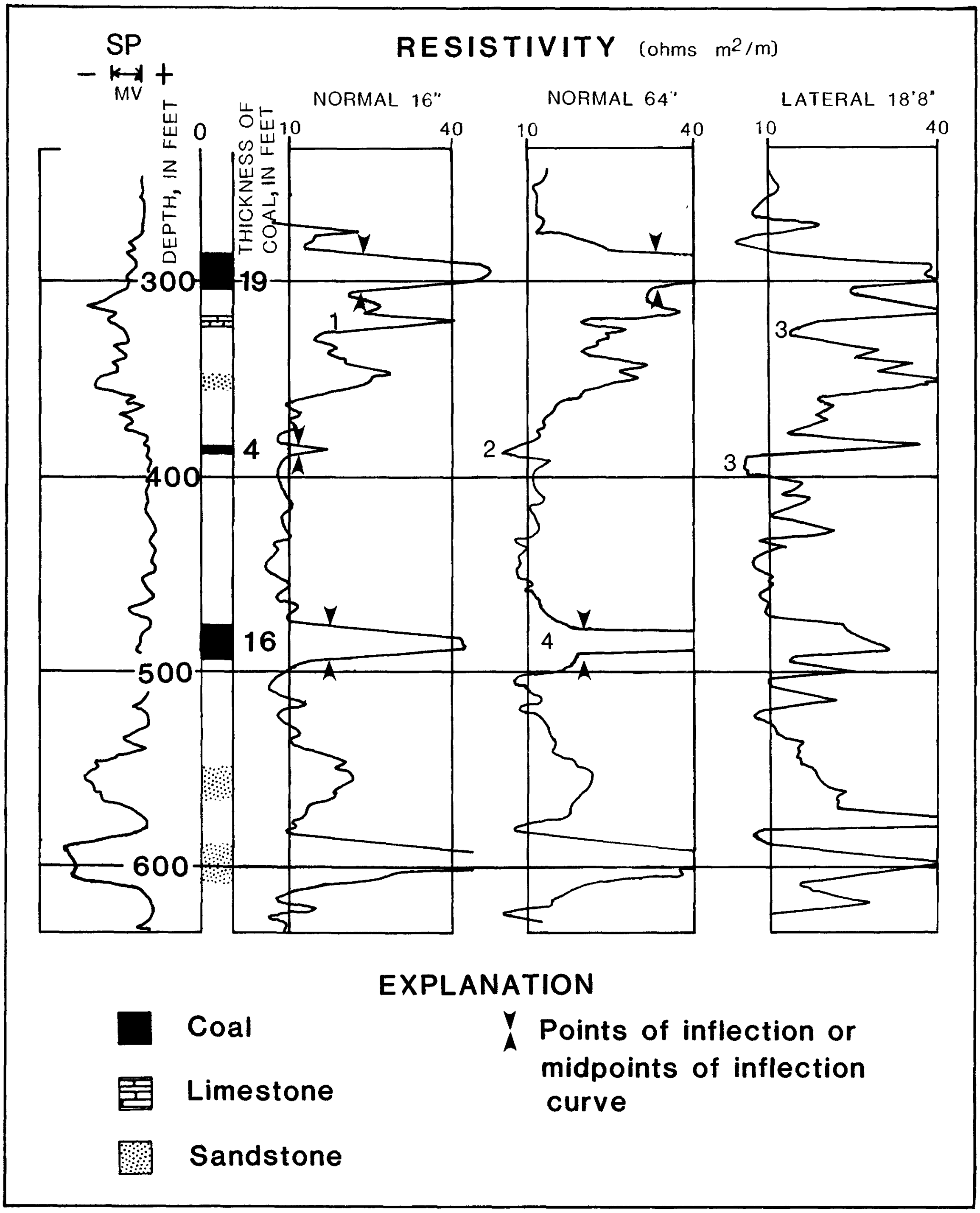


FIGURE 26.—Early conventional electric log (1957) of the Owanah Kendrick No. 1 well in Big Horn County, Montana, showing response of subbituminous coal beds in the Paleocene Fort Union Formation. Short normal peak at 320 feet (1) looks like a coal bed, but is identified as limestone on the acoustic velocity log of a nearby hole. Noteworthy are long normal reversals (2) where the resistive bed is thinner than the electrode spacing of 64 inches, and the high lateral resistivity response opposite a thin resistive bed (3), with low response just below bed, and at where the long normal curve indicates that the bed is 4 feet thinner than does the short normal curve (4) because of the difference in electrode spacing. Note also the large SP response of the sandstone beds compared to coal.

