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A Study of the United States Coal Resources

John C. Ferm
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U.S. Department of Energy
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ABSTRACT

The objectives of this study were (1) the identification of geologically significant coal resources for the United States, including Alaska and (2) the preparation of statistically controlled tonnage estimates for each resource type. Particular emphasis was placed on the identification and description of coals in terms of seam thickness, inclination, depth of cover, discontinuities caused by faulting and igneous intrusion, and occurrence as isolated or multiseam deposits -- attributes which are germane to resource types selected for federally sponsored research on advanced mining systems.

The national resource was organized into six major coal provinces: the Appalachian Plateau, the the Interior Basins, the Gulf Coastal Plain, the Rocky Mountain Basins, the High Plains, and North Alaska. Each basin within a province was blocked into subareas of homogeneous coal thickness. Total coal tonnage for a subarea was estimated from an analysis of the cumulative coal thickness derived from borehole or surface section records and subsequently categorized in terms of seam thickness, dip, overburden, multiseam proportions, coal quality, and tonnage impacted by severe faulting and igneous intrusions. Confidence intervals were calculated for both subarea and basin tonnage estimates.

Results indicate an aggregate resource in place of 11.6 trillion tons, of which North Alaska accounts for 3.5 trillion tons of subbituminous and bituminous coal; the Rocky Mountains, 2.2 trillion tons of bituminous and subbituminous deposits; and the Gulf Coast, 3.8 trillion tons of lignites. The Appalachian Plateau and Interior Basins are estimated to contain slightly less than 1 trillion tons each of bituminous coal, and the High Plains, slightly more than 0.5 trillion tons of lignite. The Appalachian Plateau and Interior Basins are estimated to contain slightly less than 1 trillion tons each, and the High Plains Province is estimated to contain a bit more than 0.5 trillion tons. About 56% of the aggregate resource lies below 2000 ft, and approximately 80% occurs in seams 15 ft - 28 in. thick. Coals which are steeply dipping, faulted, or intruded account for 124 million tons, or about 1% of the aggregate resource, with much of this coal lying below 2000 ft. About 315 billion tons of coal occur in beds over 15 ft thick and lying under less than 2000 ft of cover, with 82% of the total contained in seams of 15 - 50 ft. Of the coals lying under less than 2000 ft of cover, about 56% (2.8 trillion tons) occurs in deposits 15 ft - 42 in. thick, 18% (0.9 trillion tons) in seams of 42 - 28 in., and 19% (1 trillion tons) in beds of 28 - 14 in. Multiple seams, in which the removal of one seam may adversely impact subsequent recovery of adjacent coals, account for about 66% of the flat-lying coals above 2000 ft and 15 ft - 28 in. thick.

The implications of these results for research on advanced mining systems are discussed at length in the text.

FOREWORD

This report describing geologically significant United States coal resources is one of a series of documents produced by a program to define, develop, and demonstrate advanced underground mining systems for the resources remaining beyond the year 2000. Earlier reports established system performance goals and conceptual design requirements. The program is funded by the Division of Coal Mining, the United States Department of Energy via an interagency agreement with the National Aeronautics and Space Administration (DOE Contract No. DE-AI01-76ET12548; NASA Task Order RD 152, Amendment 90). William B. Schmidt was the project officer for the Department of Energy.

The geological analysis contained in this report documents the results of a study conducted for the Jet Propulsion Laboratory by the University of Kentucky Research Foundation, Lexington. Prof. John C. Ferm of the Geology Department, the University of Kentucky, was the principal investigator. A companion report by Hoag, et al. (1982) assesses the commercial significance of the various resource types and recommends targets appropriate for research and development of advanced mining systems.

ACKNOWLEDGMENTS

The preparation of this report involved the joint efforts of the Geology Department, the University of Kentucky, and the Jet Propulsion Laboratory (JPL), with significant contributions made by the staff of each institution. Professor John C. Ferm, the principal investigator, formulated the research strategy and participated in all phases of the effort. Paul Muthig was responsible for day-to-day direction of the geological effort and, in addition, conducted the analysis of the Rocky Mountain Province, the High Plains Lignites, the Gulf Coast Lignites, and the Interior Province. Northern Appalachia was analyzed by Harry Mathis, Central Appalachia by John Ferm, and Southern Appalachia by Gerald Weisenfluh. Paul Jaehnig was responsible for the North Alaska coals, and Vanessa Santos and Donald Neeley contributed to the analysis of the Interior Province. Judy Cass, Michael Graham, Christopher Powell and Karen Weisenfluh drafted maps and cross sections, and performed the planimetry necessary to determine the map area of each significant coal body.

Jack Harris was responsible for coordinating the efforts of the geology team at the University of Kentucky with a companion assessment of the commercial importance of selected resource types, performed at JPL. In addition, Jack Harris determined the historical production from each coal province, which was subsequently used by the geology team to estimate remaining tonnage. Milton Lavin conducted the analysis of multiseams, with important contributions from Jack Harris, Henry Stone, Dean Westerfield, and Timothy Tutt -- all of JPL. Dean Westerfield was responsible for the computer analysis of the logs which produced tonnage estimates for the various multiseam resource types, and Donald Ebbeler developed the formula used to compute the confidence interval for the tonnage in an aggregation of subareas.

The initial draft of the manuscript was assembled by John Ferm and Paul Muthig, and subsequently edited by Gerald Weisenfluh and Milton Lavin. Katherine Brubaker of the University of Kentucky typed the first series of drafts, and Joan Winkler of JPL typed the final manuscript.

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SECTION 1

INTRODUCTION

As the needs for energy in the United States grow and currently utilized resources diminish or increase in cost, coal appears to be a practical alternative energy source. During the first part of this century, coal was the primary source of energy in the U.S., but it was replaced by petroleum because the latter is readily extractable, easy to transport, and relatively clean to use. In addition, neither exploration nor extraction was capital intensive. Despite this attractiveness, the current problems of diminished or uncertain supply and increasingly high costs of petroleum focus attention on coal as a reasonable alternative or supplement.

The problems that led to the replacement of coal by petroleum, however, still remain. Extraction is difficult and, in some cases, very hazardous. Transportation as a solid material remains troublesome, and utilization presents serious environmental problems in some areas. It is probable that some of these difficulties could have been overcome or reduced in the past, but as petroleum supplanted coal, R&D budgets of a stagnating industry did not provide the necessary capital for technological upgrading. Hence, if coal is to be regarded as an energy alternative, substantial application of high technology will be required.

This report is directed toward the application of modern technology to the problems of extraction. Most of the basic problems of coal extraction have not changed substantially since the middle of the 19th century. Seams of coal commonly range in thickness from about 2 - 10 ft and are inclined from 1 - 90° from the horizontal. Some occur near the surface, whereas others are deeply buried. Some part of the thicker, better quality, near-surface coals have been mined or lost in mining, but the basic character of the contraints imposed by thickness, dip, and overburden remain.

Therefore, the first step toward development of advanced mining techniques requires assessment of coal resources from the point of view of those factors which are constraints in the extraction process. Many estimates of this kind have been made in the past, but for a number of reasons none is adequate for this purpose. Previous studies which examine the national resources in a comprehensive fashion were primarily concerned with "conventional coals" -- flat-lying seams of moderate thickness, under moderate cover (e.g. Averitt, 1975). Individual studies have been made of particular resource types (Skelly and Loy, 1980, for steeply dipping coals; Bise, 1978, for thick seams; Engineers International, 1980, for multiple seams; Pimental et al. 1979, for thin coals). However, proceeding from different premises, these studies used quite different methods, some of which are difficult to assess from the information available in published reports. Moreover, the data utilized in previous resource studies are uneven in quality, some estimates being based primarily on outcrop measurements, other estimates using logs and cores extensively. Finally, the degree of precision of previous studies is practically impossible to ascertain, there being little or no meaningful attempt to quantify the accuracy of measurement.

In consequence, the objective of the present study is to prepare a coal resource estimate for the United States (including Alaska), using a uniform description of thickness, overburden, structure, quality, and other factors that affect mining -- with particular emphasis on thin coals, thick coals, multiple seams, deep seams, and steeply inclined deposits. These data will be used to indicate general geographic areas and seam characteristics that would benefit most from the application of advanced technology to energy utilization, in general, and to extraction technology, in particular.

The study was undertaken in two phases. The objective of Phase I was to divide the coal-bearing areas of the United States into provinces which have common geologic and geographic characteristics, and to determine which of these provinces have the greatest coal resource potential. The objective of Phase II was to produce tonnage estimates for each of these selected provinces in a manner that identifies combinations of seam attributes which constitute prime targets for the development of advanced mining systems.

SECTION 2

GENERAL DESCRIPTION OF U.S. COAL PROVINCES AND PRELIMINARY RESOURCE ESTIMATES

2.1 OBJECTIVES AND APPROACH

The objectives of Phase I were (1) definition of coal-bearing provinces of the United States and (2) preparation of preliminary estimates for each province with the view of selecting those provinces most suitable for study in Phase II. The location of coal-bearing areas of the United States has long been known, and many have been the subject of detailed geologic investigations. In this study, the geology and coal characteristics of each of these areas were reviewed, and the areas were grouped into provinces based on similarity of geologic age and lithologic arrangement of the coal-bearing strata, structural attitude of coal-bearing rocks, and general coal characteristics. Each of these provinces was then examined from the view of the potential available tonnage. Preliminary tonnage estimates were based on two sources of data: (1) prior estimates (usually by state), adjusted to the coal provinces defined in this report; and (2) independent estimates derived from reported coal seam thicknesses and the areal distribution of seams reported for each province. The estimates derived from these two data sources were compared, and the provinces were then ranked on the basis of the probable total tonnage in place. This ranking was used to select the provinces to be studied in Phase II.

2.2 DESCRIPTION OF U.S. COAL PROVINCES

From east to west, the major coal provinces of the United States are (1) the Atlantic Block Fault Province, (2) the Carboniferous Fold Basins, (3) the Appalachian Plateau Province, (4) the Carboniferous Interior Basin Province, (5) the Gulf Coast Lignite Province, (6) the High Plains Lignite Province, (7) the Rocky Mountain Province, including Alaska north of the Brooks Range, and (8) the Pacific Block Fault Province, including Alaska south of the Brooks Range (see Figure 1). Characteristics of each of these provinces are described below.

2.2.1 Atlantic Block Fault Province

East of the Appalachian Mountains is a broad area of highly deformed rocks which include downfaulted blocks of sedimentary rocks of Triassic and Jurassic Age. In the eastern part of this area, these older deformed rocks and the block faulted basins are buried beneath younger sediments of the Atlantic Coastal Plain. West of the Coastal Plain and in New England these block fault basins are at the surface, and some contain mineable coal (see Figure 1). Several of the seams in Virginia and North Carolina were mined in the 19th century, but these operations (which were made difficult by steep inclination of the beds, igneous intrusions, and poor coal quality) were abandoned with the opening of the mines in the nearby Appalachian Mountain Region.

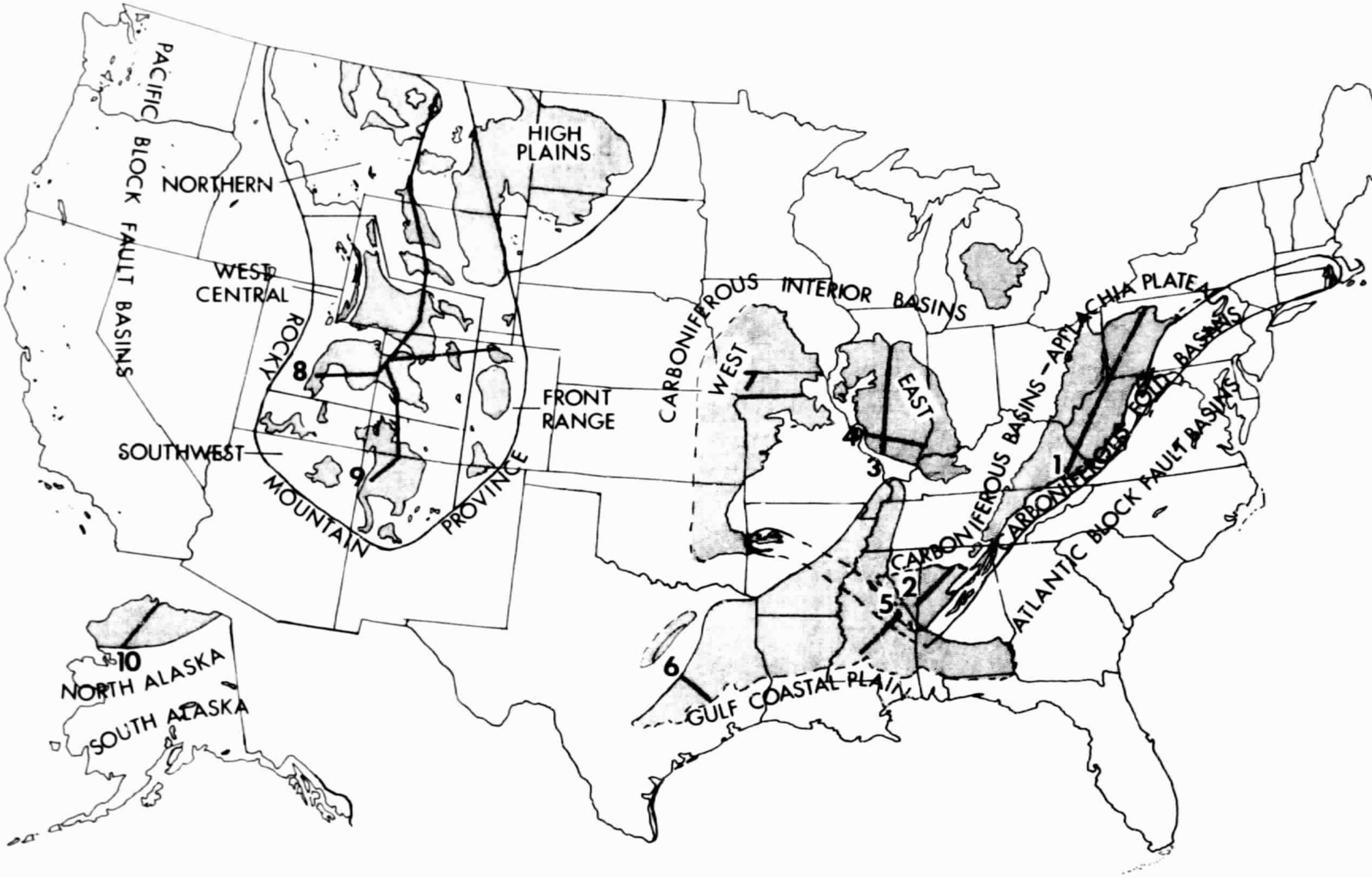

Figure 1. Location of U.S. Coal Provinces and Coal Basins Within Provinces (Also shown are locations of vertical cross sections referred to elsewhere in the text. Map is adapted from the 1980 Keystone Coal Industry Manual.)

2.2.2 Carboniferous Fold Basin Province

One of the primary reasons for the abandonment of mining in the Atlantic Block Fault Province was the opening of anthracite mines in eastern Pennsylvania. In this area, coal-bearing rocks of Carboniferous Age occur as a series of linear, canoe-shaped basins with steeply dipping coal seams on their flanks. Smaller basins of similar type are found in Rhode Island and Massachusetts, southwestern Virginia, central Alabama, west central Arkansas, and adjoining portions of Oklahoma (see Figure 1). In all of these areas, the coal seams occur on the steeply dipping flanks of synclinal basins and, in some cases, are displaced by faults.

The rank of these coals varies considerably. In New England, many of the coals are meta-anthracite and graphite; in Pennsylvania, the rank is mainly anthracite with some semi-anthracite; in southwestern Virginia, the coal is semi-anthracite and low-volatile bituminous; in Alabama, the rank is high-volatile bituminous; in Arkansas and Oklahoma, the coal ranges from low- to high-volatile bituminous.

In each of these localities, the peak of mining activity occurred in the late 19th and early 20th centuries; however, high mining costs associated with steeply dipping seams, lack of markets for high rank coals, and diminished reserves of coal led to decreased activity in these areas. Much of the current production is derived from surface mining, which has few of the problems of working underground.

2.2.3 Carboniferous Basins of the Appalachian Plateau Province

Coal basins of the Appalachian Plateau Province extend from western Pennsylvania on the north to northern Alabama on the south (see Figure 1). All coals are of Carboniferous Age. Throughout most of the area, the coal seams dip very gently, but in some places along the eastern margin of the province, dips exceed 15°. Faulting is minor compared to the adjacent fold basins, and igneous intrusion is very rare. Most of the coal is high- to medium-volatile bituminous, but in southern West Virginia and parts of western Pennsylvania and Maryland, some of the coal is low-volatile bituminous. Except in eastern Ohio and a portion of western Pennsylvania, the sulfur content is moderate to low, being higher than most Gulf Coast and Rocky Mountain coals, but lower than those of the Interior Province. Relatively little of the Appalachian coal is deeply buried.

Although the Appalachian Plateau contains coal throughout its length from Pennsylvania to Alabama, it can readily be divided into four basins on the basis of geographic position and the character of the coal-bearing strata. The northernmost of these areas is the Dunkard Basin, which includes the youngest coal-bearing strata in the Appalachian Plateau. The Dunkard Basin, which slightly overlaps the Pocahontas Basin lying directly to the southwest, contains the youngest and most important coal-bearing rocks in the province. The coal-bearing rocks of the Pocahontas Basin are older than those of the Dunkard Basin. Directly adjoining the Pocahontas Basin on the southwest are the Cumberland Plateau Fields, which extend as a series of narrow northeast trending belts in southeast Tennessee and northeast Alabama.

Southwestward, the Cumberland Plateau merges into the Warrior Basin, the exposed portion of which is located in north central Alabama. Buried portions of this basin extend northwestward into Mississippi.

Intensive coal mining began in the late 19th century in the Appalachian Plateau, and the area continues to be one of the major coal producing provinces of the United States. Both surface and underground mining are extensively practiced.

2.2.4 Carboniferous Interior Basin Province

West of a broad arch of older rocks, which form the western flank of the Appalachian Plateau, are a series of coal basins which extend from Michigan on the north, through southwest Indiana, western Kentucky, Illinois, Iowa, Missouri, and into eastern Kansas, eastern Oklahoma and north central Texas (see Figure 1). All of the coals in these basins are Carboniferous in age and are characterized by gentle dips, low- to high-volatile bituminous rank, and relatively high sulfur content. Displacement faulting occurs in a few areas, but generally these faults are not so closely spaced to affect large mineable blocks of coal. Igneous intrusions in this province are very rare. One of the unique features of the northern portion of the Interior Province is the mantle of glacial deposits which extends across Michigan southward to southeastern Illinois and central Kansas. In some areas, this material is on the order of 200 ft thick.

The northernmost of the Interior coal fields is the Michigan Basin, which occupies the central portion of that state. Mining activity there has been very modest because most of the seams are thin and erratically distributed in comparison with those in the Appalachian region to the southeast, and the Eastern Interior Basin lying to the southwest.

The Eastern Interior Basin -- located in Illinois, southwestern Indiana, and western Kentucky -- is one of the most important coal producing areas of the United States. Dips are very gentle inward toward the center of the basin, and except for the southern part, displacement faulting is absent. Surface mining has been intense, but there are large underground mines as well.

West of the Eastern Interior Basin, across the gentle arch of the Ozark Dome is the Western Interior Basin which extends from Iowa on the north to Texas on the south, with a slight gap in south central Oklahoma. Throughout this region, coal-bearing strata dip gently westward, where they are covered by younger strata. In general, the seams are thinner in the Western Interior Basin than they are further to the east, and this diminution of coal thickness continues westward in the deep subsurface. Very modest topographic relief has favored extensive surface mining in this region.

2.2.5 Gulf Coastal Plain Lignite Province

Lying to the south of and overlapping the Western Interior Basin and southern portions of the Carboniferous Fold Basins are Cretaceous and Tertiary Age sediments which comprise the Gulf Coastal Plain. The portion of these sediments which is of Eocene Age occupies a wide belt extending from the Mexican Border to the Florida panhandle, and is known to contain substantial lignite deposits in Texas, Louisiana, Arkansas, Mississippi, and Alabama (see Figure 1). Little detailed information is available concerning these deposits because most energy development efforts in this region have concentrated on petroleum and natural gas. However, it can be assumed that the seams dip gently towards the Gulf, and that igneous intrusions would be of little importance in mining. This region is known to be crossed by normal faults, but the spacing between them is probably large and would not seriously disrupt seam continuity. Available data suggest that the heating value ranges from 4,000 - 7,500 Btu/lb, with some reports as high as 9,000. There has been virtually no mining in this province.

2.2.6 High Plains Lignite Province

Widely separated from the Gulf Coastal Plain, but having coals of similar rank and age, are the lignite fields of the Dakotas and Montana (see Figure 1). These lignite seams, which are of Tertiary (Paleocene) Age, occur in nearly flat-lying strata under relatively shallow cover. However, the low heating value of the material relative to nearby Rocky Mountain coals has, until recently, hindered their development. Mining in this province has been conducted almost entirely by surface methods.

2.2.7 Rocky Mountain Province

Lying to the west and south of the High Plains Lignite Province, and east of a line which extends southward from western Montana, through eastern Idaho and central Utah, then eastward through central New Mexico and Arizona, are the coal basins of the Rocky Mountain Province (see Figure 1). The seams in this area are late Cretaceous and early Tertiary Age and comprise the major coal fields of Arizona, New Mexico, Colorado, Utah, Wyoming, and Montana. Geologically equivalent basins are found in Alaska north of the Brooks Range.

Structurally, the Rocky Mountain area consists of belts of uplifted older rocks separating broad basins which contain the coal-bearing strata. In most of the latter areas, the dips are generally less than 25^{o}, but there are major exceptions on the margins of some basins, some of which are flanked by high-angle faults. In many basins, the major coal seams outcrop along the basin margins and dip beneath great thicknesses of younger, noncoal-bearing strata. Hence, in some areas, the coals are deeply buried. Coal seams in several basins are displaced by faulting, and some are intruded by igneous rocks.

Overall, the coal varies from high-volatile bituminous to subbituminous, but in general, many of the coals in the western part of the area are higher rank than those in the east. Sulfur is relatively low, generally 1% or less, and most of the coal is utilized in steam plants. Mining in the Rocky Mountain Basins began in the early part of the 20th century, mainly by underground methods. More recently, surface mining has been introduced and presently accounts for substantial production.

2.2.8 Pacific Block Fault Province

Bounded by the western and southern margins of the Rocky Mountain Province, the Pacific Coast, and the Mexican border, are a number of small isolated, block fault basins which are structurally similar to those of the Atlantic Block Fault Province but are of Tertiary Age. Similar basins occur south of the Brooks Range in Alaska. Most of the basins of the Pacific Province are small, but some in Washington and in southern Alaska are relatively large. Some coal has been mined in these basins primarily because of proximity to potential users; however, small total reserves, structural complexities, low heating value, and high ash have limited major development.

2.3 PRELIMINARY RESOURCE ESTIMATES AND SELECTION OF PROVINCES FOR MORE DETAILED PHASE II STUDY

Preliminary resource estimates for the eight coal provinces described above are given in Table 1, which compares remaining tonnages given by the 1980 Keystone Coal Industry Manual with the estimates prepared in Phase I of this study. These tonnages are also expressed as a percentage of the total estimated national resource. Examination of this table shows some divergence between the Keystone estimates and the preliminary estimates prepared for this study. However, the diverse character of the data and methods of estimation can easily account for many of the observed differences. Whichever data set is used, Table 1 indicates that slightly less than half of the total U.S. resources are found in the bituminous and subbituminous fields of the Rocky Mountain Province, and that the geologically comparable north slope area of Alaska may contain about 16% of the total tonnage. Ranking second in importance are the lignites of the High Plains and Gulf Coast provinces. In the latter case, there is a substantial divergence between the Keystone and Phase I estimates because the Keystone estimates were prepared before the lignites of the Gulf Coast were considered to have any commercial potential, and no comprehensive reserve estimates were made.* Third in rank are the bituminous fields of the Appalachian Plateau and the Interior Province, each containing about 10% of the U.S. total. The remainder of the resources are in the carboniferous fold basins and the block fault basins of the Pacific and Atlantic provinces and southern Alaska. Collectively, they comprise about 4% of the total tonnage.

Provinces selected for the Phase II study were coal-bearing areas north of the Brooks Range (designated North Alaska), the Rocky Mountain basins, the lignite fields of the High Plains and Gulf Coast, the Carboniferous Basins of the Appalachian Plateau and the Carboniferous Interior Basins. The Carboniferous Fold Basin Province, characterized by steeply dipping seams, is excluded because of small apparent tonnage. Atlantic and Pacific Block Fault Basins, together with their southern Alaskan extension, are excluded because of low resource potential, and because of the small extent and isolated character of these deposits. If it is desirable to estimate the resources of

*Currently, new reserve estimates for the Gulf Coast lignites are being prepared by the state geological surveys of Texas, Louisiana, Mississippi, and Alabama.

Table 1. Preliminary Resource Estimates for U.S. Coal Provinces (Billions of Tons. Data in the third and fourth columns are adapted from the 1980 Keystone Coal Industry Manual.)

Province	Preliminary Estimate Tonnage	Preliminary Estimate %	Keystone Estimate Tonnage	Keystone Estimate %
Atlantic Block Fault Basins	3	0.1	nil	nil
Carboniferous Fold Basins				
New England	nil	nil	nil	nil
Pennsylvania and Virginia	45	1.0	36	0.9
Alabama	16	0.4	31	0.8
Arkansas	18	0.4	44	1.1
Total	79	1.8	111	2.8
Carboniferous Basins of the Appalachian Plateau				
Pittsburgh	179	4.0	178	4.5
Pocahontas	166	3.7	166	4.2
Warrior	18	0.4	59	1.5
Total	363	8.1	403	10.2
Interior Carboniferous Basins				
Eastern	303	6.8	431	10.9
Western	128	2.9	114	2.9
Michigan	nil	nil	nil	nil
Total	431	9.7	545	13.8
Gulf Coast Lignites				
Eastern Portion	165	3.7	3	0.1
Western Portion	467	10.5	33	0.8
Total	632	14.2	36	0.9
High Plains Lignites	520	11.7	657	16.5
Rocky Mountain Basins	1612	36.1	1829	46.1
Pacific Block Fault Basins	17	0.4	63	1.6
Alaska				
North of Brooks Range	718	16.1	289	7.3
South of Brooks Range	83	1.9	34	0.8
Total	801	18.0	323	8.1
Grand Total for U.S.	4458	100.0	3967	100.0

these areas, each field must be analyzed separately because of the considerable variation in the attitude and disposition of the coal from one basin to another.

Finally, among those basins chosen for detailed study, some minor exclusions have been made. The Cumberland Plateau, the Michigan Basin, the Texas extension of the Interior Province, the North and South Park areas of Colorado, and the Blackfoot-Valier area of Montana were all excluded because of low apparent resource potential.

The remainder of the report is devoted to preparing resource estimates for the six major coal provinces selected above. Emphasis will be placed on estimated tonnages associated with those geological attributes which will strongly influence the working environment (mining conditions) of advanced underground extraction systems. The methodology used to prepare these estimates is described in Section 3, while the estimates themselves are presented in Sections 4 and 5.

SECTION 3

METHODOLOGY FOR MAKING DETAILED RESOURCE ESTIMATES

As indicated previously the methodology used to make detailed tonnage estimates must permit resources to be grouped into categories of mining conditions which have relevance to future mining systems. Moreover, because of the limited financial resources available for this study, the procedures used must permit rapid estimates which exhibit both a level of precision appropriate for R&D planning and a fairly uniform degree of accuracy. Finally, in order to make the degree of accuracy explicit, and thus, permit meaningful assessments of resource uncertainty both within and between provinces, the methodology should place the tonnage estimates under statistical control. The approach chosen to satisfy the above criteria applies the idea of stratified random sampling to homogeneous coal blocks, which are defined from gross basinal features inferred from the ancient depositional environment. Tonnage uncertainty is then characterized by computing confidence intervals which embody minimal assumptions about the statistical properties of the resource.

The following description of the methodology is organized into three parts. The first part characterizes those geological attributes addressed by this study because of their obvious impact on the structure of future mining systems. The second part describes the detailed procedures used to make tonnage estimates and construct confidence intervals. And the third part outlines how estimates of virgin resources were adjusted to account for historical production.

3.1 CONSTRAINTS ON MINING SYSTEMS

Factors which will influence the development of any novel mining system are similar to those that have shaped mining procedures in the past. These include the thickness of the coal seam, the angle at which the seam departs from the horizontal (here, called structural attitude), the amount of rock or rock material overlying the seam (overburden), the proximity to other coal seams (interburden), discontinuities caused by closely spaced faulting or igneous intrusions, the quality of the coal, and the amount of coal available for mining. The quantification of each attribute, together with its impact on mineability are described below.

3.1.1 Seam Thickness

In this report the thickness of a mineable seam is defined as the vertical distance between the top and bottom of a coal bed, including all noncoal material which, if the seam were to be mined, would make up no more than 50% by weight of the mined product. Because the density of most noncoal material within coal beds is very nearly twice the density of coal, the thickness of noncoal material in a seam should not exceed one-third of the entire seam thickness. If noncoal material makes up more than one-third of the thickness of a coal bed, and if adjacent layers of the bed can be grouped so as to make up two or more seams in which less than one-third of each seam is made up of noncoal material, the beds can be regarded as multiple seams. If such a grouping of layers yields only one seam, with one-third of its thickness comprised of noncoal material, the layers are designated an isolated seam. If no such grouping of adjacent layers yields a seam in which one-third or less of the thickness is composed of noncoal material, the seam is regarded as currently unmineable.

An additional constraint in defining mineability is seam thickness. Throughout this study a minimum seam thickness of 14 in. was observed.

In view of constraints both on impurities within a seam and on total seam thickness, the seam thickness categories used in this study were 14 - 28 in., 28 - 42 in., 42 in. - 15 ft, 15 - 50 ft, and greater than 50 ft. The lower limit of 14 in. approximates the thinnest seams that can now be mined, usually by surface methods. A seam height of 28 in. is the extreme lower limit currently observed in underground mining; however, 42 in. is regarded as a comfortable lower limit for contemporary underground equipment. A thickness of 15 ft is the approximate upper limit for present underground mining methods and equipment. Seam thicknesses on the order of 15 - 50 ft are not readily mined in the United States by underground methods; however, multiple slice longwalling of exceptionally thick coals is practiced in Europe.

3.1.2 Structural Attitude

Categories for angular departure of a coal seam from the horizontal are 0 - 15^o, 15 - 45^o, and more than 45^o. Fifteen degrees represents the approximate upper limit for room and pillar technology in the United States. Dips of 15 - 45^o characterize areas where combinations of conventional room and pillar mining, and stoping can be used. Dips greater than 45^o would clearly require some sort of stoping method.

3.1.3 Overburden

The overburden categories used in this study are 0 - 500 ft, 500 - 2000 ft, 2000 - 4000 ft, and greater than 4000 ft. Five hundred feet is the probable limit for any sort of surface mining, and and a depth of 2000 ft is the approximate current limit for most room and pillar mining in the United States. Four thousand feet represents a depth that is possibly within the range of present underground technology; however, depths greater than 4000 ft are beyond the limits of any established methods of coal mining.

3.1.4 Interburden

Interburden expresses the vertical proximity of seams to each other and is relevant to questions of multiple seam mining. In present underground practice, when two seams are in close proximity, the thinner or less continuous one is not mined, and thus, constitutes a neglected or unavailable resource. Similarly, in surface mines, thinner seams lying either closely above or below the thicker seam are frequently not removed. Hence, seam proximity, expressed by interburden thickness, comprises an important factor in the characterization of available resources, and a primary consideration in development of advanced mining systems.

3.1.5 Faulting and Igneous Intrusion

Major displacement faults and igneous intrusions occurring at spacings of less than one mile are considered as a major impediment to mining, and areas in which such conditions prevail are indicated as a proportion of the total area available for mining. It should be understood that in contemporary practice, mining proceeds to within a few feet of a single fault or intrusion, but multiple faults or intrusions within a small area can reduce mining potential substantially.

3.1.6 Quality

Coal quality in this report is expressed in terms of standard quality criteria -- heating value in units of Btu/lb, percent sulfur, and percent ash. Btu/lb is reported to the nearest 100, typically as a range, and percent sulfur and percent ash are expressed to the nearest 1.0%. If the coals from a region have been or are being coked, this fact is also noted.

3.1.7 Amount of Coal Available

Of all constraints relevant to the development of new mining systems, one of the most important is the amount of coal available. Hence, the basic resource measure used in this report is the tonnage available in each of the coal provinces. Subsequently, the aggregate tonnage is described in terms of seam thickness, structural attitude, overburden, interburden, seam disturbance by faulting or igneous intrusion, and coal quality. The unit of measure is 1 billion tons, which is judged to be at least three orders of magnitude smaller than the aggregate national resource. In current practice, single reserve blocks of 10 - 30 million tons are considered viable economic units and blocks of 100 million tons are viewed as substantial reserves. Thus, from the perspective of a mining property, 1 billion tons is an order of magnitude greater than a typical large reserve block.

3.2 ESTIMATION OF ORIGINAL RESOURCE TONNAGE

Estimates of total original resource tonnage for provinces are the product of three separate estimates: (1) the geographic coal-bearing portion of an area of the province; (2) the thickness of coal in these areas; and (3) a factor for transforming coal volume to weight.

$$\text{Tonnage} = (\text{Area}) \times (\text{Mean Thickness}) \times (\text{Tonnage Factor})$$

The following paragraphs discuss the procedures used to estimate each factor and describe how the uncertainty surrounding total coal thickness was handled. The remainder of Section 3.2 describes how total coal tonnage was allocated to categories of seam thickness, overburden, structural altitude, disturbance by faulting and igneous intrusion, and coal quality. Estimates of tonnage that is affected by interburden thickness sufficiently small such that mining one seam may interfere with mining another is a complex issue which is treated separately in Section 5.0, titled "Analysis of Multiseam Deposits." Section 3.3 outlines how historical production was determined and how these estimates were used to infer remaining resources.

3.2.1 Estimation of Geographic Area

The coal provinces utilized in this study consist of coal-bearing areas long established by the geologic mapping performed by state and Federal agencies.* These programs, which have been conducted over a period of at least 70 years, have resulted in the definition and mapping of the principal coal-bearing rock units in most of the contiguous United States. These rock units, which are roughly tabular or wedge-shaped, are generally underlain and overlain by noncoal-bearing rocks. In this report, the coal-bearing rock units are designated as coal formations.**

In most of the United States, coal formations have been mapped at the scales of 1/24,000, 1/62,000, or 1/125,000. Mapping at these scales locates the area occupied by the coal formations to within 1000 ft horizontally, and in most cases, within 500 ft. The map scale chosen for detailed tonnage estimation in this study was 1/500,000 because at this scale, mapping errors of 500 or even 1000 ft are not within the range of measurement. The scale of 1/500,000 has the additional advantage that one billion tons of coal, (the level of precision used throughout the study) corresponds to areas ranging upward from 2 sq in. on a 1/500,000 map (see Table 2). Areas of this size are measurable with a relatively high degree of precision by standard planimetric methods (within 0.2 square inches), and measurement errors are probably random. It is felt that the combination of precisely mapped coal formations, the selection of map scale, and the use of planimetry produce reasonably precise and unbiased estimates of coal-bearing areas.

3.2.2 Estimates of Total Coal Thickness

For each of the mapped areas of a coal formation, coal thickness within the formation must be estimated. Because individual seams are known to show considerable variation from one location to another, and because the rate of variation is known to differ between seams, there is no known method of producing controlled tonnage estimates of individual seams within the limits of time and resources allocated to this study. Hence, a classical statistical device was employed, in which the total thickness of coal within a formation at any single location was regarded as a basic sampling unit, and the mean coal thickness for all sampling units was considered to be the best estimate of total coal thickness for a given area. A total of 932 sampling units were selected, mostly from public sources.

Choice of sampling units to represent total coal thickness for the coal-bearing formations presented some problems. An attempt was made to select about twenty records of boreholes or carefully measured surface sections for each area. A larger number of samples would have been desirable, but the time needed to obtain logs and prepare them for analysis dictated that such limits be set.

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*Major exceptions are areas in North Alaska and the Gulf Coast Lignite Province where the coal-bearing formations are deeply buried and have not been carefully delineated.

**Strictly applied, stratigraphic terminology requires specification of group, formation, or member for coal-bearing rock units. The term "formation", as used here, implies a body of rock containing coal without regard to its stratigraphic rank.

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Table 2. Size of Areas Representing One Billion Tons at a Map Scale of 1/5000,0000 for Anthracite Coal, Bituminous Coal, Subbituminous Coal, and Lignite

Map Area ~ sq in. / Seam Height	ANTHRACITE			BITUMINOUS			SUBBITUMINOUS			LIGNITE		
	44"	9'	18'	44"	9'	18'	44"	9'	18'	44"	9'	18'
0.5	0.1	0.4	0.8	0.1	0.3	0.6	0.1	0.3	0.6	0.1	0.3	0.6
1	0.3	0.7	1.4	0.3	0.6	1.2	0.3	0.6	1.2	0.2	0.6	1.2
2	0.6	1.5	3.0	0.5	1.3	2.6	0.5	1.3	2.6	0.5	1.3	2.6
3	0.9	2.2	4.4	0.8	2.0	4.0	0.8	1.9	3.8	0.8	1.9	3.8
4	1.2	2.9	5.8	1.1	2.6	5.2	1.1	2.6	5.2	1.0	2.6	5.2
5	1.5	3.7	7.4	1.3	3.3	6.6	1.3	3.3	6.6	1.3	3.2	6.4

The nonuniform character of the data caused considerable problems. Consistently, data for deeply buried coal formations proved to be of poor quality and/or very sparse. Although most cutting records of deep holes were of little value, some that were carefully logged were considered adequate. Generally, geophysical logs were not considered to be useful because the scale of the logging did not adequately record coal thickness. In areas of shallow cover (down to about 2000 ft), the major problem was one of selection. As a rule, where coal is (or is believed to be) present, data are generally abundant; but where the inverse is true, data are scarce. To mitigate this effect, an attempt was made to space the data points on the order of 20 mi apart because many seams whose thickness distribution is known do not appear to maintain constant thickness over such distances. The problems of such widely spaced sampling units are obvious: events recorded in one particular borehole may be used to categorize a large area in which they are of minor importance. Hopefully, such errors are random and will cancel out in a large number of measurements.

3.2.3 Treatment of Uncertainty in Estimates of Coal Thickness

The random error involved in estimates of coal thickness for a given area involves the following basic relationship:

$$S_{\bar{x}} = S/(n-1)$$

where S: the sample variance
n: the number of sample units, and
$S_{\bar{x}}$: the standard error in estimating the mean.

S_x may be used in conjunction with the t-distribution to construct confidence limits for coal thickness. These upper and lower bounds on thickness can then be applied to area measurements in order to obtain the corresponding confidence interval for the tonnage of coal in any given coal-bearing region. A similar procedure may be employed to compute confidence limits for the aggregation of areas which make up a basin (see Appendix B).

Methods for reduction of error in these estimates are suggested by the form of the above expression. The number of samples (n) can be increased, or the sample variance (S) reduced. In the present study, the sample variance was reduced by creating geographic blocks which, for various geologic reasons, could be designated as homogeneous with respect to total coal thickness. In some cases, such blocks represented outcrop versus subcrop areas. In the former, only an eroded remnant of the coal-bearing formation is present, and hence, the total coal thickness is reduced. In the latter, the coal-bearing unit is completely buried, and the original coal thickness is preserved. In other cases, blocks are a function of rock facies which are formed when the coals and coal-bearing sediments were being deposited. From a study of modern peat deposits, Ferm and Horne (1979) have shown that thick peat accumulation is restricted to certain geographic areas, for example, coastal zones. Recognition of these ancient peat-forming environments permitted blocking of coal basins into areas in which the coal is expected to be uniformly thick or thin. In a few cases, areas were blocked simply because available data were too sparse to make credible estimates, and the tonnage estimates which are reported must be regarded as uncontrolled.

Thus, by evaluating gross lithologic characteristics, one may outline general areas of potentially thick or thin coal, thereby blocking a formation into subareas, each of which is treated as an independent stratum in the selection of representative boreholes or logs.

3.2.4 Tonnage Factor as a Function of Coal Rank

The tonnage factor, which transforms coal volume into tons, is a function of coal rank. Four coal-rank categories were recognized in this study, leading to the following values for the tonnage factor:

Anthracite:	1,280,000 tons/sq mi-ft
Bituminous coal:	1,152,000 tons/sq mi-ft
Subbituminous coal:	1,132,800 tons/sq mi-ft
Lignite factor:	1,120,000 tons/sq mi-ft

The very small range of values for different ranks of coal suggests that errors due to the misestimation of rank are neglible.

3.2.5 Distribution of Tonnage by Seam Thickness

Seam thickness measurements were derived from the same data that were used to obtain the total tonnage estimates. For any given area, a proportion of total coal thickness was allocated to seam thickness categories on the basis of seam footages falling within each category, and this proportion was applied to the total tonnage estimated for the area. Confidence intervals for the tonnage in each thickness category were not calculated.

3.2.6 Distribution of Tonnage by Structural Attitude

Tonnage allocation by structural attitude was established by assignment of structural attitude to map areas. In most cases, structure was determined from published structure contour maps. However, as the dips increase beyond 15°, dip and strike symbols on large-scale geologic maps provide this information. Where different dip categories were found in a given field, the field was blocked into regions of constant dip, and the area of each region was determined by planimetry. The precision of these data are not known, especially where coal formations are deeply buried, and little quantitative information is available.

3.2.7 Distribution of Tonnage by Overburden

As in the case of structural attitude, tonnage breakdowns by depth of cover were based on map areas that were believed to have the specified overburden characteristics. The latter were derived from the difference between structural attitudes expressed on the structure contour maps, and estimates of the elevation of the overlying topography. Areas of differing depths of burial were blocked in the same manner as in the characterization of structural attitude. Because these areas are based on poorly controlled subsurface data and on generalized surface elevations, the precision of allocation of tonnage to overburden catgories is not known.

3.2.8 Measurement of Interburden and the Allocation of Tonnage to Multiseams

Examination of the proximity of seams to each other resulted in the identification of three distinct resource types: (1) currently mineable seams which are not proximal to each other (isolated seams), (2) seams which are mineable individually, but are sufficiently close to one another that exploration of one seam will interfere with subsequent recovery of the other (multiple seams), and (3) seams containing rock partings amounting to more than 50% by weight of the mined product (not presently regarded as mineable seams). Computational details are described in Section 5.

3.2.9 Determination of Tonnage Impacted by Faulting or Igneous Intrusion

Basic data indicating the degree to which faults and igneous intrusions displace or interrupt the coal seams is the least certain of all forms of categorization. Displacements on the order of 15 - 20 ft, or igneous bodies of the same dimension create very serious mining problems. However, features of this kind can rarely be identified in the course of conventional geologic mapping and, hence, do not appear on any but the most detailed geologic maps. Consequently, discontinuities of this type were treated in the following fashion. Areas where faults or igneous intrusions were shown within 1/2 mile of each other on a geologic map were indicated as faulted or intruded, and the proportion of this area was visually estimated. It is to be expected that, except in the case of the most serious displacements or intrusions, the reliability of these data will be low.

A further constraint is placed on these estimates by the amount of detail expressed on geologic maps. Geologic mapping in regions of coal occurrence is, in most cases, concentrated on the coal-bearing formations, and the formations above and below receive less attention. Moreover, if such features are shown in the adjoining rock units, it is uncertain whether they can be projected into deeply buried coal-bearing formations. As a consequence, areas of faulting and igneous intrusion were not estimated for areas more deeply buried than 2000 ft.

3.2.10 Quantification of Coal Quality

A number of analyses -- including standard measurements of Btu/lb, percent sulfur, and percent ash for specified seams -- are generally included in geologic reports. Values of Btu/lb and percent sulfur for any given area are generally tightly clustered, and the values reported in this study represents the commonly observed range, based on at least 100 analyses. Extremes in observed values are not reported because they represent very uncommon occurrences. Ash values given in this study are derived from the same sources as data on percent sulfur and Btu/lb. Since different sampling methods can provide wide variation in ash measurements, the precision of this information is not known. Coking potential is not accurately predictable from standard analytical data, and hence, in this study data on coking quality were limited to estimates of coking capacity, based upon reported coke production.

3.3 ESTIMATION OF REMAINING RESOURCES

An important consideration in developing resource estimates is the adjustment of original tonnage in place to account for coal already mined, or unrecoverable coal remaining in mined and abandoned areas. The historical data used to make this adjustment were reported only by geographic region, usually by county. This is not a particular problem for estimation of remaining resources for an entire province, because provincial boundaries coincide to a reasonable degree with county boundaries. The principal difficulty lies in determining the amounts of coal remaining in abandoned mining areas, and allocating these tonnages across categories of seam thickness, overburden, etc. This must be done by subjective judgment on a province by province basis inasmuch as the mining techniques differ substantially from area to area, and over the space of time that coal mining has been practiced. The ground rules for making these judgments are described for each province in appropriate sections of this report, but the general nature of these problems is described below.

One of the major problems in estimating remaining tonnage is the determination of the recovery fraction achieved in the past. In areas where mining began at an early period, where mines were small but numerous, and where coal had a low market value, recovery from any single block probably did not exceed 20%. In areas that have been mined in the past twenty years and where the properties were sizeable, recovery rates, although higher, are subject to wide variation. For example, in a large, well-operated mine in which retreat mining cannot be employed (pillars and barriers are left intact), recovery probably does not exceed 45%. In contrast, recovery can reach about 70% in well-operated mines which can practice retreat mining or utilize longwall methods. Finally, well managed surface mines can achieve nearly 100% recovery in areas of moderate relief, but such recovery rates typically apply only in very small areas.

Assignment of recovery rates to thickness categories presented additional problems. In the eastern part of the United States, major underground mining has been concentrated in seams exceeding 42 in. Today, however, coals of very high quality can be successfully mined in seams as thin as 28 in. In contrast, large western mines operate in seams 6 - 10 ft thick, and will usually discontinue operations when the seam thins to 4 - 5 ft. In surface mining, thickness is not critical because the controlling factor is simply the ratio of total coal to overburden removed. However, in most cases, 28 in. may be considered a practical lower limit in the eastern fields (unless a thicker seam lies in close proximity above or below), and 4 ft may be considered an average lower limit for subbituminous mines in the western fields.

The assignment of mined or lost-in-mining tonnages to overburden categories is not quite so complex since very little coal in the United States is mined at depths greater than 2000 ft. A major difficulty arises, however, in assigning tonnages mined or lost in mining to the 0 - 500 ft overburden category because many underground mines with poor recovery have been developed at that depth, whereas, many surface mines with almost total recovery operate with overburden of about 100 - 150 ft. Hence, unless all or nearly all of the tonnage in a particular area is known to have been derived by surface methods, the same average recovery figure is used throughout the interval of 0 - 2000 ft. Finally, no allocation of tonnage mined or lost-in-mining has been made in areas of steeply inclined, faulted, or intruded beds because such areas are mined only under special circumstances, and the tonnages relative to other seams are small.

SECTION 4

RESOURCES OF MAJOR U.S. COAL PROVINCES

As a result of the preliminary estimates made in Phase I, the coal provinces of the U.S. which are believed to have the greatest resource potential are the Carboniferous Appalachian Plateau Province, the Carboniferous Interior Province, the Gulf Coast Lignite Province, the High Plains Lignite Province, the Rocky Mountain Province, and the North Alaska Province (Alaska north of the Brooks Range). Each of these provinces is described below in terms of geographic extent, salient geological features, coal quality, and previous mining activity. Summary resource tonnage is tabulated for each province and for important subareas within a province. In Section 5.0, tonnage estimates are prepared for a resource subset called multiseams. Multiseams can be divided into two subresources: (1) coals which are so intimately interbedded with rock that the coal and rock are mined as one unit; and (2) coals which are thick enough to be mined separately, but close enough vertically such that removing one will interfere with recovering another. Detailed data about the distribution of tonnage by thickness, overburden, dip, etc., within a subarea are tabulated in Appendix A, in the order which provinces are described in the text.