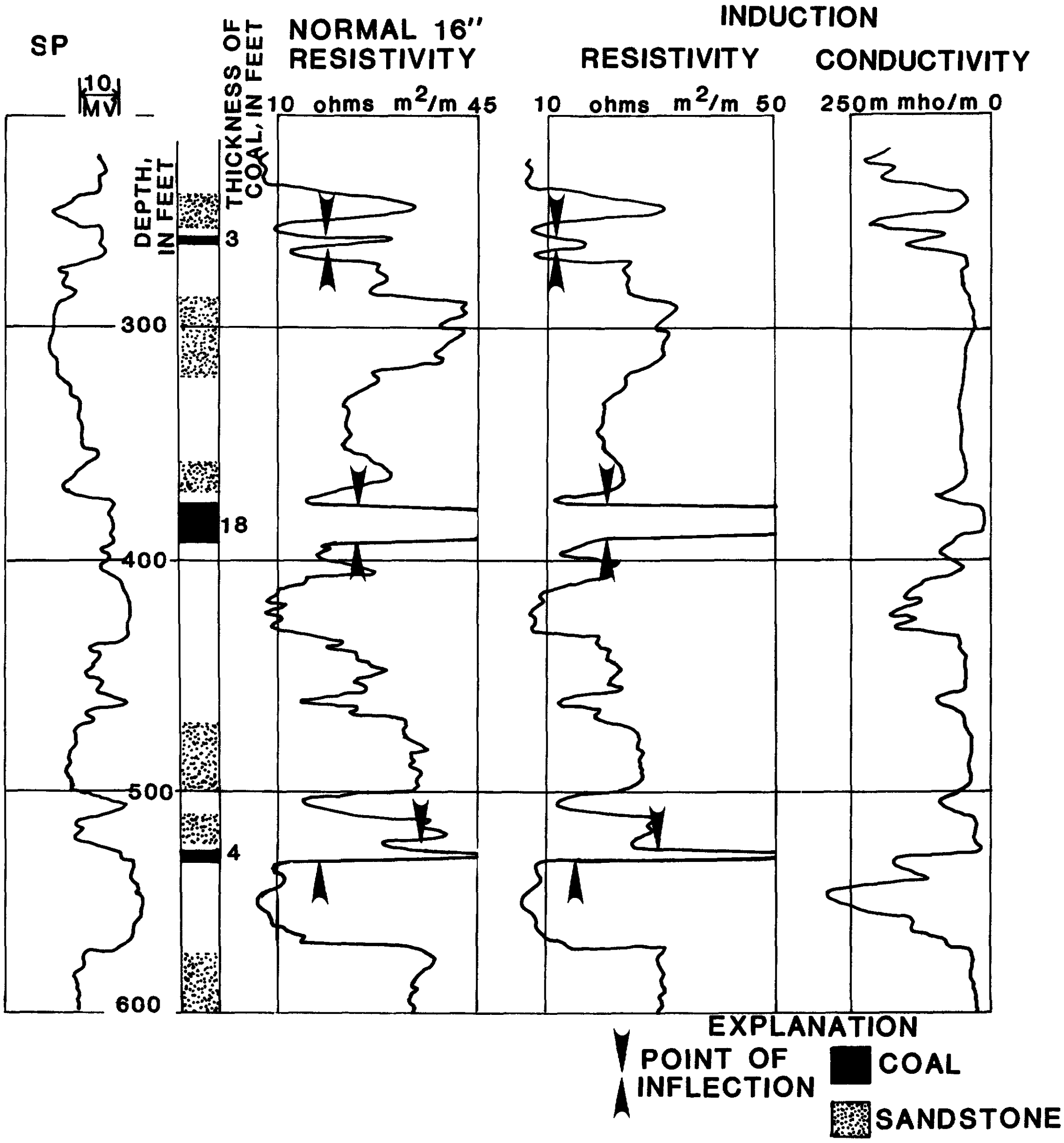


FIGURE 27.—Induction and conductivity geophysical logs (1960) of the Hose-Austin Drilling Company, Bones Brothers No. 1 well, Rosebud County, Montana, showing response of subbituminous coal in Paleocene Fort Union Formation.

of the "single point" resistivity type in coal exploration drill holes can provide precision similar to those of radiation-type logs.

COMPOSITION AND RANK OF COAL

Geophysical logs can also provide information on the composition and rank of coal. High-ash or shaly zones (partings) in coal generally are recorded on logs by curves indicating that they are more radioactive, more dense, and less resistive than purer coal. High-rank coal is more dense and has a shorter interval travel time in sonic logs than low-rank coal. Efforts have been made to quantify compositional factors of coal, such as moisture and ash content, using geophysical logs. Bond and others (1971) report that in the Illinois basin an experimental program using computer processed data from logs of coal exploratory drill holes produced excellent determinations of moisture and ash in coal. However,

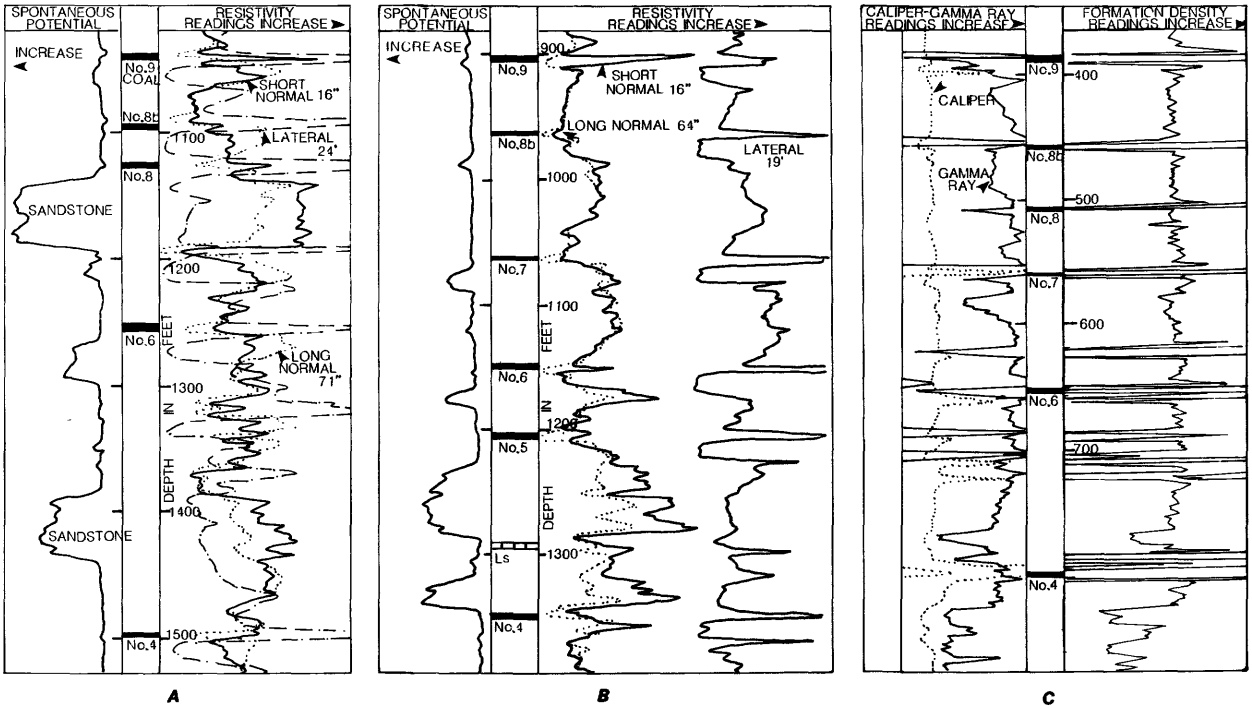


FIGURE 28.—Examples of oil- and gas-well geophysical logs from western Kentucky that can be used for coal bed correlations and coal resource evaluations.

attempts to quantify coal composition using geophysical logs from wells in the Northern Great Plains have had erratic results.

STRATIGRAPHY AND STRUCTURE

Geophysical logs that have been properly related to a known stratigraphic section can be used to correlate coal beds and determine their structure. In many areas a coal bed and adjacent rocks are recorded on geophysical logs as a unique curve, or sets of curves, that can be recognized on logs of drill holes throughout a large area (see fig. 28, No. 9 coal bed). Recognition of "signature" curves permits correlation of stratigraphic units across any area where the lithology remains reasonably constant and in some places allows correlation throughout a coal basin. Properly correlated logs can provide the necessary data to construct coal bed maps that show structure, thickness of coal, and thickness of overburden.

Geophysical logs are also useful in studying the ancestoral sedimentary environments of coal beds. In the Appalachian coal region, Wanless and others (1963) used electric logs of oil and gas wells augmented by drill-hole and outcrop data to identify and map sedimentary environments of some coal-bearing rocks of Pennsylvanian age. Daniels and Scott (1980; 1982) in Kentucky and in Montana used geophysical logs of coal drill holes to refine their interpretations of drillers' lithologic logs in a study of ancestoral sedimentary swamp environments of Pennsylvanian and Tertiary rocks.

SUMMARY

Geophysical logs of oil and gas wells are the source of abundant data on coal beds, but the value of any of these logs in any particular coal area or basin depends in large part on a knowledge of the coal-bearing rocks and of how the data are recorded on the curves of the geophysical logs. Consequently, it is advisable for those planning to use geophysical logs for coal interpretation to study the logs of drill holes in an area where the lithology is known to determine the reaction of logging equipment to various rock types. Use of a suite of several types of logs is recommended for the best results.

It is important to recognize and discard poor quality or ambiguous logs so that erroneous data is not used in calculating coal resources.