4.1 CARBONIFEROUS BASINS OF THE APPALACHIAN PLATEAU

4.1.1 Extent

The coal fields of the Appalachian Plateau extend southward from western Pennsylvania and eastern Ohio through western Maryland, West Virginia, eastern Kentucky, southwestern Virginia, and into northeastern Tennessee (see Figure 1). Southwestward from northeast Tennessee, coal-bearing rocks occur in the Cumberland Plateau of Tennessee, northwest Georgia, and northern Alabama. The coal beds of these latter three areas are thin and erratic, and their resources are not considered here. Adjoining the Cumberland Plateau to the southwest is the Warrior Basin of Alabama, the southernmost of the Appalachian coal basins. Much of this basin is buried beneath younger rocks of the Gulf Coastal Plain, but the basin is known to extend into northern Mississippi and to emerge from beneath the Coastal Plain sediments in the Arkoma Basin of Arkansas and Oklahoma.

4.1.2 Geology

Geologic structure in the Appalachian Plateau Province is relatively simple, and except in very small areas on the eastern and southern margins of the province, dips rarely exceed 15°. Displacement faulting is generally very minor and of small scale, and igneous intrusions are even more rare.

The pattern of distribution of mineable seams varies considerably throughout the Appalachian Plateau. The major coal producing basins from north to south are the Dunkard Basin, the Pocahontas Basin and the Warrior Basin (see Figure 1). The occurrence of the major coal-bearing formations in the two northern basins -- Dunkard and Pocahontas -- is illustrated in Figure 2. The sandstones in the lower part of the cross section are believed to be ancient barrier island deposits, with the coal-bearing rocks occurring on the landward (southward) sides.

As indicated in Figure 2, the rocks containing thick seams overlap one another, with the northernmost being the younger. In the Dunkard Basin there are two coal-bearing formations -- the Allegheny and the Monongahela. Rocks of the Allegheny formation display a transition from barrier facies on the extreme north, through a major coal-bearing deltaic facies in the middle portion, to fluvial deposits with little coal in the south. The Monongahela formation (including the famous Pittsburgh coal seam) is younger than the Allegheny, and grades from a major coal-bearing province in the north, to fluvial deposits with little coal in the south.

Lying beneath and southward of these Dunkard Basin deposits are the coal-bearing rocks of the Pocahontas Basin. The coal-bearing formations in this area include the Pocahontas Formation of Virginia and southern West Virginia, and the Lee and New River Formations of Virginia, West Virginia, and eastern Kentucky. The oldest formations, the Pocahontas and New River-Lee, contain important coals along the southern margin of the basin. Within a short distance northward, however, these coal-bearing strata grade into a sandstone dominated facies with no mineable coals.

Overlying and slightly offset from the Pocahontas and New River-Lee is the second major coal-bearing facies in the Pocahontas Basin -- the Kanawha (West Virginia) and Breathitt (Kentucky) formations. This group of rocks is thick along its southern outcrop, and contains many mineable coals before grading northward into barrier sandstone deposits. These barrier deposits (Pottsville) underlie the coal-bearing portions of the Allegheny formation in the Dunkard Basin. This northward shingled effect of the coal-bearing facies in the Pocahontas and Dunkard Basins, combined with the overall structure of the basin, produces an area in which most of the mineable coals occur within 1000 ft of the surface, and virtually all are within 2000 ft.

The distribution of coal-bearing strata in the Warrior Basin is less well known than those further north because much of the Warrior Basin lies buried beneath younger sediments of the Gulf Coastal Plain. The cross section on Figure 3 shows the major distribution of the coals in the outcropping and near-subsurface portion of the basin, as well as what can be inferred from oil and gas test wells in the deeply buried portion of this area. Examination of this section shows that the coal seams are clustered into groups (called "coal groups" by the Alabama Geological Survey) separated by rock bodies 200 - 500 ft thick. As one proceeds from the outcrop into the subcrop, these divisions are not so obvious, but the quality of the data is not high and may be misleading.

The Warrior Basin is limited on the southwest by a northwest trending belt of upturned and folded rocks, which has been traced eastward from the Ouachita Mountains into central Mississippi (see Figure 1). The northwest extension of the coal-bearing portion of the Warrior Basin is less well established. Where the outcropping, coal-bearing strata of the Warrior Basin

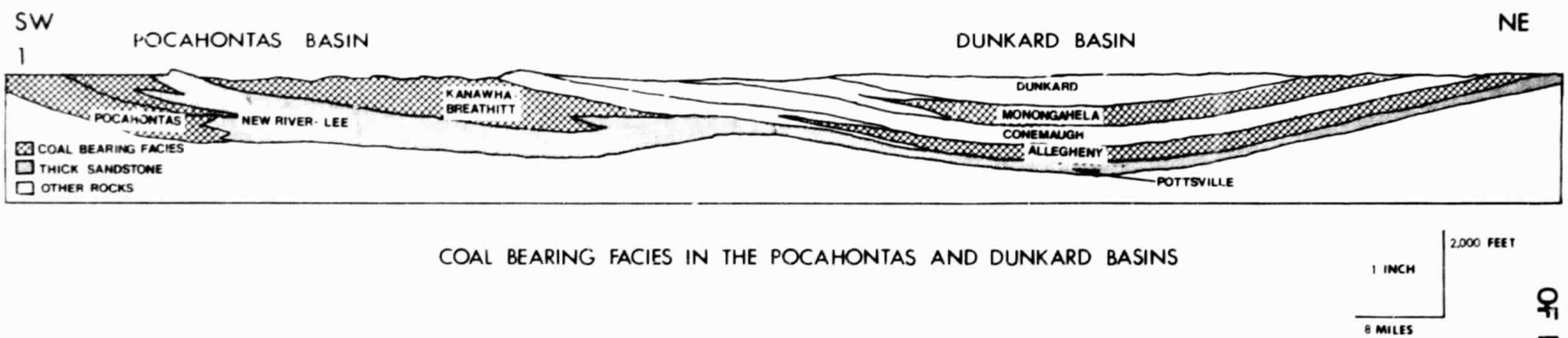

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Figure 2. Cross Section of the Dunkard and Pocahontas Basins in the Appalachian Plateau Province (See Figure 1 for location of this cross section.)

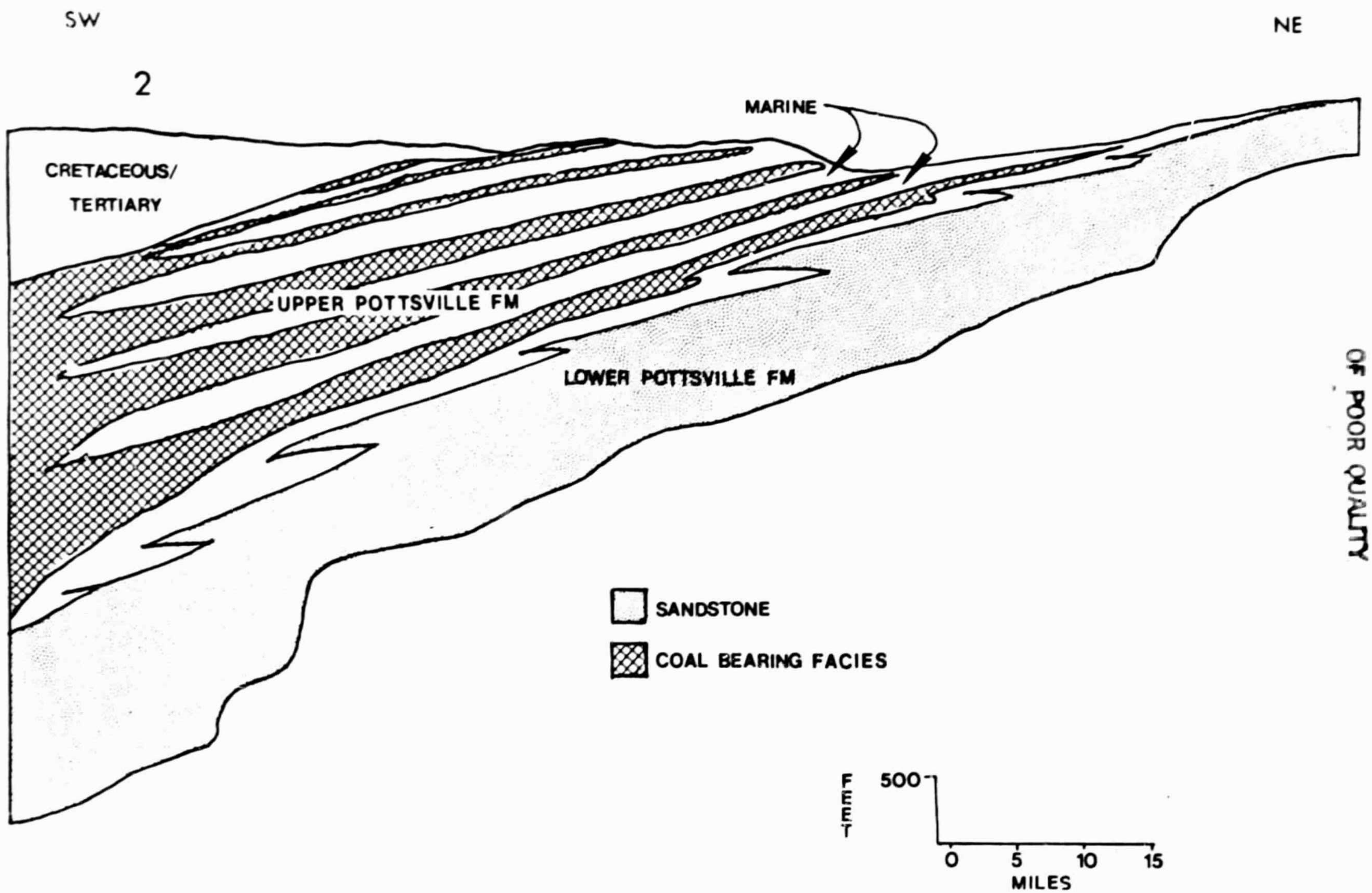

Figure 3. Cross Section of the Warrior Basin in the Appalachian Plateau Province (See Figure 1 for location of this cross section.)

emerge from beneath the Coastal Plain in Arkansas, the coal seams are not of significant thickness. Therefore, somewhere between northeastern Mississippi and central Arkansas the seams become too thin to be mineable. Because of very sparse data, it seemed prudent to extend the coals of the Warrior Basin only a short distance into the northwestern subsurface.

4.1.3 Quality

The quality of the coal in the Appalachian Plateau Province shows considerable variation although the lowest rank is high-volatile bituminous. Energy content in most of the area ranges from about 11,000 - 13,000 Btu/lb. In southern West Virginia and adjoining portions of Virginia, some of the coal is medium- to low-volatile bituminous. Sulfur values are highest in the northwestern parts of the Dunkard Basin in eastern Ohio and northwestern Pennsylvania. In this region, sulfur ranges from 1 - 4% and is commonly about 2 - 3%. Elsewhere in the Dunkard and the Pocahontas Basins, sulfur commonly ranges from 0.5 - 1%. The reported ash content of the mined coal varies widely, depending primarily on the number of partings and the cleaning processes used. Reported ash of the coal itself ranges from 2 - 20%. Some coking quality coals occur on the eastern side of the Appalachian Plateau in Pennsylvania, southern West Virginia, Virginia, southeastern Kentucky, and the eastern side of the Warrior Basin.

4.1.4 Mining

The coal fields of the Appalachian Plateau were the first exploited in the United States, with mining beginning in earnest in the late 19th century. Initially, all the coal was mined by underground methods, but since the late 1940's, surface mining has gained considerable importance. A substantial volume of tonnage originates from large mining operations, often owned by steel companies. However, in times of increased coal demand, the near-surface character of the seams leads to a multitude of small producers who, in the aggregate, can mine significant tonnage. Although most of the underground production comes from mines using room and pillar mining methods and continuous mining equipment, there are an increasing number of longwall installations. In many small operations, conventional mining methods (drill and blast) are employed.

4.1.5 Coal Resources of the Dunkard Basin

Total original resources in the Dunkard Basin are estimated to be slightly over 335 billion tons (see Table A-1 in Appendix A), with the Monongahela Formation containing about one-third of the tonnage, and the Allegheny, the rest. The Monongahela estimate was prepared in two parts (see Figure 4 and Tables A-2 to A-4). Monongahela I is an area where part of the coal-bearing formation has been eroded and, hence, has smaller thicknesses of coal. In Monongahela II, the entire formation is buried beneath younger noncoal-bearing strata, and the full thickness of the coal-bearing formation is preserved.

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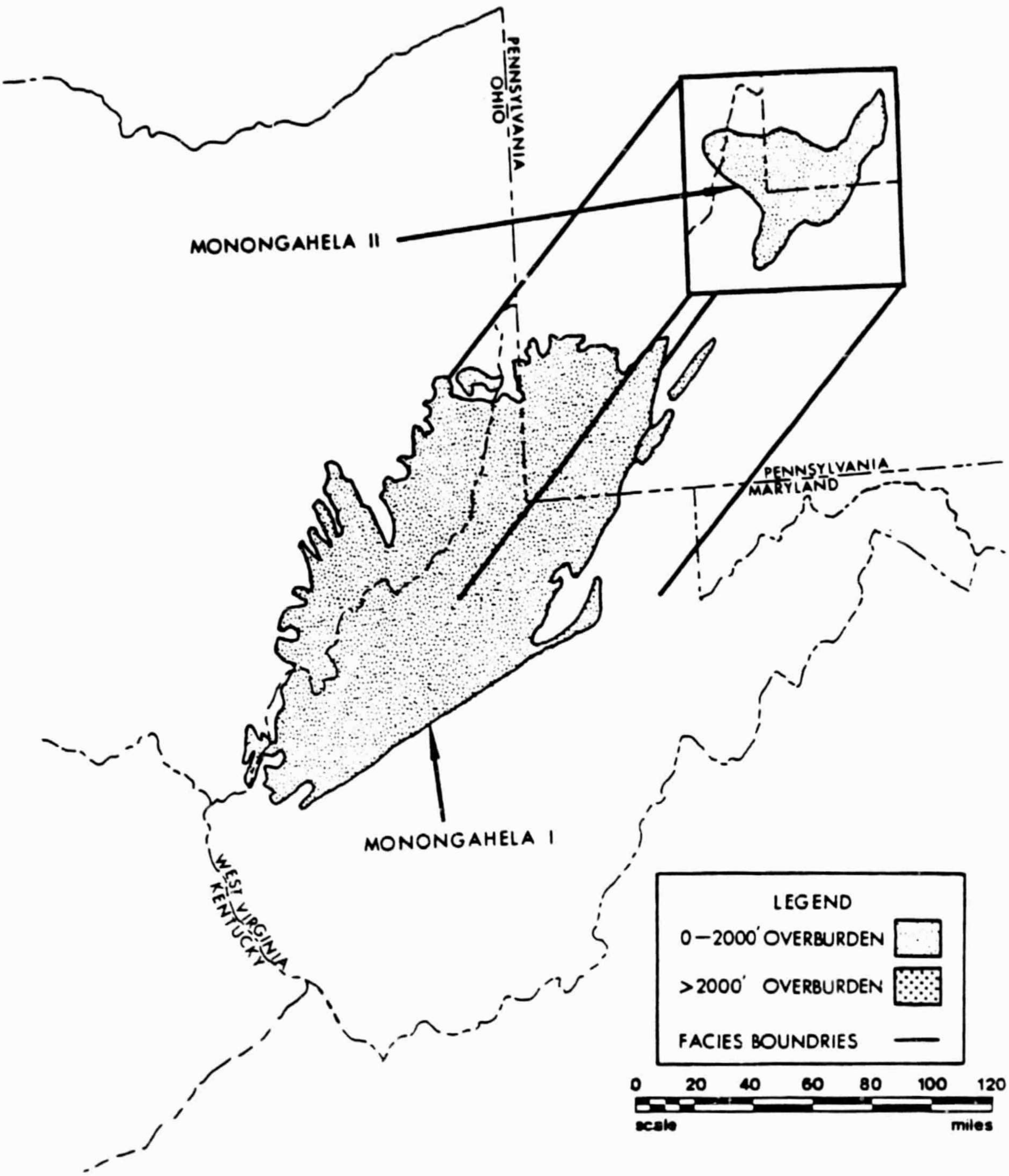

Figure 4. Location of Areas of Coal Resource Estimation for the Monongahela Formation in the Dunkard Basin of the Appalachian Plateau Province (Larger area -- "Monongahela I" -- represents the area where the formation is partially eroded; smaller area -- "Monongahela II" -- represents the area where the full thickness of the formation is present. See Tables A-3 and A-4 for resources in each area and Table A-2 for total resources.)

The estimate for the Allegheny Formation was prepared only for the northwestern part of the stratigraphic group of rocks designated Allegheny on geologic maps because most seams in the southern part are thin and erratically distributed. In the north, where the mineable seams occur, there appears to be no distinct pattern of distribution of total coal thickness. Hence, the area was treated as a single block, and the results are shown on Figure 5 and Table A-5.

The Monongahela estimate is reasonably well-controlled since the coal occurrences are not deeply buried, and exploration data are relatively abundant. The estimates for the Allegheny are based on projections from the outcrop and shallow subsurface into the deeper subsurface, and thus, are less well-controlled.

Table 3, which summarizes original resource data for the Dunkard Basin, shows that of the total of 335 billion original tons, about 45% occurs in beds 15 ft - 42 in. thick, 30% in beds of 42 - 28 in., and 25% in beds of 28 - 14 in. thick. About 40% of the tonnage occurs within 500 ft of the surface, and none below 2000 ft. None of the total tonnage is estimated to be affected by displacement faults or intrusions, and none is estimated to occur in beds dipping more than 15°.

The remaining resources of the Dunkard Basin, also shown on Table 3, are based on the assumption of 45% recovery, in both 0 - 500 ft and 500 - 2000 ft overburden categories, and on the assumption that 70% of the mined tonnage has been derived from beds 15 ft - 42 in. thick, 25% from beds 42 - 28 in. thick, and 5% from beds 28 - 14 in. thick. According to these estimates, only about 10% of the original resource has been utilized, and of the remaining 300 billion tons, slightly less than half is in the 15 ft - 42 in. category, and under less than 2000 ft of overburden.

4.1.6 Coal Resources of the Pocahontas Basin

Total original resources of the Pocahontas Basin are estimated to be about 335 billion tons, or about the same as the Dunkard Basin (see Table A-6). Estimation of resources in this basin is complicated by the shingled arrangement of the coal formations, wherein thick coal seams of one formation overlap the thin seams of another (see Figure 2). This factor, combined with structural attitude and local relief, yields seven resource subdivisions, designated P-I through P-VII on Figure 6. Block P-I includes thin coals of the lower part of the Breathitt Formation, whereas, P-II reflects thick coals of both the upper and lower parts of the Breathitt Formation in eastern Kentucky and Virginia, as well as its Kanawha equivalent in West Virginia. P-III contains some lower Breathitt and upper New River coals in Virginia and West Virginia. Areas P-IV and P-V represent, respectively, subcrop and outcrop of the Pocahontas coals overlain by the thin New River coals. Block P-VI represents the outcrop area of thin lower and thick upper Kanawha coals, and P-VII represents their subcrop equivalent. Among these blocks, the belt of thick upper and lower Breathitt-Kanawha coals in Kentucky, Virginia, and West Virginia (block P-II) clearly contains the largest resources (see Tables A-7 through A-13).

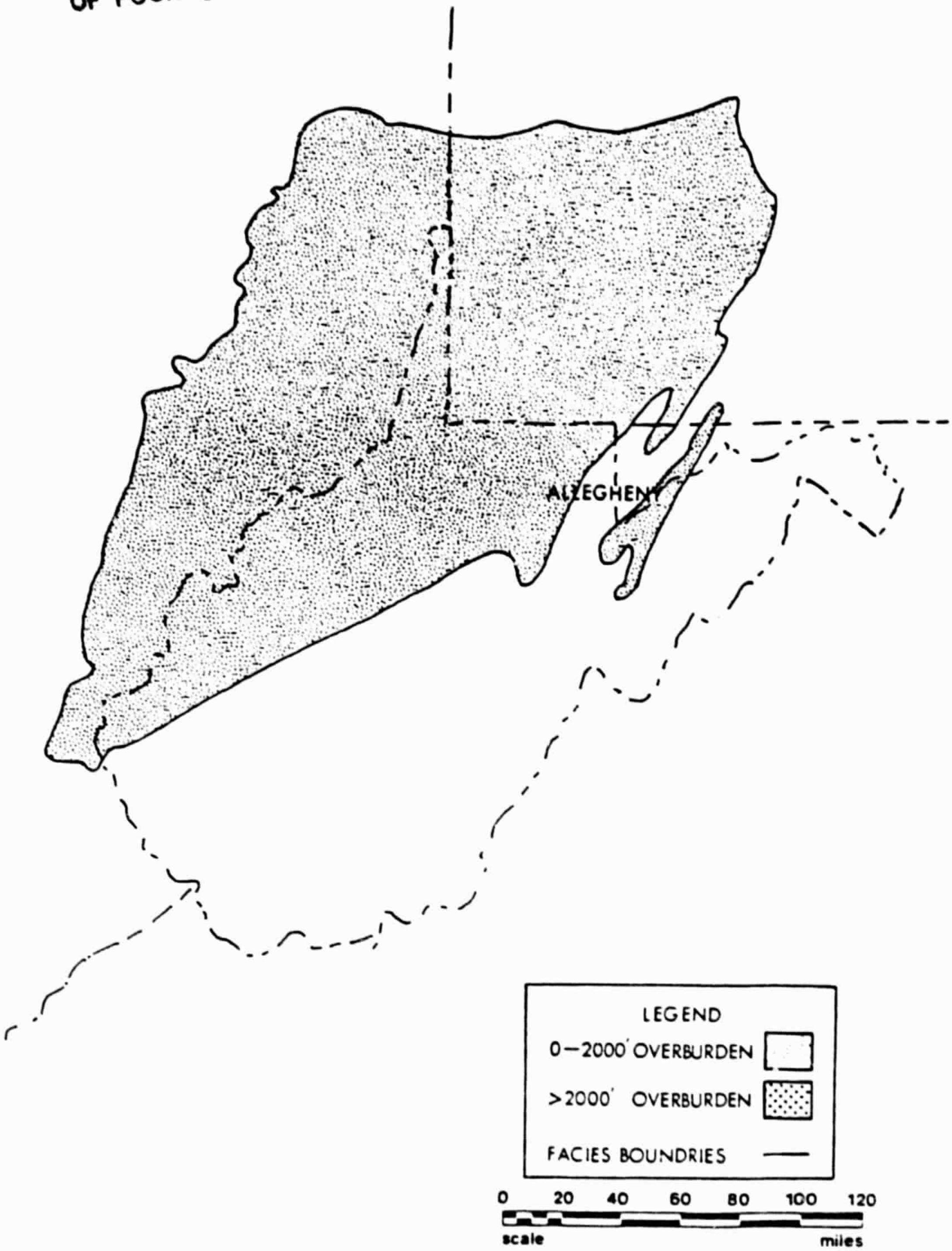

Figure 5. Location of Areas of Coal Resource Estimation for the Allegheny Formation in the Dunkard Basin of the Appalachian Plateau Province. (See Table A-5 for resources.)

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Table 3. Original and Remaining Resources of the Dunkard Basin

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 in. 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥ 15° Faulted, and/or Intruded	Totals
Original Tonnage	0	0	156	103	76	335	131	204	0	0	0	335
Tonnage Mined/Lost	0	0	22	8	1	31	15	16	0	0	0	31
Remaining Tonnage[b]	0	0	135	95	75	304	116	189	0	0	0	304
Percent	0	0	44	31	25	100	38	62	0	0	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 70% of historical tonnage was derived from seams 15 ft - 42 in. thick, 25% from seams of 42 - 28 in., and 5% from seams of 28 - 14 in.

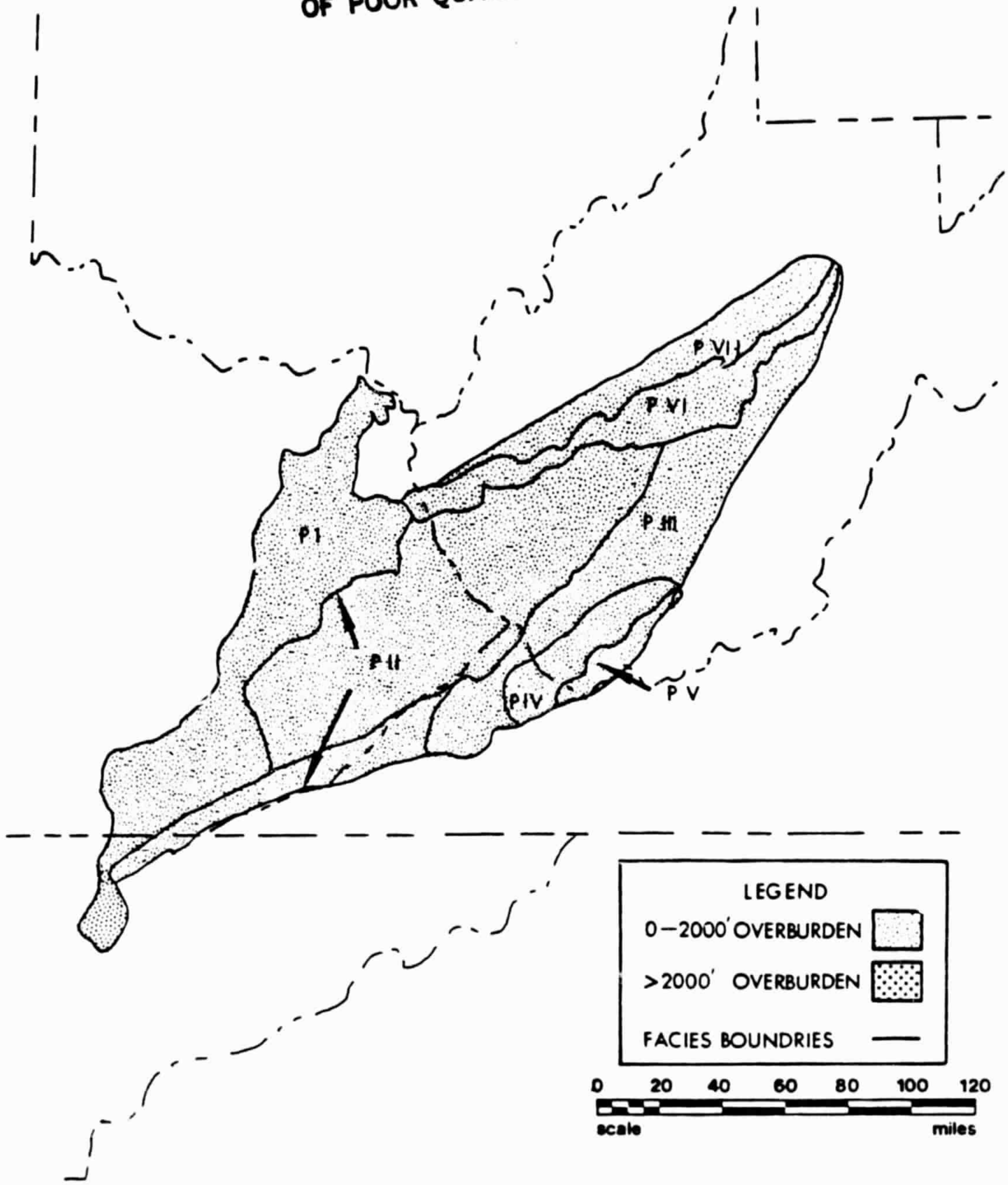

Figure 6. Location of Areas of Coal Resource Estimation for the Pocahontas Basin in the Appalachian Plateau Province. (Areas "P-I" through "P-VII" represent outcrop and subcrop areas of different coal formations in the Pocahontas Basin. See text for description of coals in each area and Tables A-6 through A-13 for resources.)

The summary of the original resource data for the Pocahontas Basin presented in Table 4 indicates that of the total of roughly 335 billion tons, 52% occur in beds 15 ft - 42 in. thick, 21% in beds 42 - 28 in. thick, and 27% in beds 28 - 14 in. thick. About one-third of the original tonnage occurred within 500 ft of the surface, and none below 2000 ft. Estimates of the remaining resources of the Pocahontas Basin, shown in Table 4, are based on the assumption of 45% recovery throughout the interval of 0 - 2000 ft, and on the assumption that 70% of the mined tonnage was derived from seams 15 ft - 42 in. thick, 25% from 42 - 28 in. coals, and 5% from 28 - 14 in. seams. Table 4 suggests that only about 7% of the original resources have been utilized, and of the remaining 160 billion tons, about 50% are in the 15 ft - 42 in. category, at depths of less than 2000 ft.

4.1.7 Coal Resources of the Warrior Basin

Total original resources of the Warrior Basin (see Table A-14) are estimated to be about 200 billion tons, which is approximately two-thirds of the tonnage in either the Dunkard or Pocahontas Basins. Blocking of the Warrior Basin into the three areas shown in Figure 7 is based upon the synclinal shape of the basin. The Warrior-I block consists of the entire coal-bearing sequence in the Warrior Basin under less than 2000 ft of cover, whereas, Warrior-II includes seams in the lower two-thirds of the sequence, part of which is under less than 2000 ft of cover, and part deeper than 2000 ft. Warrior-III includes only the lowest seams in the Warrior sequence. Tonnage estimates for each of these blocks are shown on Tables A-15, A-16, and A-17. Table 5, which summarizes the original resource data for the Warrior Basin, shows that of the total of roughly 200 billion tons, only about 15% are in beds 15 ft - 42 in. thick and about 25% in beds 42 - 28 in. thick. This is a significant departure from the thickness distribution observed in the Pocahontas and Dunkard Basins, which have a much larger portion of thick seams, and a smaller proportion in the 28 - 14 in. category. In addition, the Warrior Basin differs from those further to the north in having about 15% of its resources in areas with more than 2000 ft of overburden.

Estimates of the remaining resources of the Warrior Basin are based on the assumption of 45% recovery in both the 0 - 500 ft and 500 - 2000 ft overburden categories, and on the assumption that 70% of the mined tonnage is derived from beds 15 ft - 42 in. thick, 25% from beds 42 - 28 in. thick, and 5% from beds 28 - 14 in. thick. It is possible that a greater percentage of historical production should be assigned to thinner seams, but the aggregate tonnage mined and lost-in-mining is so small that the above estimates would not be seriously affected. It may be further assumed that no coal has been mined from areas with greater than 2000 ft of overburden. These assumptions indicate that only about 1% of the original resource has been utilized; thus, except for the 15 ft - 42 in. category, the resource is virtually intact.

Table 4. Original and Remaining Resources of the Pocahontas Basin

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Instructions										Dip ≥ 15° Faulted, and/or Intruded	Totals
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	0	174	72	90	335	112	224	0	0	0	336
Tonnage Mined/Lost	0	0	16	6	1	23	11	12	0	0	0	23
Remaining Tonnage[b]	0	0	158	56	89	312	100	212	0	0	0	312
Percent	0	0	50	21	29	100	33	67	0	0	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 70% of historical tonnage was derived from seams 15 ft - 42 in. thick, 25% from seams of 42 - 28 in., and 5% from seams of 28 - 14 in.

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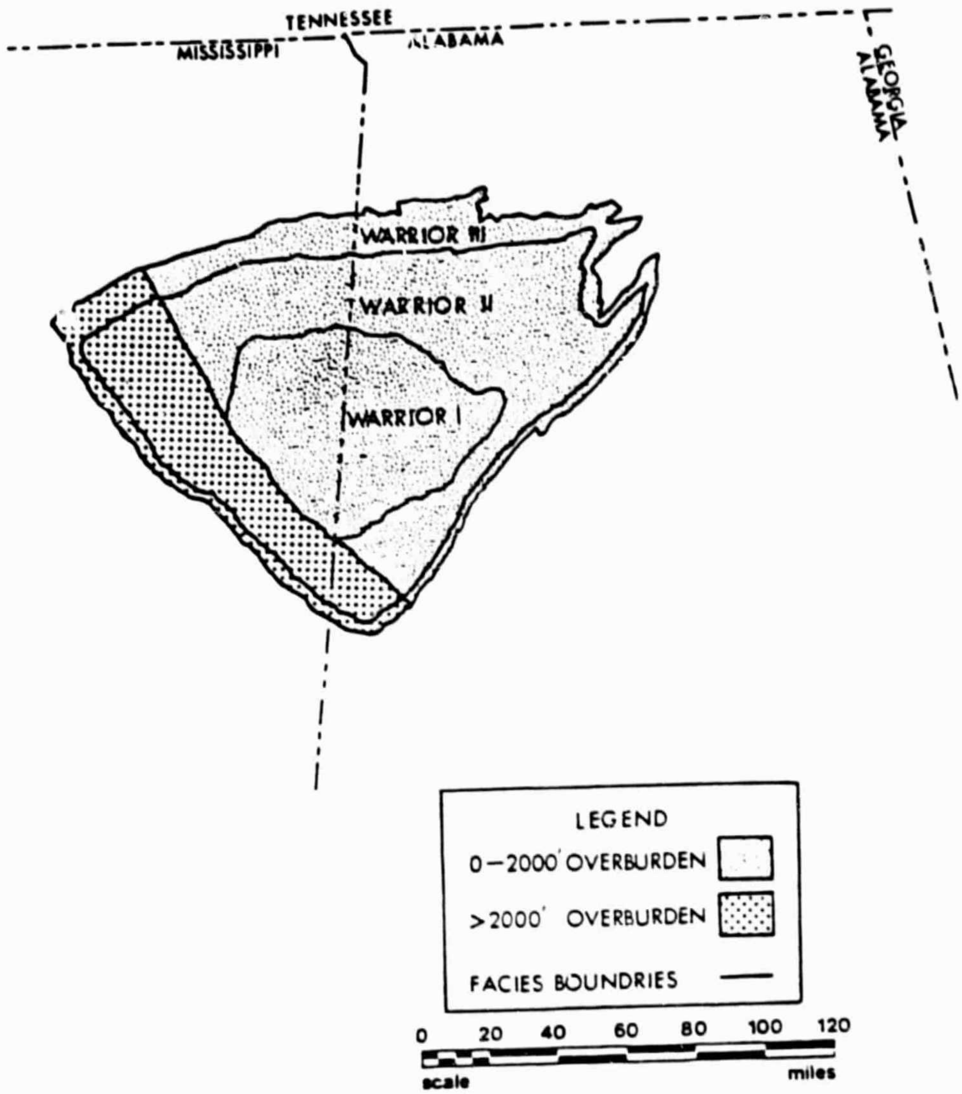

Figure 7. Location of Areas of Coal Resource Estimation in the Warrior Basin in the Appalachian Plateau Province (Area "Warrior I" includes all seams in the Warrior Basin Sequence, area "Warrior II" includes the lower two-thirds of the seams, and "Warrior III" includes only the lowest seams. See Tables A-15 through A-17 for resources of each area and Table A-14 for total resources.)

Table 5. Original and Remaining Resources of the Warrior Basin

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Instrusions										Dip ≥ 15° Faulted, and/or Intruded	Totals
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	0	30	47	90	166	22	145	28	0	0	194
Tonnage Mined/Lost	0	0	1.6	0.6	0.1	2.3	1.1	1.2	0	0	0	2.3
Remaining Tonnage[b]	0	0	28	46	90	164	21	144	28	0	0	192
Percent	0	0	15	24	46	85	13	72	15	0	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 70% of historical tonnage was derived from seams 15 ft - 42 in. thick, 25% from seams of 42 - 28 in., and 5% from seams of 28 - 14 in.

4.1.8 Summary of Remaining Coal Resources of the Appalachian Plateau Province

Table 6, which summarizes the remaining resources for all major basins of the Appalachian Plateau, indicates that of a total of about 800 billion tons, nearly all the resource occurs in areas with overburden of 2000 ft or less, and 30% of the total lies under less than 500 ft of cover. It also indicates that about 40% of the remaining tonnage is under less than 2000 ft of cover and occurs in beds 15 ft - 42 in. thick. The thinner seam categories -- 42 - 28 in. and 28 - 14 in. -- contain about 30% of the resource. An insignificant proportion of the tonnage lies in steeply inclined beds, seams made discontinuous by faulting or igneous intrustion, and coals under more than 2000 ft of overburden.

4.2 CARBONIFEROUS INTERIOR PROVINCE

4.2.1 Extent

Extending southwestward from the state of Michigan into northeast Texas are a series of basins containing coal of Carboniferous Age (see Figure 1). Of these, two of the largest have been selected for detailed study: (1) the Eastern Interior Basin, which is located mainly in Illinois, with extensions into southwestern Indiana and western Kentucky; and (2) the Western Interior Basin, which is located principally in south central Iowa, northwestern Missouri, eastern Kansas, and northeastern Oklahoma. The portion of this basin lying in northeast Texas is excluded from this study because of small resource potential.

4.2.2 Geology

The geologic structure of the Eastern and Western Interior Basins is substantially different. The Eastern Interior Basin is a true structural basin, dipping toward the center, with the deepest part in southeastern Illinois (see Figure 8). The Western Interior Basin is actually the eastern flank of a large, flat-bottomed, somewhat diffuse structural depression that extends from the Ozark Dome westward to the Front Range of the Rockies (see Figure 9). The expression "Western Interior Basin" however, applies only to the eastern flank of this large depression because it is in this area that coals of mineable thickness occur.

In both the Eastern and Western Interior Basins, dips are very low, generally less than a few degrees, and faulting is negligible except in the southernmost part of the Eastern Basin. Normal faults with a displacement of about 200 ft are relatively abundant in western Kentucky and some parts of southern Illinois, but the zones in which displacement occurs occupy small areas. Mining in areas between the faults is not affected. As in the Appalachian Plateau, igneous intrusions do occur, but are not significant with regard to mining.

The mineable coal seams in both the Eastern and Western Interior Basins, are restricted to rather thin but widespread groups of rocks. Figure 8, a cross-section which extends north and south through the Eastern Interior

Table 6. Summary of Original and Remaining Resources of the Appalachian Plateau Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft										Dip ≥ 15° Faulted, and/or Intruded	Totals
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	0	[illegible]	221	256	837	264	573	28	0	0	865
Tonnage Mined/Lost	0	0	39.3	14.2	2.8	56.3	28.1	28.2	0	0	0	56.3
Remaining Tonnage[b]	0	0	321	207	253	781	236	545	28	0	0	809
Percent	0	0	39	25	31	96	29	67	4	0	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 70% of historical tonnage was derived from seams 15 ft - 42 in. thick, 25% from seams of 42 - 28 in., and 5% from seams of 28 - 14 in.

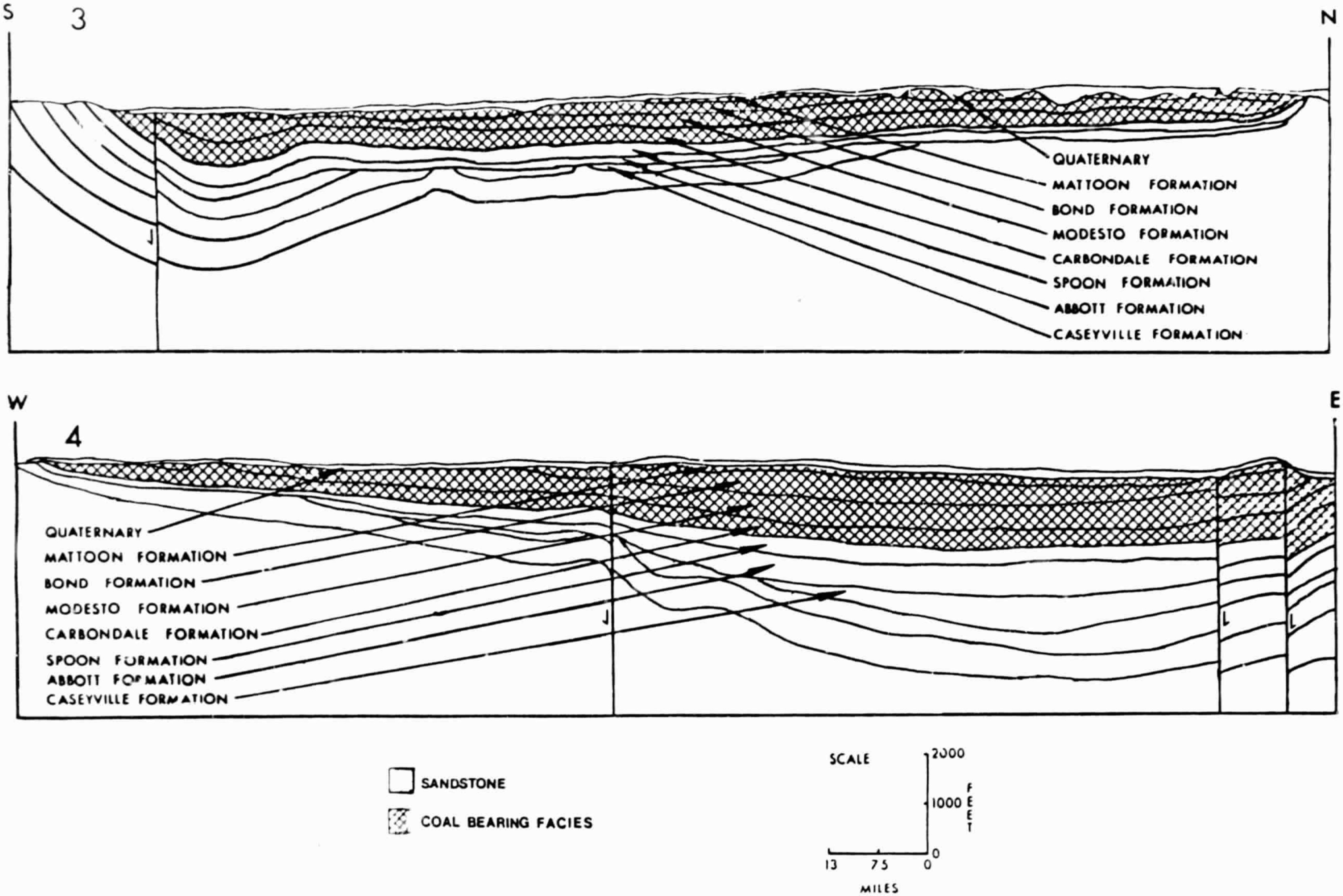

Figure 8. Cross Sections of the Eastern Interior Basin in the Carboniferous Interior Province (See Figure 1 for location of this cross section.)

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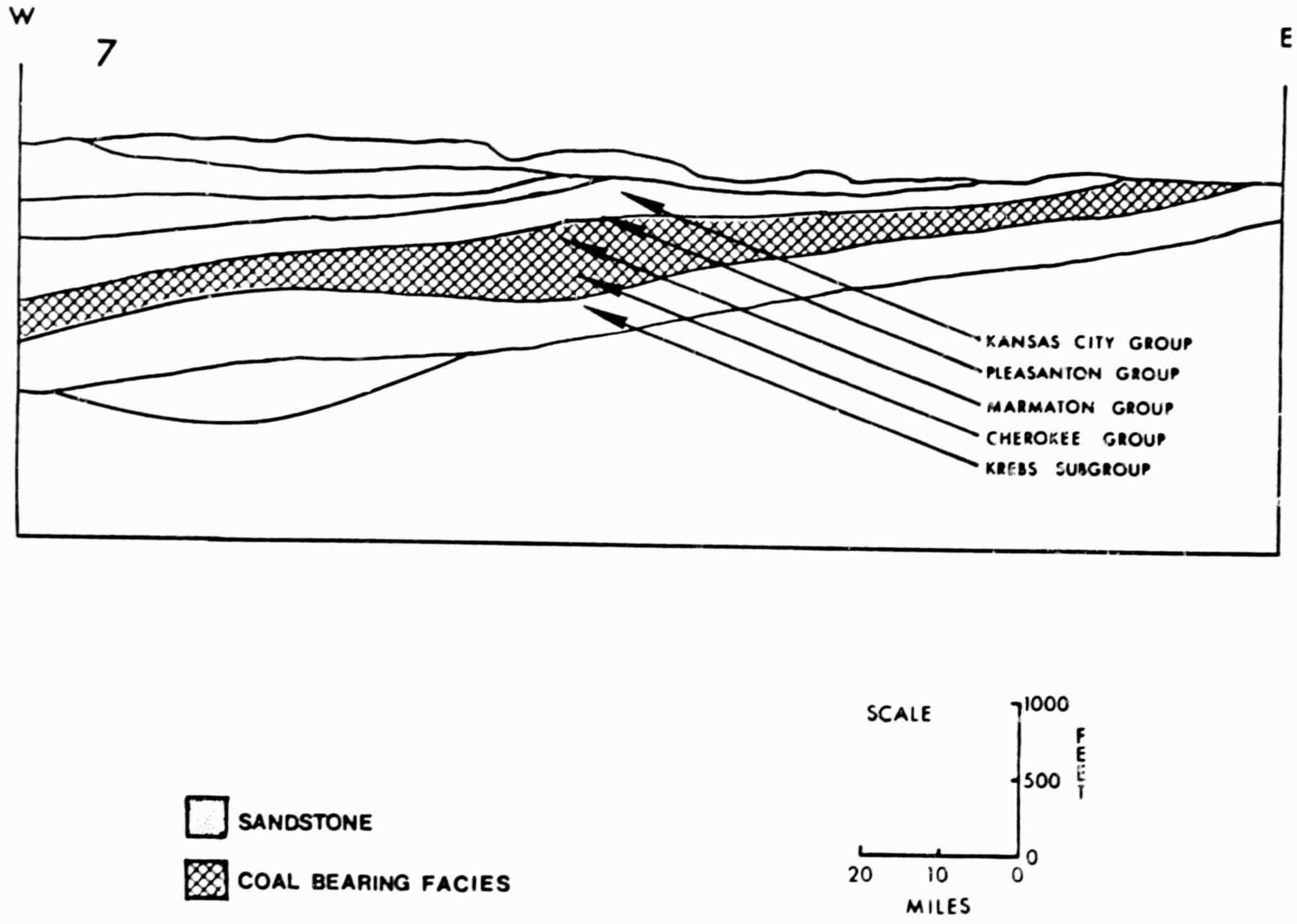

Figure 9. Cross Section of the Western Interior Basin in the Carboniferous Interior Province (See Figure 1 for location of this cross section.)

Basin, shows the entire coal-bearing sequence for the region. However, most of the mineable seams are concentrated in a zone 200 - 300 ft thick in the lower part of the sequence. Vertical sections through this sequence in different parts of the area show that the thickness of any one seam varies throughout the basin, but thinning of one apparently is compensated by thickening of another, and no clear pattern of regional variation in coal thickness is evident.

The general distribution of mineable seams within the coal-bearing rocks in the Western Interior Basin is very similar to that found in the Eastern Interior. The major mineable seams are confined to a 200 - 500 ft interval in the lower part of the total sequence. As in the Eastern Interior Basin, the seams of the Western Interior show no clear clustering of thick coal in any one part of the basin. The major difference between the two basins lies in the extension of the coal-bearing strata into the deep subsurface on the western side of the Western Interior Field -- a feature not found in the Eastern Interior Basin. In this area, coal seams in excess of 14 in. extend downward to at least 2000 ft beneath the surface. The western extent of these deeply buried seams may be greater than is indicated on the cross section of Figure 9, but data in this area is too sparse to include these coals in the resource estimate. Glacial deposits cover the coal-bearing rocks north of central Kansas and southern Illinois, yielding a uniformly level aspect to the terrain. This lack of surface relief, in conjunction with gentle dips of the coal-bearing rocks, leads to a constant distance between the surface and the underlying coals over wide areas of the province.