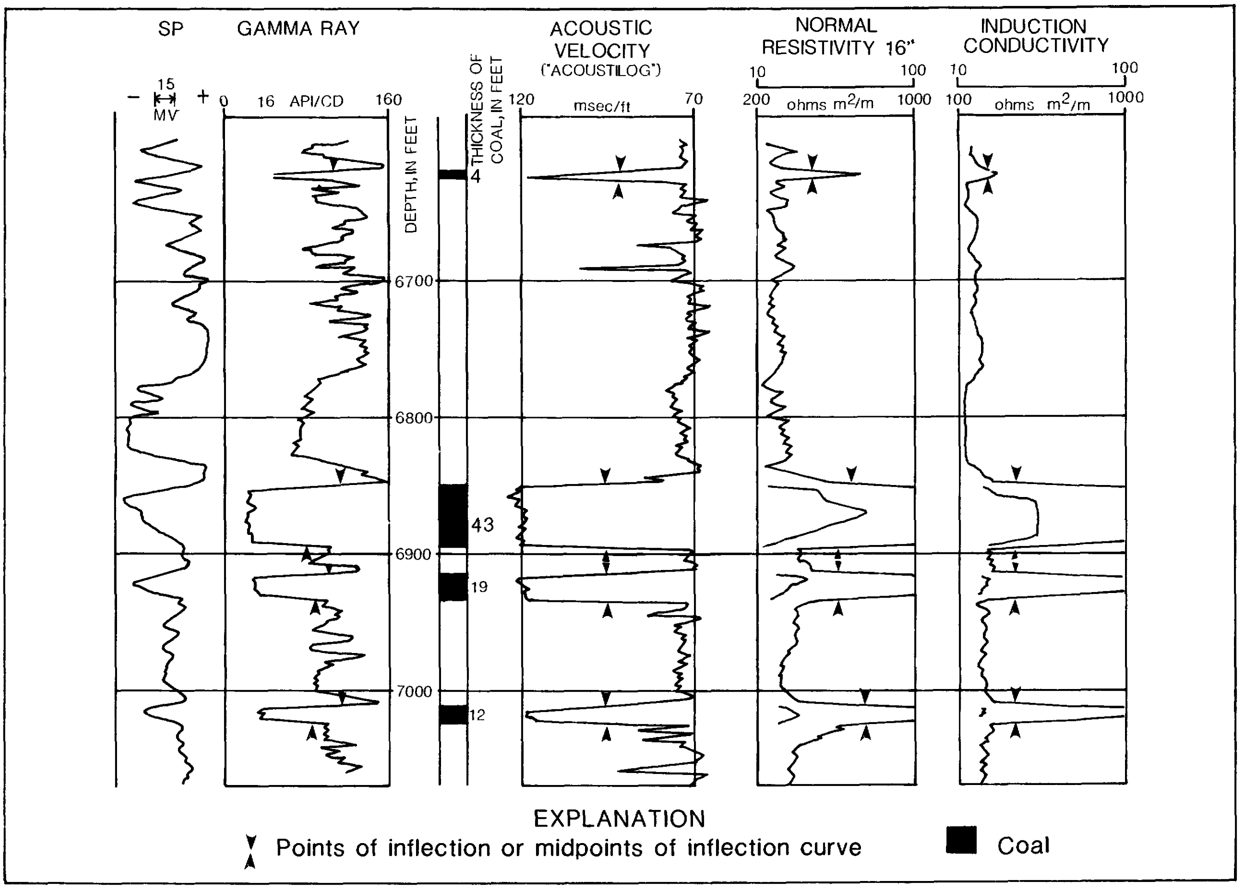


FIGURE 29.—SP, gamma ray, acoustic velocity (sonic), normal resistivity, and induction conductivity logs (1971) from the Davis Oil Grady Fed No. 1-2 well, Sweetwater County, Wyoming, showing response of subbituminous(?) coal beds in the Paleocene Fort Union Formation.

INTENDED AUDIENCE

This circular was prepared for two audiences: (1) coal resource specialists, coal geologists, and coal-mining engineers; and (2) the public, Congress, and many State and Federal agencies who desire more than a casual knowledge about the need for and procedures of coal resource classification.

The definitions, criteria, guidelines, and illustrations are designed to aid coal geologists and engineers in preparing their reports by providing guidance in calculating, categorizing, and describing the coal resources/reserve base/reserves they are evaluating. The description of geophysical log usage also should provide aid in obtaining and using subsurface information on the areal extent, thickness, and correlation of coal beds and should open up a vast and generally untapped data source for most coal geologists. Adherence to the categories of resource assignment, to the definitions, and to the criteria can result in more accurate, precise, explicit, and consistent reports.

The classification system and terminology described in this circular are equally applicable to hand and computer system determinations of resources and reserves. The illustrations are applicable to manual methods of coal resource/reserve base/reserve tonnage estimations. Computer programs have been designed that will yield similar tonnage estimates of coal resources. Those wishing to inquire about the computer software and methodologies should write to Chief, Branch of Coal Resources, 956 National Center, U.S. Geological Survey, Reston, Virginia 22092.