Rock units that contain most of the mineable coals in the Interior basins are believed to be similar in age to the Allegheny rocks of the Dunkard Basin, and in many respects, a strong resemblance is evident. First, the rock units in which the mineable seams occur are relatively thin (200 - 500 ft), and the coal seams are rath· · uniform in distribution. In both of the Interior Basins and in the ·legheny Formation of the Dunkard Basin, the major coal-bearing sequence is underlain by formations dominated by sandstones, and many individual seams are overlain by rocks containing abundant evidence of deposition in marine water. This characteristic is found in some Allegeheny coal seams but is much more pronounced in the Eastern Interior, and is especially true of the seams in the Western Interior Basin.

4.2.3 Quality

There is substantial variability in the rank of coal of the Interior Province, ranging from about 11,000 to nearly 15,000 Btu/lb. Higher values of Btu/lb appear to be associated with coals occurring at greater depths. Sulfur content is higher than most of the coals in the Appalachian Region. In the Eastern Interior, sulfur commonly runs from 3 - 5%; in the Western Interior, the percentage is slightly higher. An association between the type of roof rock and the sulfur content of the underlying coal has been observed in this region. Where black shale and/or limestone with marine fossils overlie the coal, the sulfur is high (on the order of 3 - 4%), but where gray shale without marine shells overlies the coal, the sulfur content of the coal may be as low as 2 - 2.5%. Hence, the Western Interior coals with extensive marine cap rock can be expected to be somewhat higher in sulfur than Eastern Interior seams, where this phenomenon is less common. Although ash content varies considerably, it commonly runs about 10%. Most of the coals are used for steam generation, but some from southern Illinois are blended with higher rank coals to produce coke.

4.2.4 Mining

Substantial underground mining has been conducted in the Interior Province since about the turn of the century, and surface mining has been practiced extensively since the early 1900's. Uniformity of distance between the surface and the underlying coals has encouraged surface mining. The level character of the terrain and the mantle of glacial deposits in the northern part of the region have discouraged small mining operations that are so characteristic of the Appalachian Province, and most of the tonnage is produced by large mines. Many of the large underground operations utilize continuous mining machines, and some use modern longwall equipment; however, conventional methods are still employed in many large mines.

4.2.5 Coal Resources of the Eastern Interior Basin

Table A-18 indicates that the total original resources of the Eastern Interior Basin are estimated to be on the order of 377 billion tons. These totals are derived from Tables A-19 and A-20, which describe the resources of the "thick" and "thin" blocks of Eastern Interior coals as delineated in Figure 10. Table 7, which summarizes the original resource data, shows that of the total resources, 45%, or about half, are in seams 15 ft - 42 in. thick, and the remainder are in the thinner seams. Slightly less than two-thirds of the total tonnage occurs at depths of 500 ft or less, and nearly all lies within 2000 ft of the surface. A trivial percentage is estimated to be sufficiently disturbed by faulting as to be mineable only with great difficulty, and igneous intrusion is similarly of very minor importance.

The remaining resources of the Eastern Interior Basin, summarized in Table 7, are based on the assumption of 45% recovery in both the 0 - 500 ft and 500 - 2000 ft overburden categories, and on the assumption that 70% of the mined tonnage has been derived from beds 15 ft - 42 in. thick, 25% from the 42 - 28 in. category, and 5% from seams of 28 - 14 in. According to these assumptions, only about 4% of the original resource has been utilized, and of the remaining 364 billion tons, about 45% is 15 ft - 42 in. thick, and lying under less than 2000 ft of cover.

4.2.6 Coal Resources of the Western Interior Basin

Table 8, which summarizes the data for the Western Interior Basin estimates total original resources at about 377 billion tons -- coincidentally, the same as for the Eastern Interior (see Table A-21 and Figure 11). Of this total, about 60% is in beds 28 - 14 in. thick, and the remainder is about equally divided between the 15 ft - 42 in. and 42 - 28 in. categories. Roughly 20% of the total tonnage lies within 500 ft of the surface, about 70% from 500 - 2000 ft deep, and less than 10% below 2000 ft. None of the total tonnage is expected to be affected by displacement faulting or igneous intrusion.

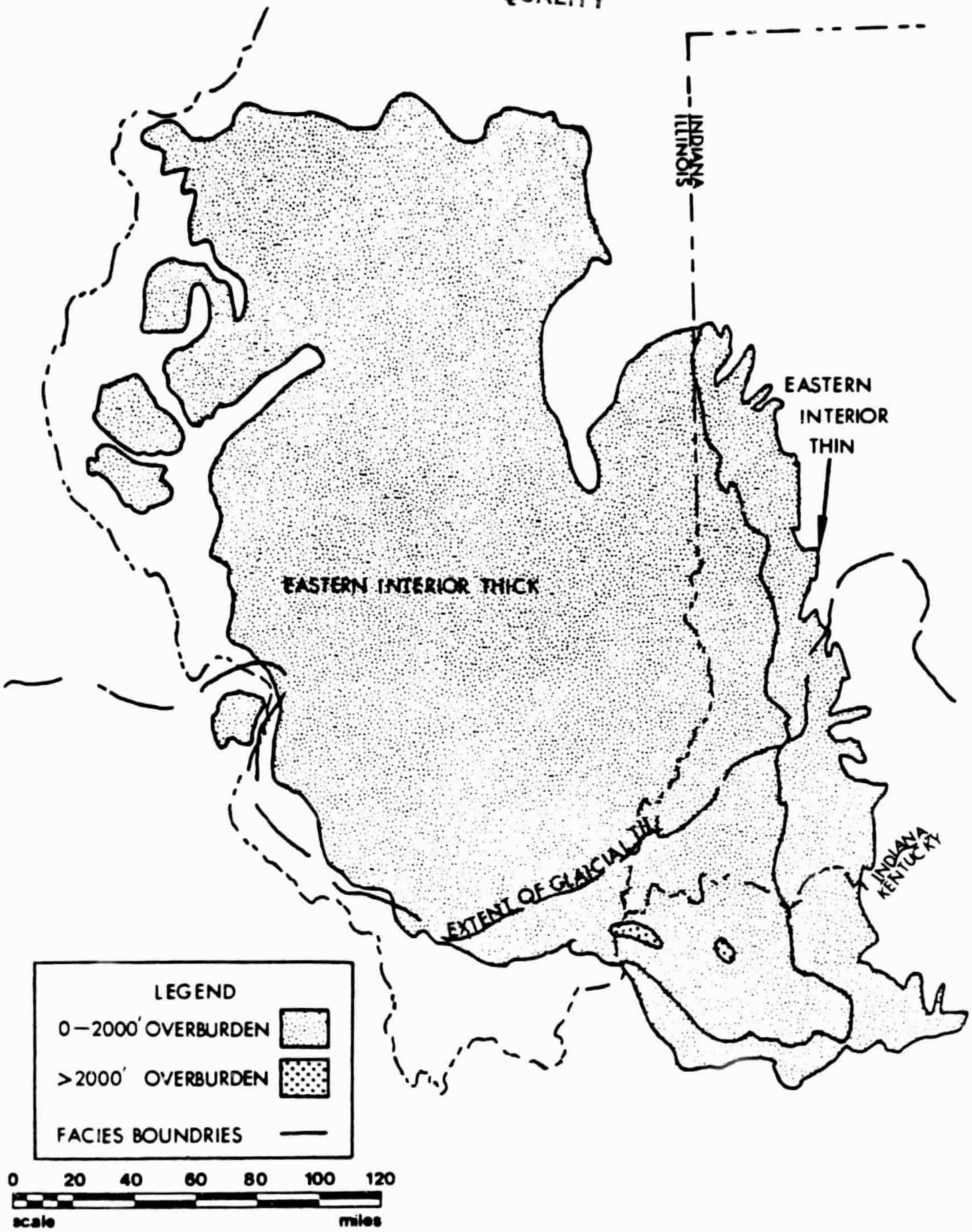

Figure 10. Location of Areas of Coal Resource Estimation in the Eastern Interior Basin in the Carboniferous Interior Province (Area designated "Eastern Interior Thick" consists mainly of the major coal bearing formations. Area designated "Eastern Interior Thin" is mainly thin older seams that have no importance elsewhere in the basin. See Tables A-19 and A-20 for each area and Table A-18 for total resources.)

Table 7. Original and Remaining Resources of the Eastern Interior Basin

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥15° Faulted, and/or Intruded	Totals
Original Tonnage	0	0	173	77	112	362	223	139	2	0	13	377
Tonnage Mined/Lost	0	0	9	3	1	13	6	7	0	0	0	13
Remaining Tonnag[b]	0	0	164	74	111	349	217	132	2	0	13	364
Percent	0	0	45	20	30	95	60	35	0.5	0	4.5	100

[a] Figures mav not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 70% of historical tonnage was derived from seams 15 ft - 42 in. thick, 25% from seams of 42 - 28 in., and 5% from seams of 28 - 14 in.

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Table 8. Original and Remaining Resources of the Western Interior Basin

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions										Dip ≥ 15° Faulted, and/or Intruded	Totals
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	0	65	63	220	348	72	276	29	0	0	377
Tonnage Mined/Lost	0	0	0.5	0.5	0.4	1.4	0.7	0.7	0	0	0	1.4
Remaining Tonnage[b]	0	0	64	62	220	347	71	275	29	0	0	376
Percent	0	0	17	17	58	92	19	73	8	0	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 65% recovery and the assumption that 33.3% of historical tonnage was derived from seams 15 ft - 42 in. thick, 33.4% from seams of 42 - 28 in., and 33.3% from seams of 28 - 14 in.

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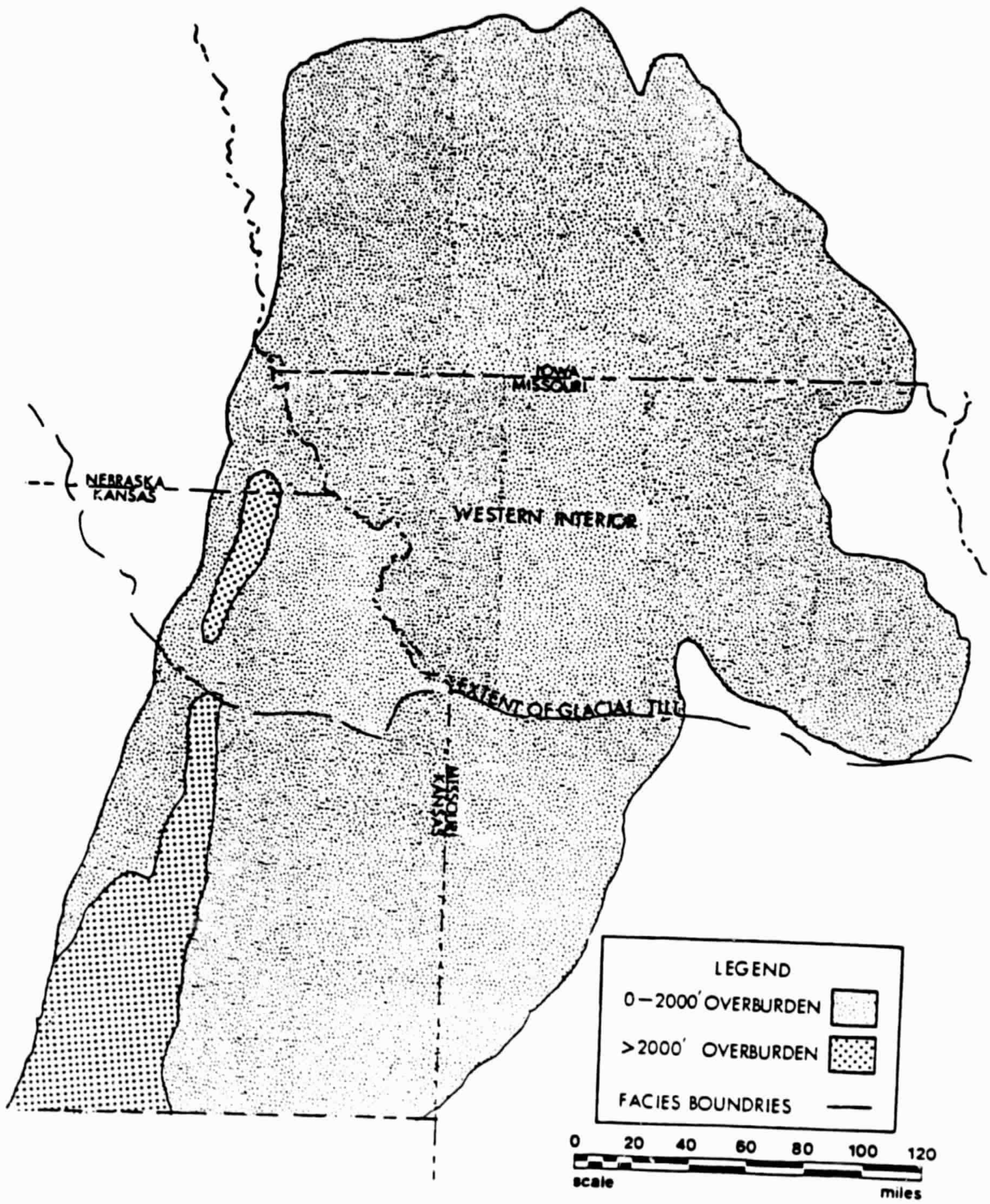

Figure 11. Location of Area of Coal Resource Estimation for the Western Interior Basin in the Carboniferous Interior Province (See Table A-21 for resources.)

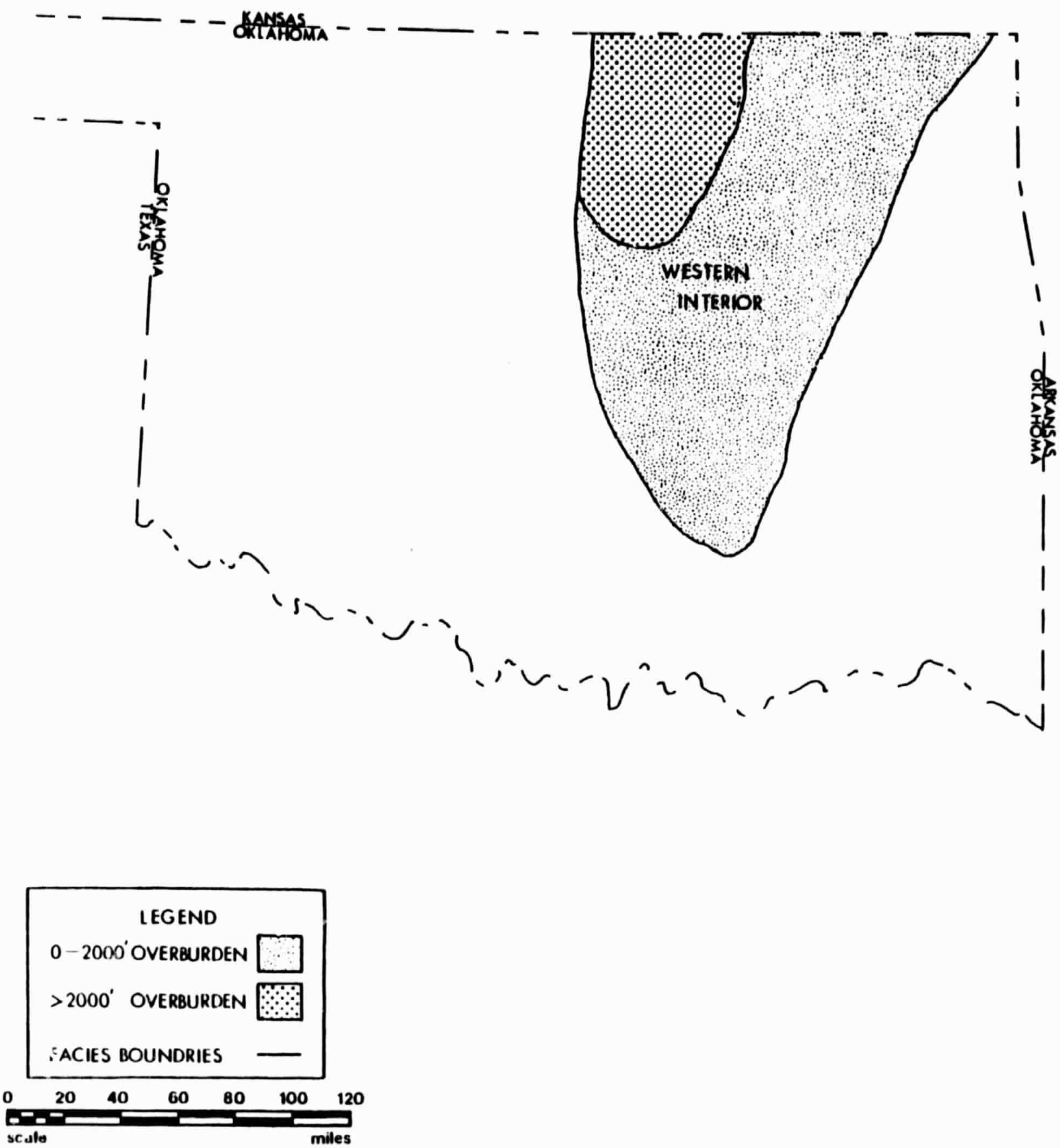

Figure 11. (Cont'd)

The remaining resources of the Western Interior Basin, shown on Table 8, are based on the assumption of 65% overall recovery, inasmuch as surface mining has been the dominant mining method in the region. Moreover, it is assumed that the tonnage mined or lost-in-mining is distributed equally among the three thickness categories, since surface mining is not so severely constrained by seam height as underground methods. These assumptions imply that less than 1% of the original resource has been utilized, and that about 60% of the remaining resource is in beds 28 - 14 in. thick, beneath less than 2000 ft of cover.

4.2.7 Summary of Remaining Coal Resources in the Interior Province

Table 9, which summarizes the remaining resources for both Interior Basins, indicates an aggregate of about 740 billion tons, of which about 40% occurs in areas with less than 500 ft of overburden, almost all of the remainder lying under less than 2000 ft of cover. About 30% of the remaining tonnage under less than 2000 ft of cover occurs in beds 15 ft - 42 in. thick, about 20% occurs in beds of 42 - 28 in., and 45% in beds of 28 - 14 in. Tonnages in steeply dipping, faulted, or intruded areas are of only minor importance.

4.3 THE GULF COAST LIGNITE PROVINCE

4.3.1 Extent

The geologic province designated the Gulf Coastal Plain extends west to east from the Mexican border to central Georgia, and south to north from the Gulf shore to central Texas, southeast Arkansas, southernmost Missouri and Illinois, western Kentucky and Tennessee, northeast Mississippi, and central Alabama and Georgia. As shown on Figure 1, lignite deposits at or near the surface do not extend to the northern limit of the province, but are primarily restricted to a broad area of northeast Texas, northern Louisiana, and central Mississippi. Smaller deposits are known in central Texas, southern Arkansas, and central Alabama. Lignites of unknown but very modest extent occur in western Kentucky and Tennessee.

4.3.2 Geology

The geologic structure of the Gulf Coastal Plain Lignite Province is dominated by strata which dip uniformly gulfward from the outcrop area, with an inclination of a few degrees or less. The major exceptions to this trend occur in northeastern Texas and northern Louisiana, where broad domal structures about 60 mi in diameter interrupt the general southward dip. Although creating local reversals in dip, the main effect of these domes is expansion of the outcrop and shallow subcrop areas of the lignite-bearing formations.

Igneous intrusions are of no importance in the Gulf Coastal Plain Province. However, normal faulting is a characteristic feature of the region. The trend of these faults is generally at right angles to the

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Table 9. Summary of Original and Remaining Resources of the Carboniferous Interior Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions										Dip ≥ 15° Faulted, and/or Intruded	Totals
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	0	238	140	332	710	295	415	31	0	13	754
Tonnage Mined/Lost	0	0	10	4	1	14	7	7	0	0	0	14
Remaining Tonnage[b]	0	0	228	136	331	696	288	408	31	0	13	740
Percent	0	0	31	18	44	93	39	54	4	0	3	100

[a] Figures may not add to indicated totals due to round-off.

[b] Calculated by combining Tables 7 and 8.

direction of dip, and, as a rule, the displacement is generally downward toward the Gulf. Because the thickness of sediments increases abruptly on the south side of these faults, and because the displaceme increases with depth (some faults do not reach the surface), it is hypothe .zed that the faulting was contemporaneous with sedimentation and provided a major mechanism for basin subsidence. It is doubtful that these displacements would impede mining because, like the faults of the Eastern Interior Basin, they appear to be reasonably widely spaced. This pattern of faulting would, however, have the effect of rapidly increasing the depth of cover in surface mining operations.

Lignite is found throughout much of the Gulf Coast Tertiary sequence, and peats occur in the Holocene. However, the best known lignite occurrence is in the formations of Eocene Age, particularly in the Wilcox Formation of the lower Eocene, and the Jackson Formation near the top of the Eocene sequence (see Figures 12 and 13). In these rock groups, the major influences on lignite formation (called depositional controls) were (1) the depositional setting of thick peats in the delta plain portion of the fluvio-deltaic deposits, and (2) the gulfward growth faulting which produced thickening of the lignite deposits in a southward direction.

Knowledge concerning the depositional controls on lignite (peat) accumulation has been derived from known occurrences of peat in Holocene alluvial deposits of the Mississippi River and its delta plain, where depositional processes can be directly observed. On the alluvial plain of the Mississippi, few peat deposits are known, but as the delta plain is approached, the number, thickness, and areal distribution of peat deposits increase. Near the Gulf shoreline, peat deposits diminish, and no peats are found in subaqueous environments of the Gulf. This same pattern is seen in the Eocene lignites, in which the depositional system consists of fluvial sand deposits with little peat, grading laterally into deltaic sands and shales with abundant peat, which in turn, grade into marine shales with no peat. To this is added the effect of increased total sedimentary accumulation due to growth faulting. The salient features of the depositional setting are depicted in Figure 12, a north-south cross section of the shallow subsurface in east Texas, and in Figure 13, a similar section in central Mississippi. In both cross sections, well-defined, lignite-poor alluvial sandstones extend gulfward and thin into deltaic sands, shales, and lignites. Underlying and overlying the thick fluvial sands are other deltaic lignite deposits formed during the progradation and retreat of the alluvial sand wedge. Underlying the deltaic deposits are shales representing marine offshore sediments upon which the deltaic plain deposits were built. In both cases, the total sedimentary accumulation increases toward the Gulf, presumably due to growth faulting or other mechanisms of subsidence.

The result of this combination of deltaic facies and seaward thickening of the sedimentary succession leads to two major characteristics of the Gulf Coast lignites. First, a greater number of lignites are located in the thick downdip portion of the succession, and second, because similar wedges of sediment make up overlying deposits, the lignite-bearing strata extend to very great depths beneath the surface.