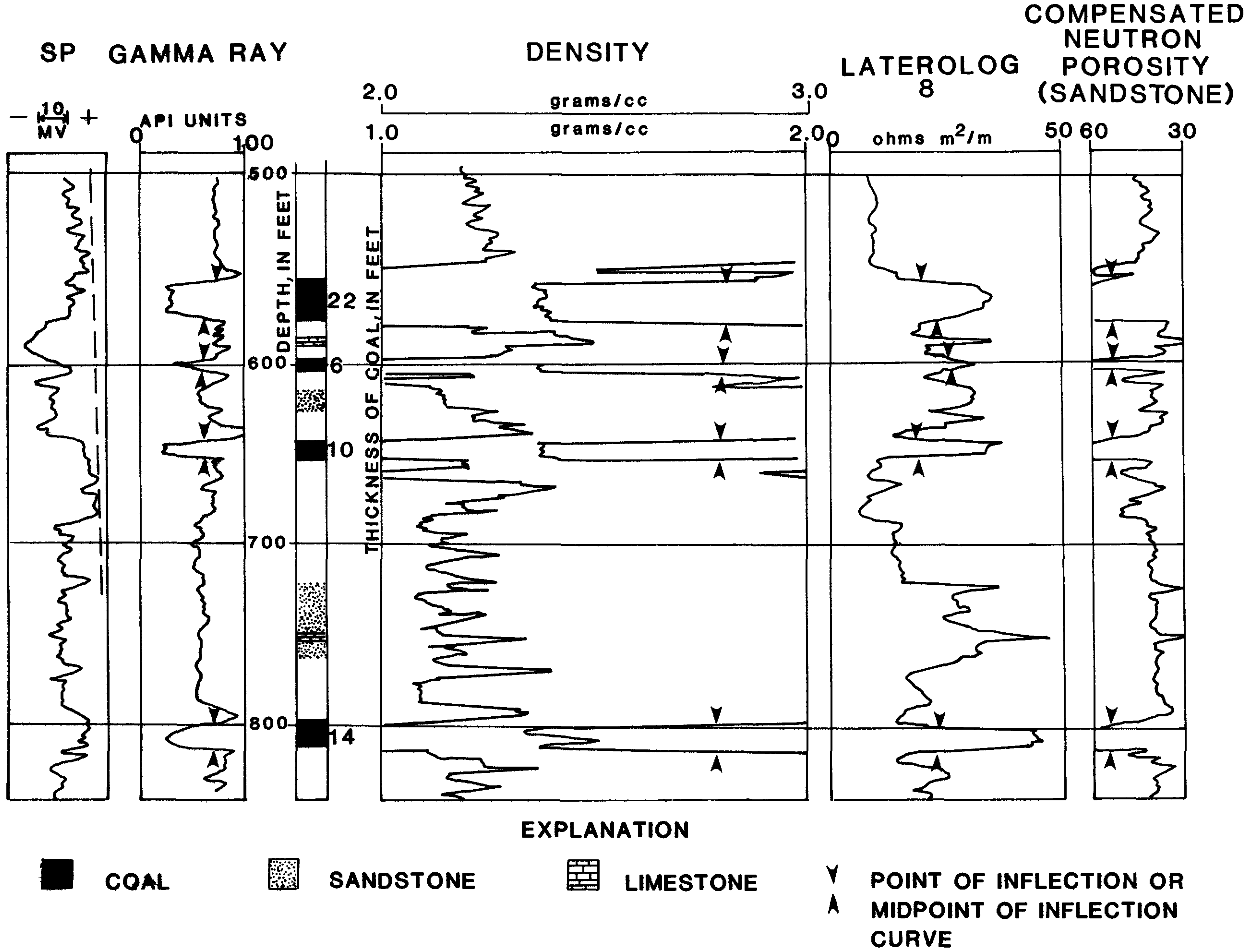


FIGURE 30.—SP, gamma ray, density, dual induction-lateral log, and neutron logs (1978) from Getty Tri-County No. 1 well, Rosebud County, Montana, showing response of subbituminous coal in the Paleocene Fort Union Formation.