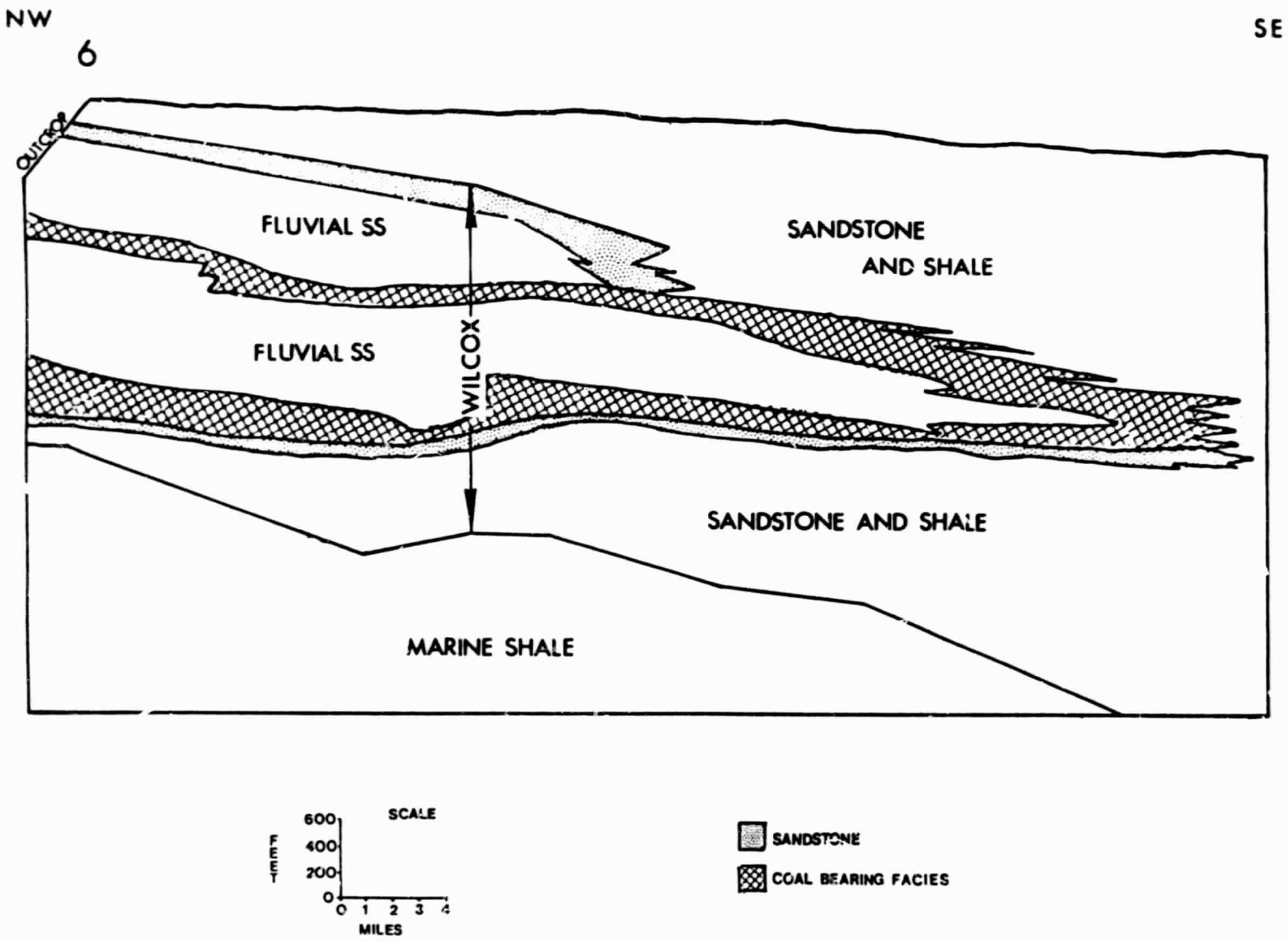

Figure 12. Cross Section of Tertiary Lignite-Bearing Strata in a Mississippi Portion of the Western Gulf Coast Lignite Province (See Figure 1 for location of this cross section.)

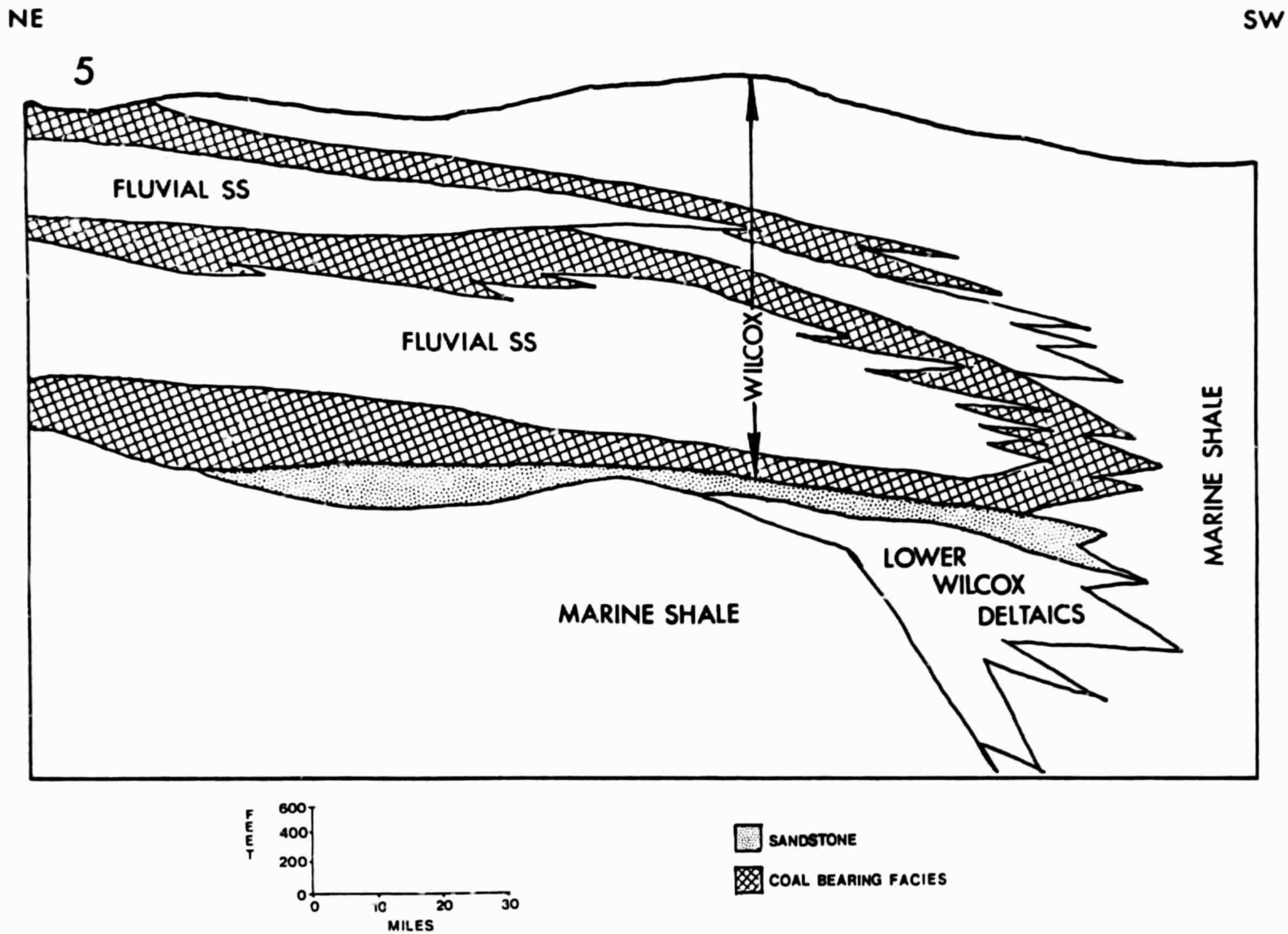

Figure 13. Cross Section of Tertiary Lignite-Bearing Strata in a Mississippi Portion of the Eastern Gulf Coast Lignite Province (See Figure 1 for location of this cross section.)

4.3.3 Quality

Relatively little data are available concerning the quality of the Gulf Cost lignites. Measurements of heating value range from about 3,000 up to 7,000 Btu/lb, with some reports ranging as high as 9,000. In the case of the Eastern Interior Basin, some of this variation may result from differences in the depth of burial. Sulfur is said to range from less than 1% to about 2.5%, and reported ash values range from 5 - 50%. Under present conditions, this material could be used only for steam generation.

4.3.4 Mining

The lignite resources of the Gulf Coastal Plain are virtually untouched. In the early 1900's, there was some experimentation with lignite as locomotive fuel, but this was not successful. At present, there is substantial surface mining in Texas, and development could extend into other areas. There has been no underground mining, and in view of the poorly consolidated character of the sediments overlying and underlying the lignites, it is very doubtful that any known method of underground mining could be applied.

4.3.5 Lignite Resources of the Gulf Coastal Plain Province

The Gulf Coastal Plain has long been known as a major source of petroleum and natural gas. Although the presence of lignite is well known, the characterization of these deposits and examination of their potential importance is a development of only the past few years. Because much of the subsurface data gathered in this area has been directed to petroleum and natural gas, and because recent data pertinent to the lignites are closely held, the amount of information available for estimation of the lignite deposits is extremely small and often of poor quality.

As a consequence, considerable difficulties had to be overcome in preparing tonnage estimates. First, because standard data such as core or cutting records could not be obtained, the major source of information was geophysical logs which are not nearly as precise as cores or even outcrop records. Second, the geophysical response to lignite in the presence of fresh water is not readily interpreted, and hence, in some areas no information was available. As a result, in a few cases it was necessary to estimate total lignite by drawing an analogy with the total lignite-bearing facies in other areas where the geologic setting is the same, but where there are better records. In such cases, no confidence intervals can be placed on the data, and they are presented as a "best guess" rather than a controlled estimate. The two major areas handled in this fashion are noted below:

(1) Thickness data for shallow, subsurface Mississippi (Mississippi-I on Figure 15) is not available, and so data from the geologically similar shallow subsurface of Louisiana-I (Figure 15) are used to estimate tonnage.

(2) Lignite thicknesses from the deep subsurface of Louisiana (Louisiana-II on Figure 15) is based on data about the deep subsurface of Mississippi (Mississippi-II on Figure 15).

Under these circumstances, it is not possible to subdivide the Gulf Coast Lignite Province on the basis of lignite thickness. Consequently, the major subdivisions of the region shown on Figure 14, 15, and 16 are based primarily on depth below the surface of the lignite-bearing strata, and on units of convenient measurement size. Tonnage estimates for these areas are shown on Tables A-22 through A-30.

To prepare these estimates, data from only the Wilcox formation were used. As indicated above, lignites and peats are known to occur throughout the Gulf Coast succession, ranging from the late Cretaceous deposits in Texas, through the Holocene of Louisiana. Of these, the Eocene Wilcox is the only unit from which data are consistently available, and at the same time, it is the formation which probably contains the largest single body of resources. It appears reasonably certain that all other lignite-bearing formations combined would not exceed the total for the Wilcox, and would probably contain no more than 30% of the Wilcox tonnage.

Analysis based on the approximations described above indicate that the total and remaining resources of the Gulf Coast Lignite Province aggregate about 3,800 billion tons (see Table 10). Of this total, approximately 400 billion tons or about 10% is judged to occur within 500 ft of the surface, and 1,500 billion tons or 40% lie 500 - 2000 ft below the surface. Resources below 2000 ft are estimated to be 1,900 billion tons, or about 50% of the total. Clearly, utilization of these deeply buried resources would require mining technology substantially different from any known today.

4.4 HIGH PLAINS LIGNITE PROVINCE

4.4.1 Extent

The coal region designated as the High Plains Lignite Province includes a substantial area of western North Dakota and eastern Montana, with extensions into northwestern South Dakota and northeastern Wyoming. Geologically, this area is an eastward extension of the Rocky Mountain Province which it adjoins, but because most of the coal is of lignite grade, it is considered a separate province (see Figure 1).

4.4.2 Geology

The structure of the High Plains lignites is extremely simple, with very gentle dips westward in the east side of the basin, and eastward, in the west side. The deposits are virtually flat-lying (dips less than 1°), and there are no displacement faults or igneous intrusions. The northern part of the area lying in North Dakota and Montana, like the Carboniferous Interior Basins, is blanketed by a mantle of glacial deposits. The rocks in which the lignites occur are very similar in character to those of the Gulf Coast and to adjoining portions of the Rocky Mountain Province. In the High Plains, lignites occur in early Tertiary (Eocene and Paleocene) deltaic or shoreline deposits of the Fort Union Formation, which overlies a major marine shale unit. The principal difference is that the lignite-bearing succession is much thinner (1000 ft) than in the Gulf Coast, and so these lignites are rarely found at depths greater than 2000 ft.

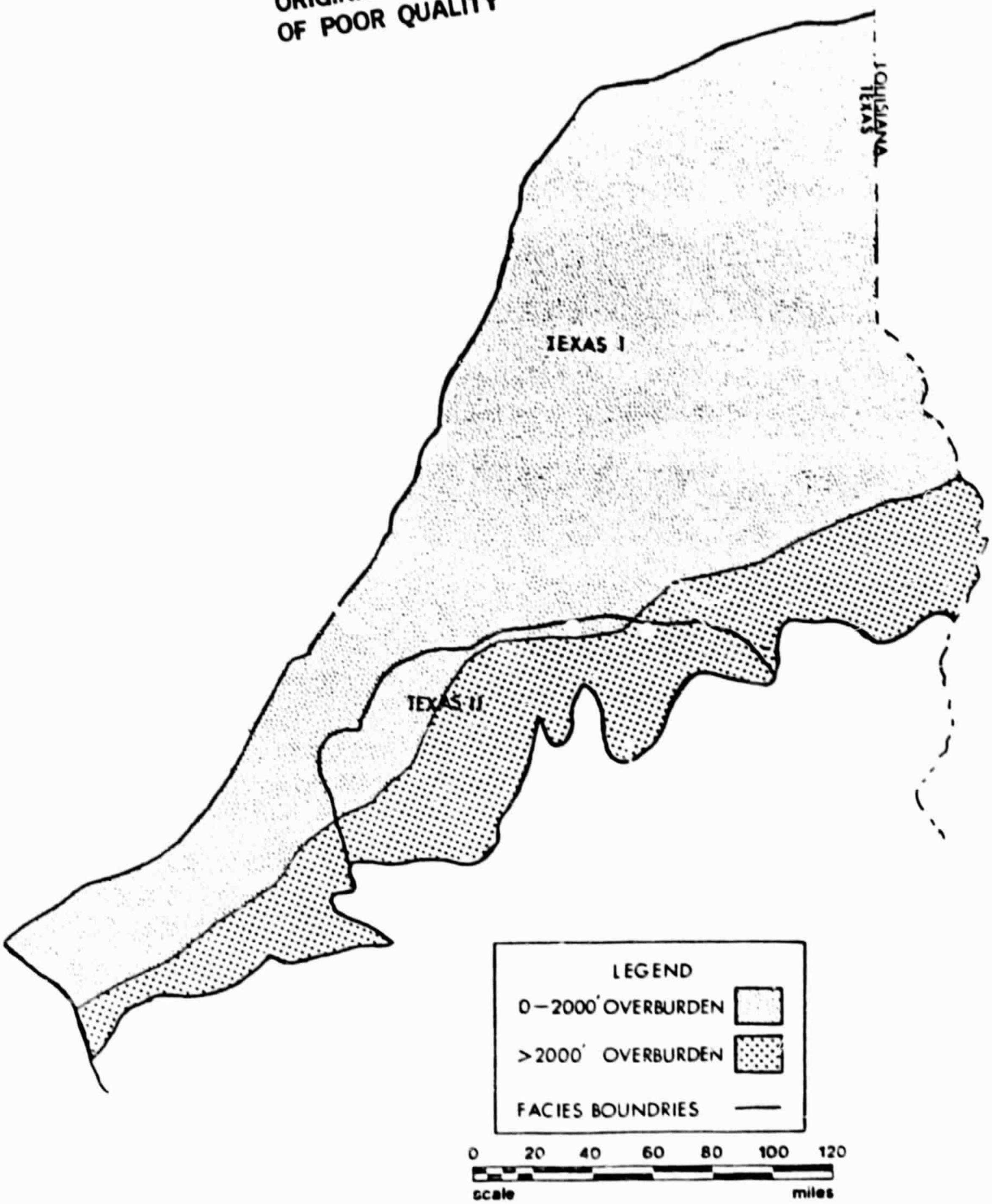

Figure 14. Location of Areas of Resource Estimation for the Texas Portion of the Gulf Coast Lignite Province (Area designated "Texas I" indicates relatively thin lignite; "Texas II" are areas where lignite is relatively thick. See Tables A-22 and A-23 for resources in each area.)

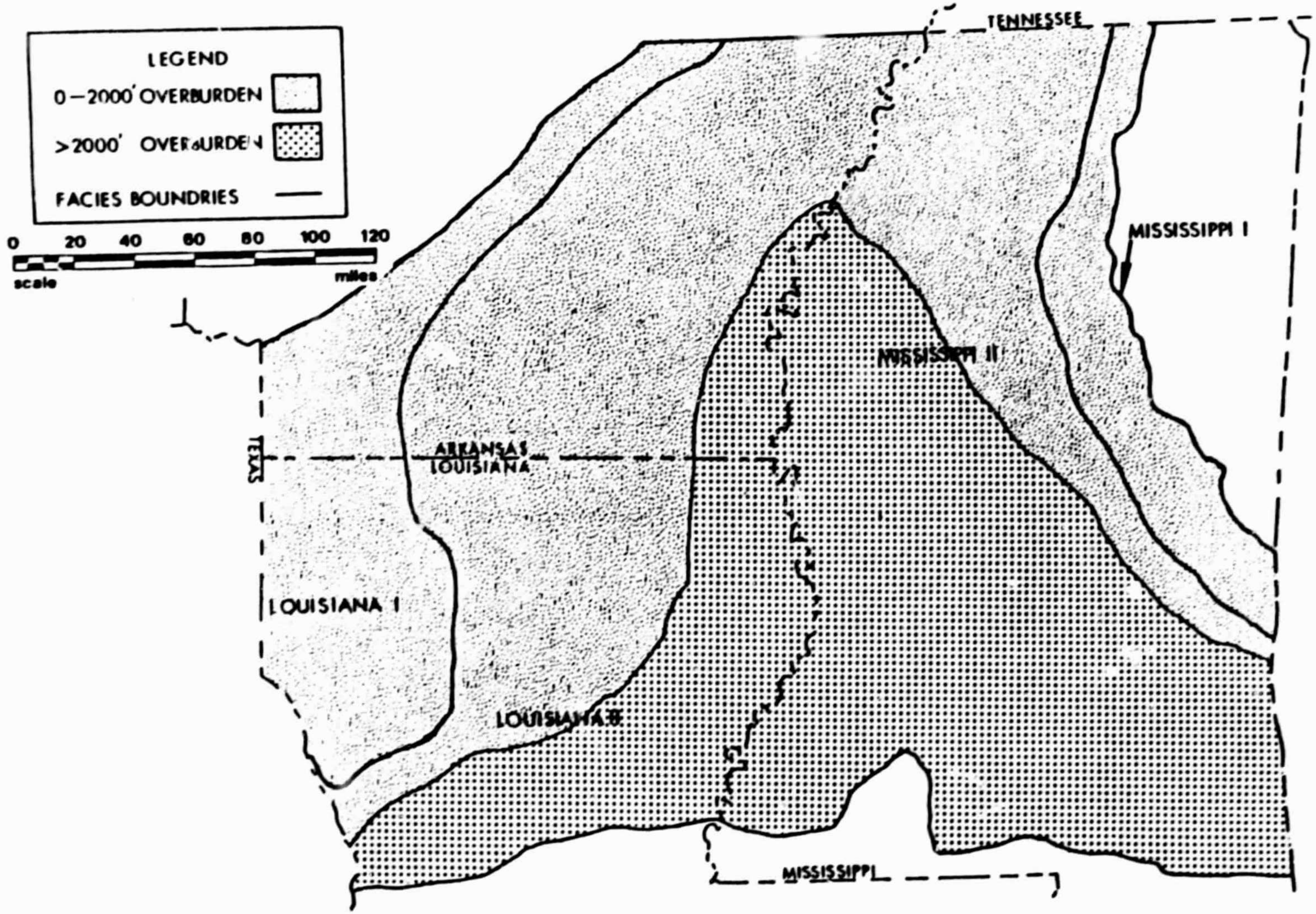

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Figure 15. Location of Areas of Resource Estimation for the Louisiana, Arkansas, and Mississippi Portions of the Gulf Coast Lignite Province (Areas designated "Louisiana I" and "Mississippi I" indicate lignites within 500 ft of the surface; "Louisiana II" and "Mississippi II" indicate cover greater than 500 ft. Most of the lignite in the Arkansas area is under less than 500 ft of cover. See Tables A-24 through A-28 for resources in each area.)

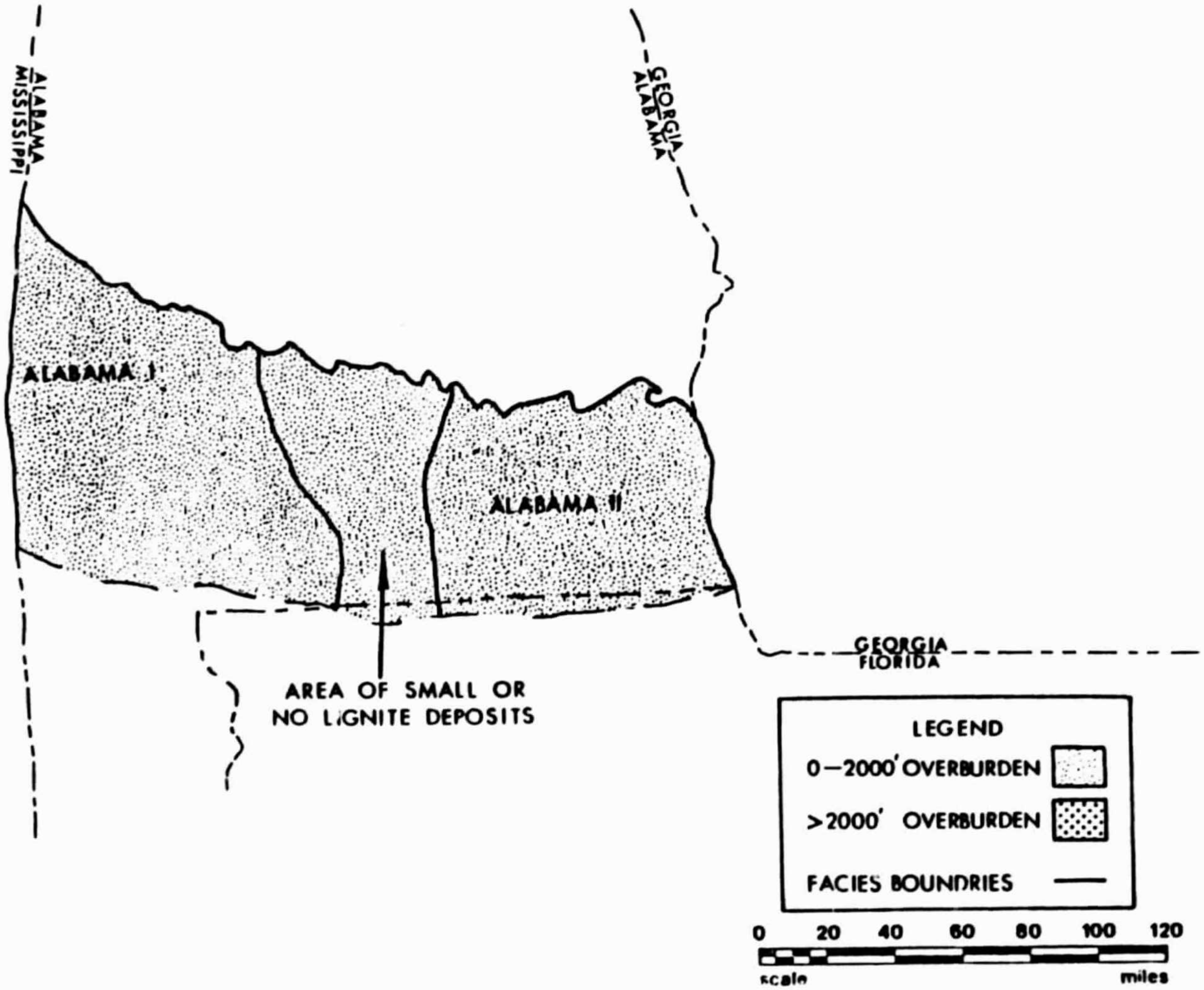

Figure 16. Location of Areas of Resource Estimation for the Alabama Portion of the Gulf Coast Lignite Province (Areas designated "Alabama I" indicate relatively thin lignite; "Alabama II" are areas where lignite is relatively thick. See Tables A-29 and A-30 for resources in each area.)