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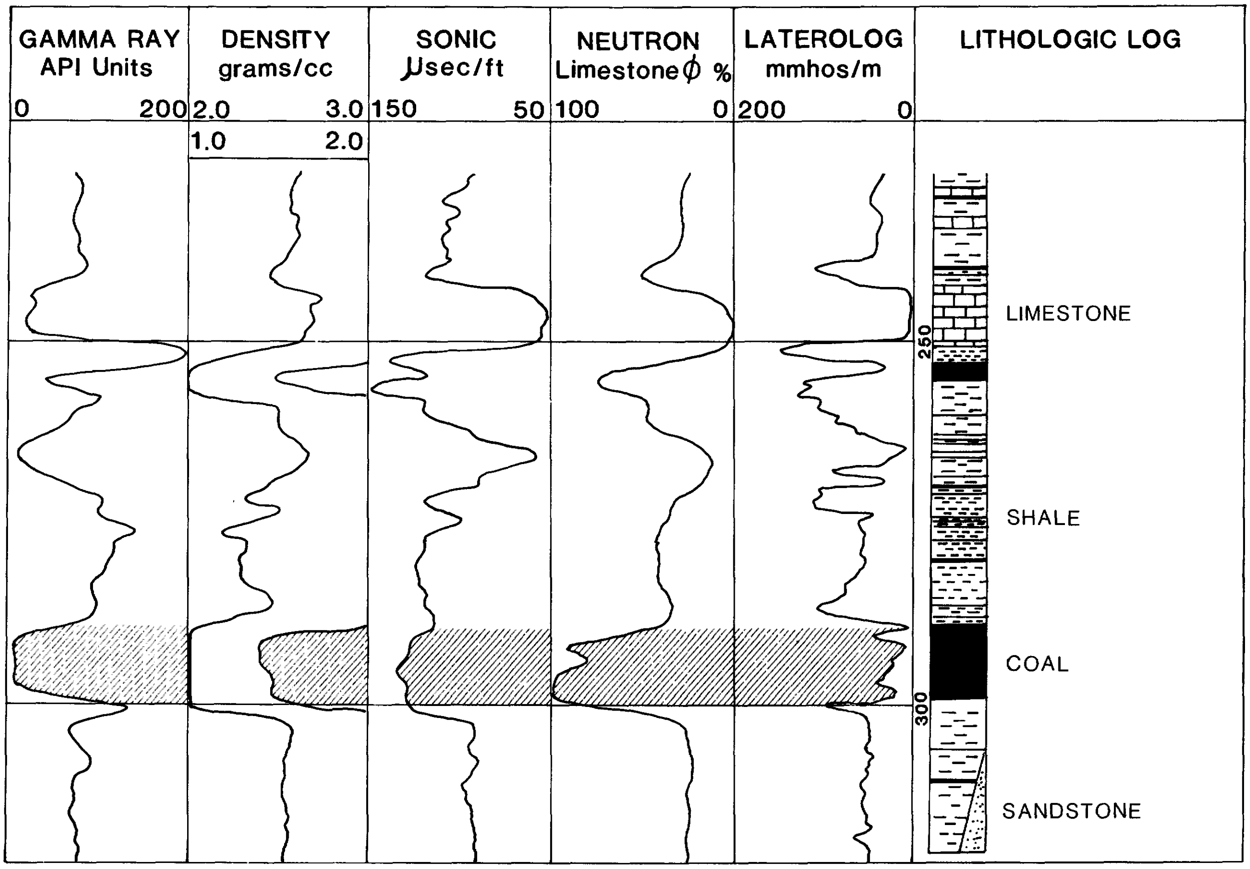

FIGURE 31.—Five geophysical logs of a coal exploration drill hole in the Illinois basin (Midcontinent region) showing response of bituminous coal and limestone of Pennsylvanian age on gamma ray, density, neutron, acoustic velocity (sonic), and lateral logs. Modified from Bond, Alger, and Schmidt (1971).

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