Table 10. Summary of Original and Remaining Resources of the Gulf Coast Lignite Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥ 15° Faulted, and/or Intruded	Totals
Original Tonnage	14	32	1306	376	193	1921	402	1519	1409	456	0	3786
Tonnage Mined/Lost	----------	----------	----------	----------	----------	nil	----------	----------	----------	----------	0	nil
Remaining Tonnage[b]	14	32	1306	376	193	1921	402	1519	1409	456	0	3786
Percent	0.3	1	35	10	5	51	11	40	37	12	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Because historical production is very small, the remaining resources are essentially the same as the original tonnage.

4.4.3 Quality

Heating values range from a low of 6600 to a high of 8400 Btu/lb. This range is smaller than the variation exhibited by the Gulf Coast lignites, probably because of a more uniform depth of burial. Sulfur is reported to be low, ranging from 0.3 - 1.9%, with an average of 1.5%. Ash content is reported ranging from 3.7 - 12.7%, with a mean of about 7.0%.

4.4.4 Mining

Initially, the High Plains lignites were used for domestic purposes, but towards the turn of the century, a few small mines were opened for locomotive fuel. Although drift and vertical shaft mines have been attempted in the past, only surface methods are now being employed; the unconsolidated character of the sediments enclosing the lignite makes ground control very difficult in underground mining.

4.4.5 Lignite Resources of the High Plains Province

Total original resources of the High Plains are of the order of 600 billion tons, or about 15% of the amount found in the Gulf Coastal region. However, nearly 97% of the High Plains Lignite is found within 2000 ft of the surface, compared to 51% in the Gulf Coast (see Tables 11 and A-31). Since there appears to be no preferential areal distribution of lignite thickness in the High Plains Province, the blocks High Plains-I and High Plains-II on Figure 17 reflect merely differing degrees of erosion of the lignite-bearing formation. High Plains-I includes areas in which the lignite-bearing formation is partially eroded, and hence, has a smaller total thickness of lignite than High Plains-II, in which the lignites are predominantly in the subsurface. Estimates for these areas are on Tables A-32 and A-33.

Because the amount of mining has been minimal, the remaining resources are essentially the same as the original tonnage (see Table 11). Of the 600 billion tons, most lies within 2000 ft of the surface and, of this, 10% occurs in seams 50 - 15 ft thick, and 65% in seams 15 ft - 42 in. thick. About 20% is in thinner beds, and only about 10% lies within 500 ft of the surface.

4.5 ROCKY MOUNTAIN PROVINCE

4.5.1 Extent

The Rocky Mountain Province is one of the largest of the U.S. coal provinces, both in terms of area and total resource tonnage. Unlike the other provinces, in which the coal fields overlap or closely adjoin one another, most of the basins of the Rocky Mountain Province are widely separated and readily identifiable as individual basins. The basins selected for this study include the Black Mesa and San Juan Fields of northern Arizona, northern New Mexico, and southern Colorado; the Alton-Kaiparowits Basins of southern Utah;

Table 11. Summary of Original Remaining Resources of the High Plains Lignite Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions										Dip ≥ 15° Faulted, and/or Intruded	Totals
		0 - 2000 ft										
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	63	404	62	63	593	58	534	14	0	0	607
Tonnage Mined/Lost	0	----------	----------	----------	----------	nil	----------	----------	----------	0	0	nil
Remaining Tonnage[b]	0	63	404	62	63	593	58	534	14	0	0	607
Percent	0	10	66	11	10	97	9	88	3	0	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Because historical production is very small, the remaining resources are essentially the same as the original tonnage.

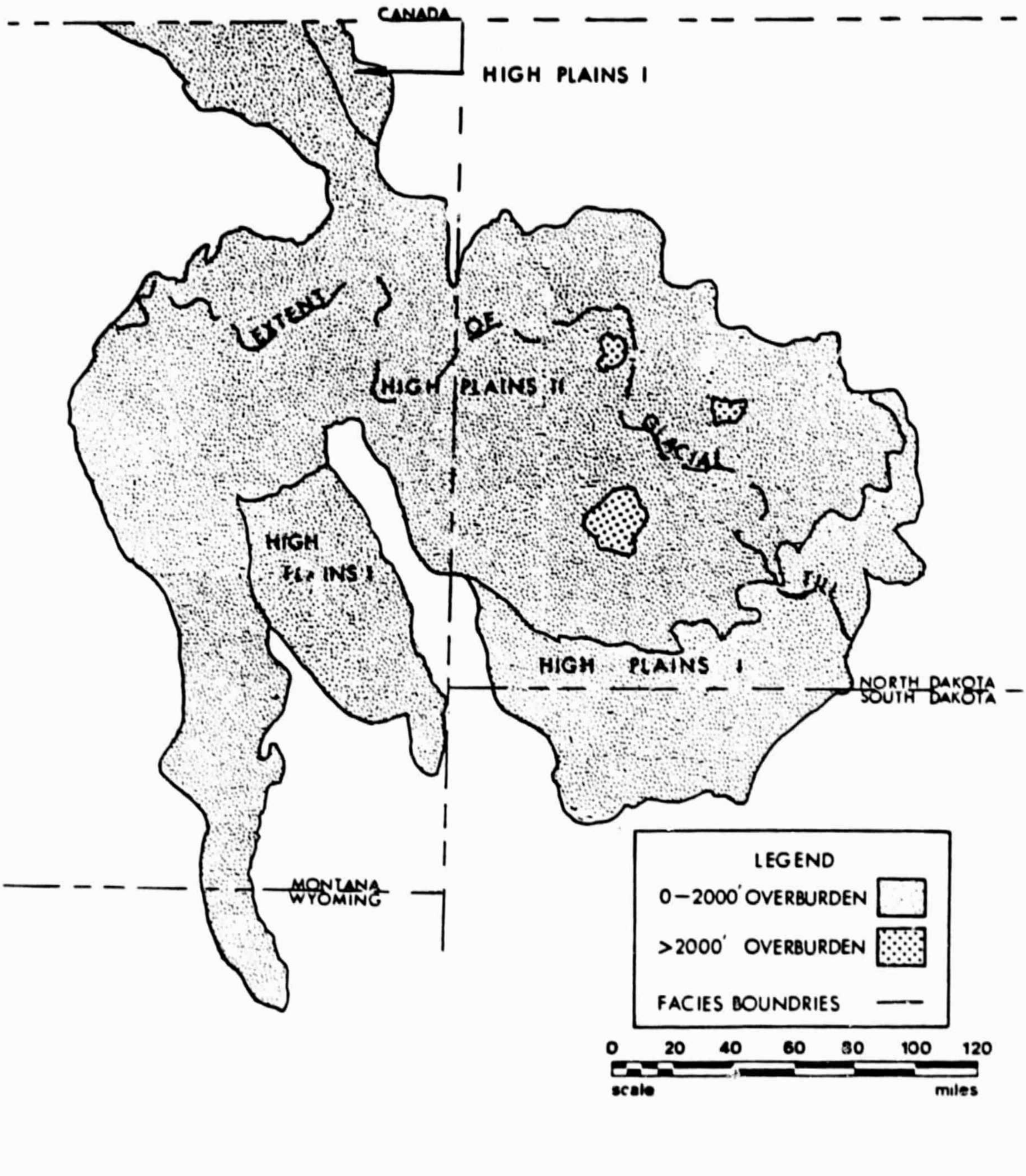

Figure 17. Location of Areas of Resource Estimation in the High Plains Lignite Province (In the area designated "High Plains I", the lignite-bearing formation is partially eroded; in "High Plains II", the full sequence is present. See Tables A-32 and A-33 for resources in each area and Table A-31 for total resources.)

the Raton Basin of southern Colorado and New Mexico; the Denver Basin of central Colorado; the Piceance-Uinta Basin of western Colorado and eastern Utah; the Green River Basin of central and western Wyoming; and the Powder River, Wind River, Big Horn, and Bull Mountain Basins of western Wyoming and southeastern Montana (see Figure 1). Smaller coal-bearing areas in North and South Park, Colorado, and the Blackfoot-Valier area of north central Montana have been excluded from detailed study because of very sparse data and small resource potential.

4.5.2 Geology

Within the general context of isolated coal basins separated by prominent areas of uplift, the character of the Rocky Mountain Basins is relatively diverse with respect to structural attitude (dip of the seams), displacement faulting, and depth of burial. In most Rocky Mountain Basins, dips on one side of the basin usually are greater than those on the other and, in a very general way, dips in the western basins are greater than those in the eastern part of the province. For example, in the basins of central Utah and Wyoming, dips on the steep flank exceed 70°, whereas, those on the gentle flank may be as low as 10°. In contrast, the steep flank of the Denver and Raton Basins in central Colorado and north central New Mexico dip on the order of 45°, whereas, the gentle flanks in some places dip only a few degrees. Dips nearer the centers of the basins are generally much more gentle that those on the basin flanks.

Although vertical displacement faulting is found everywhere in the province, it appears to be more intense on the steep margins of the basins, and as a rule, is more intense in the western basins than in those of the eastern part of the province. For example, the Wasatch and the western Green River Basins are commonly cut by major displacement faults, but such features are relatively rare in the Powder River Basin. Igneous intrusions are common but not abundant features of all Rocky Mountain Basins, with more intrusions occurring in the Alton-Kolob, Raton, and Piceance III-A areas.

Finally, the deeply buried character of the coal in the center of most of these basins appears to be a result of the structural history of the province. The major uplifts which now separate the basins developed in late Cretaceous and Tertiary time, and the material eroded from these highlands filled the adjoining basins with great thicknesses of sediment. Hence, in most basins the major coal seams of the late Cretaceous and early Tertiary are deeply buried under a mantle of younger debris.

The basic pattern of coal distribution within the basins of the Rocky Mountain Province is very similar to that of the Gulf Coastal Plain (compare Figures 18 and 19 with Figures 12 and 13). In a landward direction (the left side of Figure 18), the sediments are alluvial fan and alluvial plain deposits with little or no coal. These sediments grade seaward (toward the right on the section) into alluvial deposits with some thin coal seams, which develop laterally into thick seams that accumulated on the ancient shore line. Seaward of this zone of thick coal accumulation are sandstones of delta front and/or barrier origin, which grade laterally into dark-colored marine shales.

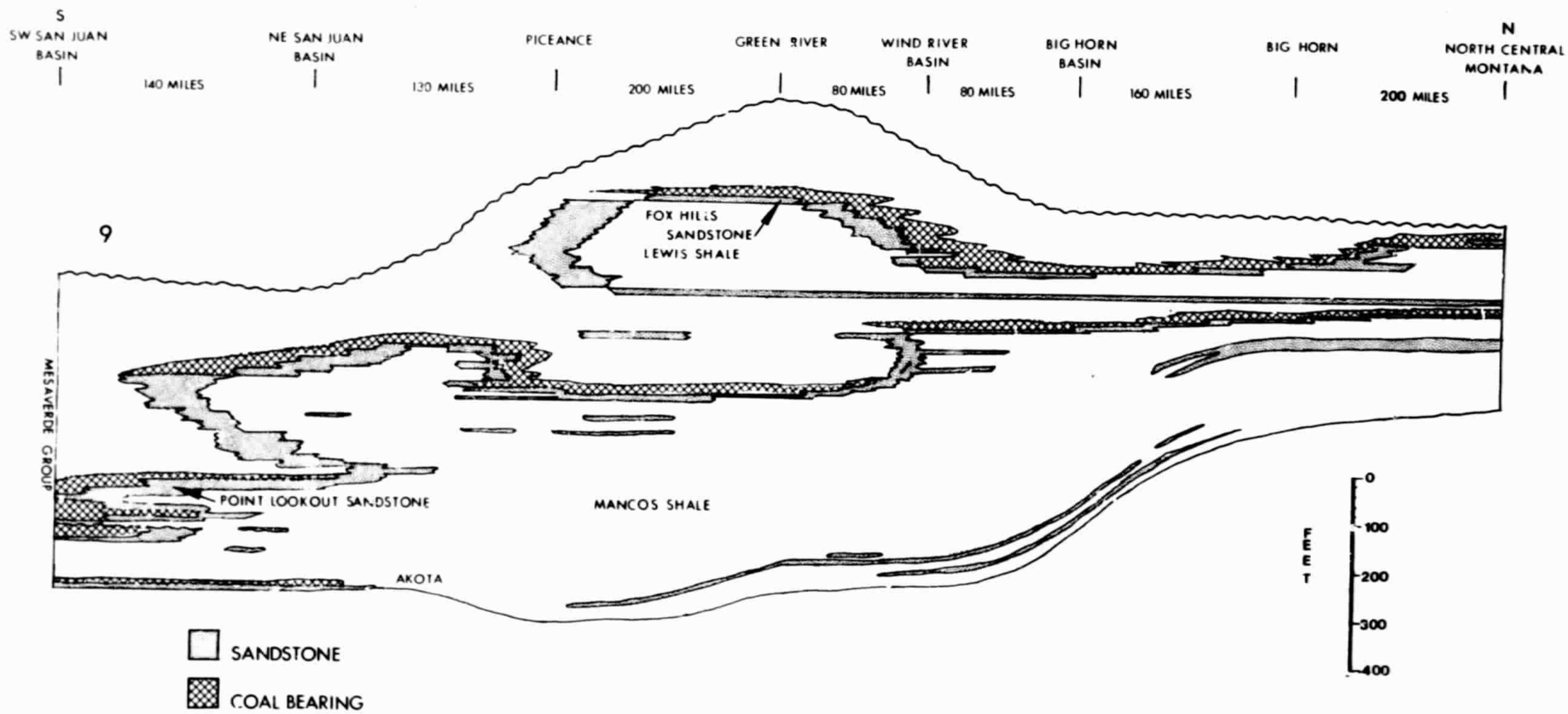

Figure 18. Cross Section of Cretaceous and Tertiary Coal-Bearing Strata in a South-North Direction Across the Rocky Mountain Province (See Figure 1 for location of this cross section.)

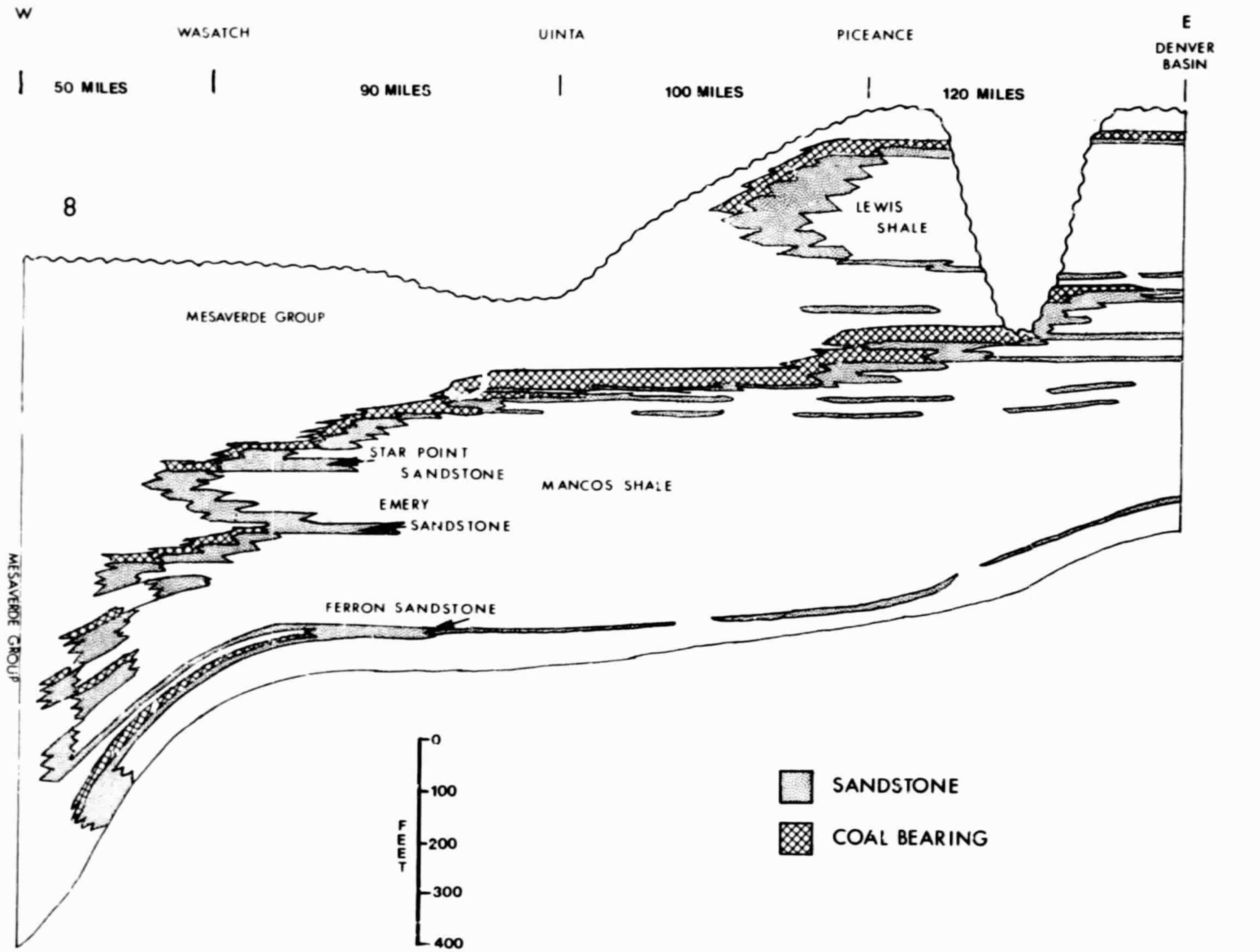

Figure 19. Cross Section of Cretaceous and Tertiary Coal-Bearing Strata in a West-East Direction Across the Rocky Mountain Province (See Figure 1 for location of this cross section.)

The present arrangement of the coal seams in the Rocky Mountain Province arises from the distribution of the facies described above, in response to the influences of subsidence and sediment supply. The general pattern in the province is one of progradation from south to north and from west to east (see Figures 18 and 19), which indicates that sediment was derived from the south and west, and that sedimentation rates exceeded subsidence. This progradation yields an overall sequence with marine shales in the lower part, grading upward into delta front and shoreline sandstones which are overlain by thick coal seams. These thick coals are overlain by thinner seams of the alluvial plain and are followed, in turn, by noncoal-bearing alluvial plain and alluvial fan deposits.

This general progradational sequence is interrupted periodically by marine transgression. (Note the Lewis shale in the central part of Figure 18, and the intertonguing of Mancos shale with the Mesaverde Formation on the left of Figure 18.) These interruptions were caused by subsidence in excess of sediment supply, and resulted in a reversal of the normal coal-bearing sequence, with shoreline coals overlain by fine-grained marine deposits. This overlapping of coals by marine or brackish water strata can lead to a deterioration in coal quality similar to that noted in the Carboniferous Interior Basins.

The interaction between sedimentation and subsidence yields substantial differences in total coal accumulation in different parts of the Rocky Mountain Province. In general, excess sedimentation leads to progradation, and excess subsidence is manifest by transgression. Thus, if there is a near balance between subsidence and sediment supply and if the supply of sediment is large (as, for example, in the Dakota and Mesaverde coals on the western side of Figure 19), zones of shoreline coals are stacked upon one another with intervening marine shales. However, the sedimentation rate which produced these particular formations was so great that these coals are relatively thin and not widespread. In contrast, a near balance of sedimentation and subsidence in absence of major sedimentary influx (such as in the Power River Basin of Wyoming), resulted in coals of the order of 100 ft thick, virtually unbroken by layers of other sediment.

4.5.3 Quality

The quality of the coal in the Rocky Mountain Province varies from bituminous to lignite, with most seams being of subbituminous rank. The coals of the Dakota group commonly range from 9,000 - 14,000 Btu/lb and are predominately bituminous. The Mesaverde coals range from 8,000 - 14,000 Btu/lb, depending on the area. The coals of the Powder River Basin are mainly low rank subbituminous, with heating values of 7,000 - 9,000 Btu/lb, whereas, those of the Green River and Uinta are mainly subbituminous to bituminous with an energy content of 8,000 - 14,400 Btu/lb. Values of 6,500 - 7,500 Btu/lb are reported in parts of the Denver Basin, indicating coals of lignite rank. In general, rank decreases from bituminous to subbituminous and lignite from west to east across the province, but this trend is interrupted in places where the coal is deeply buried, metamorphosed, or strongly deformed.

The sulfur content of the coal is usually very low compared to Appalachian and Interior coals, with a range of 0.4 - 5.8% and an average that is below 2.0%. The ash content varies from 3 - 5% and averages about 10%. More specific quality information will be presented in conjunction with the resource estimates for each coal-bearing region.

4.5.4 Mining

Major production of coal in the Rocky Mountain Province began with the construction of the western railroads, and production was maintained at a high level until steam-powered locomotives were replaced by diesel engines. In response to the energy crisis of the 1970's, production has resumed to serve the utility market, and mine mouth power plants have been introduced to reduce transportation costs. Currently, the province is undergoing a period of intense exploration and development.

During the early part of this century, underground mining was conducted by conventional methods. At present, mining companies are utilizing conventional, continuous, longwall, and surface mining methods, with conventional methods being replaced by continuous and longwall mining. Strip mining is being conducted in areas where coal lies near the surface and where the dips are gentle. In many areas, however, the steep dips and concomitant increase in depth of cover reduce the potential for surface mining. There have also been a few in-situ combustion experiments in this area.

4.5.5 Identification of Coal Resource Districts in the Rocky Mountain Province

Because the Rocky Mountain Province is composed of geographically isolated basins, some quite distinct geologically, and because the total tonnage is so large, the province is divided into four districts for purposes of detailed resource estimation. Although the districts are based primarily on geographic proximity of the basins, they are also to some degree homogenous with respect to geology and rank of the coal. The first of these districts, designated the Southwest District, includes the San Juan Basin of northwestern New Mexico and southwestern Colorado, the Black Mesa Basin of Arizona, and three small fields in south central Utah -- the Henry Mountains, Kaiparowits, and Kolob-Alton Fields (see Figure 1).

Directly north of the Southwest District is a group of coal basins which are designated the West Central District. This district includes the Wasatch and adjoining Emery and Uinta areas of east central Utah, and the Piceance Basin of northwestern Colorado. The West Central District also includes the very large Green River Basin located in southwestern Wyoming and northwestern Colorado, as well as the much smaller Hanna-Carbon area located just to the east.

Lying to the northeast of the basins comprising the West Central District are a series of coal basins which make up the Northern District. These include the Wind River and Big Horn of Wyoming, the very large Powder River Basin in northeastern Wyoming and southeastern Montana, and the Bull

Mountain area of southeastern Montana. The northeastern portion of the Powder River Basin is arbitrarily separated from the adjoining High Plains Lignite Province on the basis of coal rank. In the Powder River area, the coal is mainly subbituminous in contrast to coals of lignite rank in the High Plains Province.

The last district of the Rocky Mountain Province includes the Denver Basin of east central Colorado, and the Raton Basin of south central Colorado and north central New Mexico. Because of the proximity of these basins to the Front Range of the Rockies, they are designated the Front Range District.

4.5.6 Coal Resources of the Southwest District

Although the Southwest District contains only about 10% of the nearly 2200 billion tons of the total coal resources of the Rocky Mountain Province (Table A-34), it is geologically unique in that it contains some of the oldest coal seams in the Province. As shown on Figure 18, the coals of this region include those of the Dakota Formation as well as some of the oldest coals of the regressive Mesaverde Formation. The bulk of the resource is subbituminous, but the coals of the westernmost basins are bituminous, and some of the seams in the eastern approaches are of lignite rank. Most analyses show sulfur content of less than 1%, but some coals range upward to 5%. Ash content is high, averaging 10 - 15%. The coal basins of the Southwest District are illustrated on Figure 20, and resource estimates for each of the basins studied are given on Tables A-34 through A-43.

The Kolob-Alton area is one of the smallest fields of the Southwest District, with an estimated 15 billion tons. All of this coal lies in the Dakota formation, over half occurring at depths greater than 2000 ft (Table A-35). Reported sulfur content ranges up to 5%, which is very high for the Rocky Mountain area. As is common for this province, most coal is 15 ft - 42 in. thick.

Directly adjoining the Kolob-Alton area on the east is the Kaiparowits Plateau, which contains both Dakota and Mesaverde coals (see Table A-36). Total coal resources are over twice those of the Kolob-Alton area, and analyses of both ash and sulfur content suggest a better quality. Most of the Kaiparowits coal occurs at depths of less than 2000 ft and occurs in seams 15 ft - 42 in.

Just to the northeast of Kaiparowits is the Henry Mountains Field (see Figure 20), with very small resources (see Table A-37). The Henry Mountains coals occur in both the Dakota and Mesaverde formations and exhibit quality, seam thickness, and depth of cover similar to the Kaiparowits seams.

Lying to the southeast of the Alton-Kolob, Kaiparowits, and Henry Mountains fields is the Black Mesa area of northwestern Arizona, which contains 50 billion tons of coal, a quantity comparable in size to the aggregate resources of the three fields previously described. The tonnages are about equally distributed between the Dakota and Mesaverde formations (Tables A-38, A-39, and A-40), and are all buried under less than 2000 ft of cover. Most of these coals are in the 15 ft - 42 in. thickness category. Sulfur content is relatively low, but ash content runs as high as 50% in some samples. Heating values range from 12,000 down to 5,000 Btu/lb.

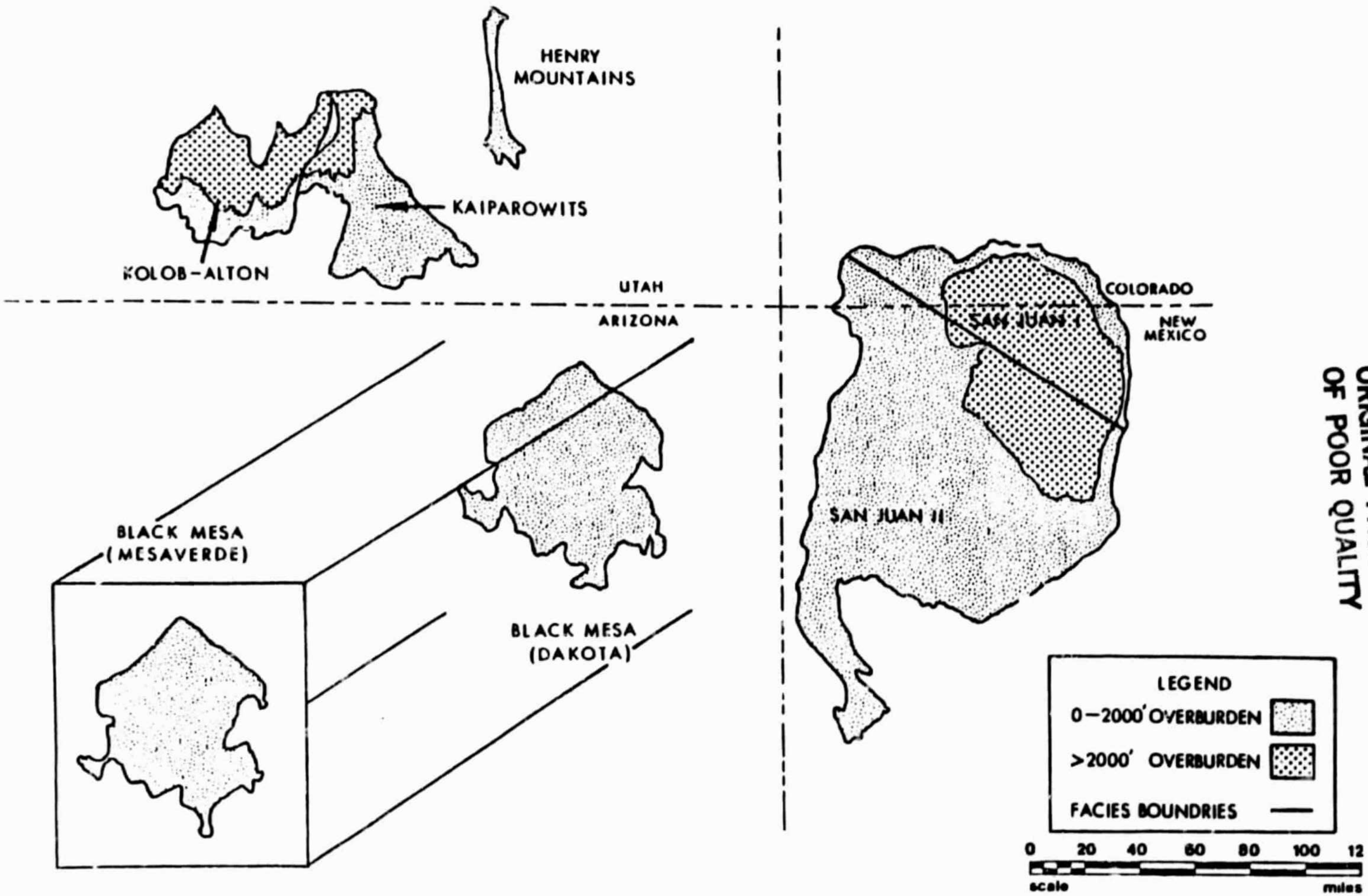

Figure 20. Location of Areas of Coal Resource Estimation in the Southwest District of the Rocky Mountain Province (See Tables A-35 to A-37 for the resources in the Kolob-Alton, Kaiparowits, and Henry Mountains areas respectively. See Table A-38 for total resources in the Black Mesa area, and Tables A-39 and A-40 for Dakota and Mesaverde resources in Black Mesa. See Table A-41 for total resources in the San Juan area, and Tables A-42 and A-43 for the partially eroded and full thickness of the coal formations in "San Juan I" and "San Juan II" areas, respectively. Total resources for the district are on Table A-34.)

The San Juan Basin is the largest in the Southwestern District and contains nearly two-thirds of the district's resources (Table A-41). Although most of the coal is in the Mesaverde formation (mainly in the northeastern part of the district), some coal is in the Dakota. Of the total of 180 billion tons, well over half occurs at depths of less than 2000 ft, and over half of this tonnage is in the 15 ft - 42 in. thickness category (Table A-41). The reported sulfur content of the coal is less than 1%, but the ash ranges from 15 - 20%. Heating values of 8000 - 10000 Btu/lb place most of the coal in the subbituminous rank. Tonnage estimates for the San Juan Basin were prepared in two parts -- San Juan I and San Juan II (Tables A-42 and A-43 and Figure 20). In San Juan I, the coal-bearing formation is almost completely buried, and hence, the full thickness of the coal-bearing rocks is preserved. In San Juan II, the coal-bearing formation lies at or near the surface, so only a portion of the original coal remains.

Original and remaining resources of the Southwestern District are shown on Table 12. The calculation of mined or lost-in-mining tonnages, assumes that recovery averaged 45%, and that all of the previous production came from seams 50 - 15 ft and 15 ft - 42 in. thick. The amount mined or lost in mining is trivial in comparison to the original resource. Of the remaining resource of nearly 300 billion tons, about 60% occurs at depths of less than 2000 ft, 30% lies more deeply buried, and about 10% occurs in areas where displacement faulting or igneous intrusion would be an impediment to mining. In areas under shallow cover (2000 ft or less), nearly 75% of the resources are reported to occur in beds thicker than 42 in. One must bear in mind, however, that thinner seams are not considered to be mineable and, hence, often go unreported.

4.5.7 Resources of the West Central District

The West Central District is the largest of the Rocky Mountain districts and contains about half of the total resources in the province. Geologically, the region is fairly complex, being composed of older Mesaverde and some Dakota coals in the Wasatch and Emery areas, somewhat younger Mesaverde coals in the Uinta and Piceance Basins, both younger and youngest Mesaverde coals in the Green River Basin, and Tertiary coals in the Hanna-Carbon area (see Figures 19 and 21). The rank of the coal varies from predominantly bituminous in the Emery, Wasatch, Uinta, and Piceance Basins, to subbituminous in the Green River and Hanna-Carbon areas. Sulfur content probably averages about 1% but ranges up to 5%, and ash is probably less than 10%. Most resources are reported to occur in beds 15 ft - 42 in. thick, and nearly 80% are found in areas with more than 2000 ft of overburden (see Table A-44).

The Emery area -- the smallest part of the West Central District -- is an extension of the Wasatch Plateau Field in which a much greater area of the coal-bearing formations has been eroded, yielding a substantially reduced total coal thickness. Total resources are estimated at about 20 billion tons, or about 1% of the total resource of the West Central District (see Table A-45).

Table 12. Original and Remaining Resources of the Southwest District of the Rocky Mountain Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥15° Faulted, and/or Intruded	Totals
Original Tonnage	0	6	125	20	27	178	85	94	80	6	28	292
Tonnage Mined/Lost	0	0.1	0.1	0	0	0.2	0.1	0.1	0	0	0	0.2
Remaining Tonnage[b]	0	6	125	20	27	178	85	94	80	6	28	292
Percent	0	2	43	7	9	61	29	32	27	2	10	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 50% of historical tonnage was derived from seams 50 - 15 ft thick, and 50% from seams of 15 ft - 42 in.

The Wasatch Field adjoins the Emery area directly to the north and is somewhat larger in area (Figure 21). It is characterized by much greater total coal thicknesses, with some of the resources occurring in beds greater than 15 ft thick (see Table A-46). Heating values range from 11,700 - 12,800 Btu/lb, and both sulfur and ash are reported to be low. Like most other Rocky Mountain Basins, a large proportion of the resources lie under more than 2000 ft of cover.

The Uinta Basin (Figure 21) directly adjoins the Wasatch area on the east, but because the rate of progradation of the Mesaverde shoreline system was relatively rapid, the total coal thickness is substantially less. Like the Emery and Wasatch Fields, the coal is ranked as bituminous with slightly lower values of Btu/lb, and somewhat higher sulfur and ash content. The total coal resources of Uinta Basin are estimated to be lower than the tonnage in the Wasatch Field (see Table A-47).

The Piceance Basin, which lies directly east of the Uinta Basin, contains slightly less than twice the total resources of the Uinta, Wasatch, and Emery Fields combined, the coal being of similar quality. Its resources are concentrated in seams thicker than 42 in., and a large proportion of the tonnage occurs at depths greater than 2000 ft (Tables A-48 to A-52 and Figure 21.) Substantial parts of the coal-bearing strata have been eroded in both Piceance I and III-A, and hence, the total coal tonnages in these two areas are somewhat smaller than the tonnage in Piceance II and III-B. The total coal thicknesses in the two latter areas are very large as a result of the stabilization of the prograding Mesaverde shoreline, and the accumulation of thick shoreline peat deposits.

The Green River Basin is the largest field in the West Central District, containing 800 billion tons or about 70% of the district's resources. The rank of the coal in the area is, however, mainly subbituminous with a heating value of 8,000 - 12,000 Btu/lb (see Figure 21 and Table A-53). Ash and sulfur content are similar to other coals in this district. Much of the coal is very deeply buried, with about 70% lying at depths greater than 4000 ft. (Because limited data permitted a projection of coal thicknesses into only half of the deep subsurface area, this is probably a low estimate.)

The Green River Basin is unique in that the major coal-forming shoreline environments occur twice in the rock sequence. As shown on Figures 18 and 19, Mesaverde coals were formed by shoreline progradation over the thick Mancos marine shale. Marine transgression (represented by the Lewis shale) followed deposition of these coals, and a second, younger set of coals was deposited as a consequence of subsequent detrital progradation over the Lewis marine deposits.

The Hanna-Carbon Basin lies to the east of the Green River area (Figure 21), and the coals within it range in age from latest Cretaceous to earliest Tertiary. Total resources are small relative to the Green River, but the coal quality is generally comparable (Table A-54). A relatively large portion of the resources is in seams greater than 15 ft thick and under less than 2000 ft of cover.

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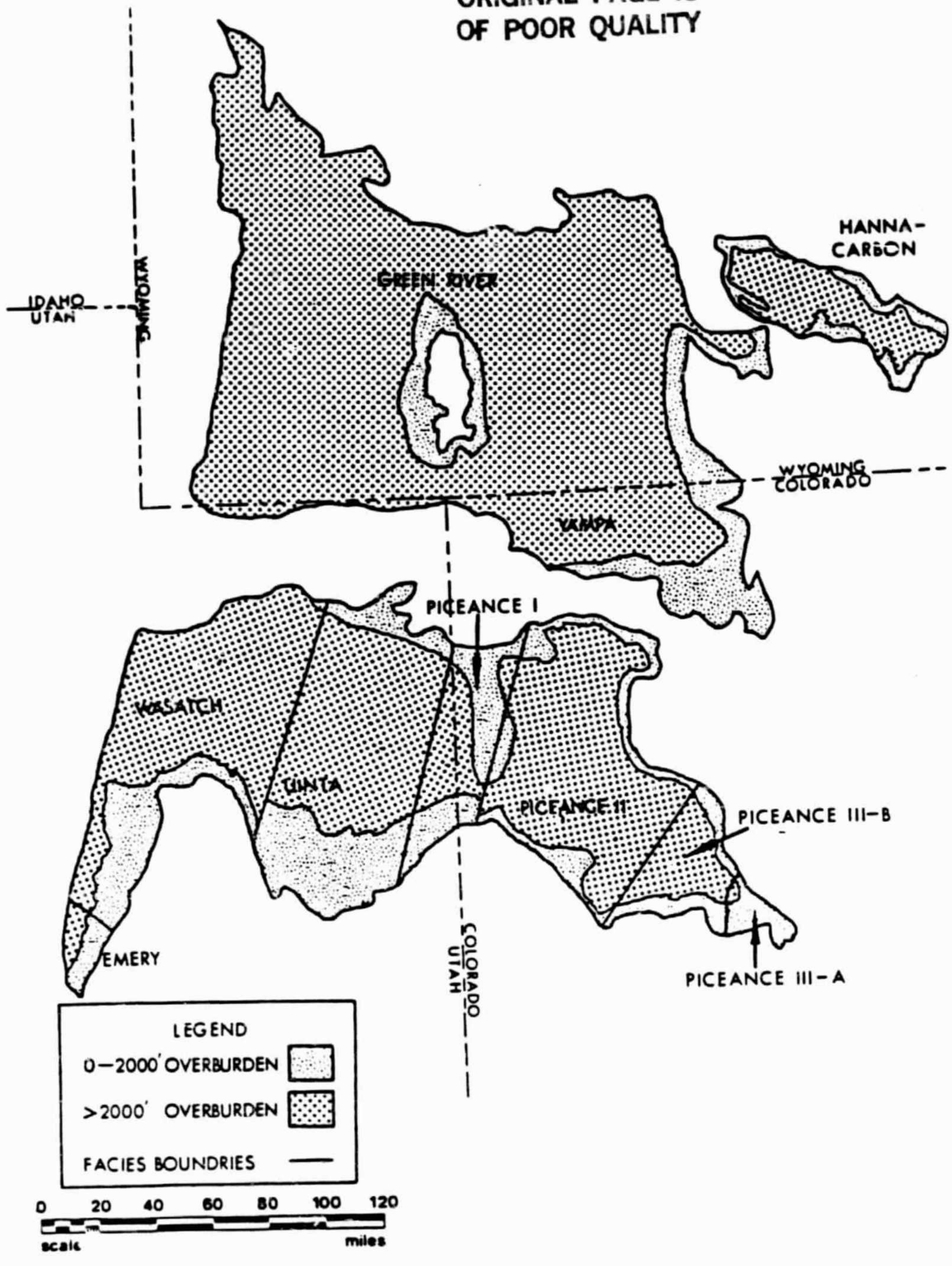

Figure 21. Location of Areas of Resource Estimation for the West Central District of the Rocky Mountain Province. (See Tables A-45 to A-47, A-53, and A-54 for resources in the Emery, Wasatch, Uinta, Green River and Hanna-Carbon areas, respectively. See Table A-48 for total resources in the Piceance area and Tables A-49 and A-51 -- "Piceance I" and "Piceance III-A", respectively -- where the coal-bearing formations are partially eroded. See Tables A-50 and A-52 -- "Piceance II" and "III-B", respectively -- for areas where the full sequence of the coal bearing formations are present, and Table A-44 for total resources for the district.)

Original and remaining resources of the West Central District are shown on Table 13. In the calculation of remaining resources, it is assumed that recovery has not exceeded 45%, that mining has not extended below 2000 ft, and that two-thirds of the resource was derived from seams at least 42 in. thick. These assumptions imply that only 1.5 billion tons have been mined or lost in mining. Of the remaining tonnage, it is estimated that about 80% occurs at depths from which the coal is not readily extractable, and about 5% occurs in areas where steep dip, displacement faulting, or intrusion will impede extraction (Table 13). The remaining 15% of the resource appears to be concentrated in seams thicker than 42 in., but these data may be biased because thin seams are not often recorded.

4.5.8 Resources of the Northern District

The Northern District contains about one-third of the total resources in the Rocky Mountain Province (Table A-55). The coal-bearing basins of this region are shown on Figure 22. Geologically, the region is relatively simple, containing late Cretaceous and early Tertiary coals of the Mesaverde, Lance, and Fort Union Formations -- a pattern similar to the Hanna-Carbon Fields of the West Central Province and the basins of the High Plains Lignite Province. The rank of these coals varies from bituminous to lignite, but most of the resource is subbituminous. Reported sulfur content ranges up to about 2%, but is probably 1% or less for most seams. The ash content varies considerably, and may range as high as 50% for some coals. Many of the seams are very thick, with about 30% of the tonnage attributed to seams thicker than 15 ft. In contrast to other districts in the Rocky Mountain Province, about one-third of the total tonnage occurs within 2000 ft of the surface, and slightly less than 10% lies within 500 ft of the surface.

The Wind River Basin is one of the smaller basins in the Northern District, and is located in the southwestern part, about 30 mi from the Hanna-Carbon Field. The total coal thicknesses are rather moderate for the Northern District as a whole, and some of the coal is of lignite grade. In some respects, the Wind River Basin is similar to other Rocky Mountain basins, with sulfur content ranging downward from 2%, ash running about 10%, and resources being concentrated in the 15 ft - 42 in. thickness category. Most of the coal occurs at depths greater than 2000 ft. Little tonnage occurs in beds dipping more than 15°, and much of the coal is under shallow cover (Table A-56).

The Big Horn Basin lies just to the north of the Wind River area and has a similar geologic setting. However, the total resources are substantially larger, as a result of both greater area and greater thickness of coal (see Table A-57 and Figure 22). Approximately 80% of the tonnage lies beneath 2000 ft of cover and can be regarded as an important resource under present mining constraints.

The Bull Mountain Basin, a very small area lying just to the north of the Big Horn Basin, has total resources amounting to 11 billion tons (see Figure 22 and Table A-58). A substantial portion of these coals occur at depths less than 500 ft, and all lie within 2000 ft of the surface. All seams

Table 13. Original and Remaining Resources of the West Central District of the Rocky Mountain Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥ 15° Faulted, and/or Intruded	Totals
Original Tonnage	0	18	103	25	23	168	52	117	204	756	62	1191
Tonnage Mined/Lost	0	0.5	0.5	0.5	0	1.5	0.8	0.7	0	0	0	1.5
Remaining Tonnage[b]	0	17	102	25	23	167	51	116	204	756	62	1189
Percent	0	1	9	2	2	14	4.3	10	17	64	5	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 33% of historical tonnage was derived from seams 50 ft - 15 in. thick, 34% from seams of 15 ft - 28 in. and 33% from seams of 42 - 28 in.

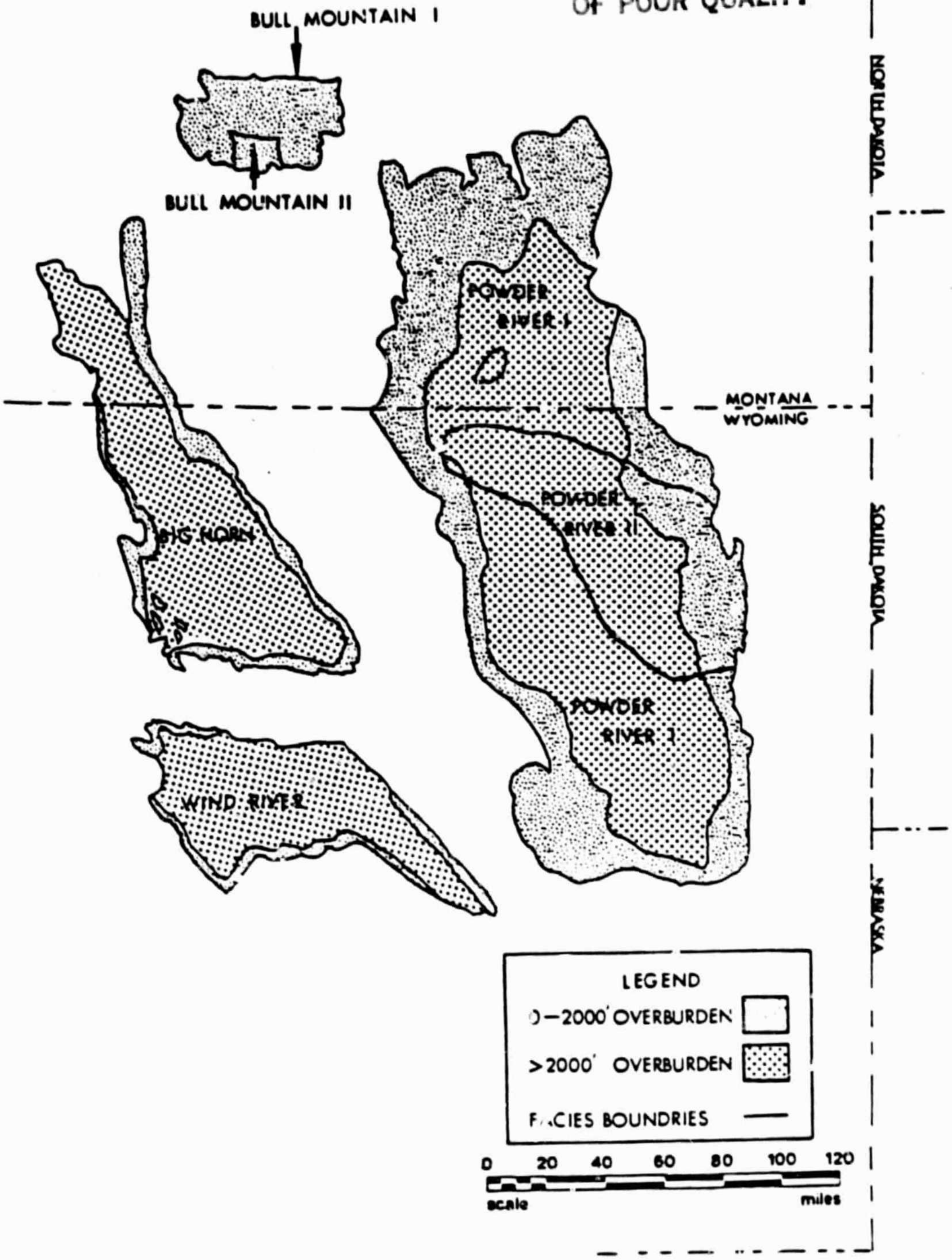

Figure 22. Location of Areas of Resource Estimation for the Northern District of the Rocky Mountain Province (See Tables A-56 and A-57 for resources in the Wind River and Big Horn areas and Table A-58 for total resources of the Bull Mountain area. Tables A-59 and A-60 show, respectively, resources for "Bull Mountain I" where the coal-bearing formations are partially eroded and "Bull Mountain II" where the full coal-bearing sequence is present. Table A-61 shows total resources for the Powder River area, and Tables A-62 and A-63 show, respectively, resources for "Powder River II" where the coal is thicker and the full sequence is present. Table A-55 shows total resources for the district.)

dip less than 15°, and about 40% of the resources are in seams from 15 ft - 42 in. thick. These coals are mainly bituminous with a sulfur content similar to other Rocky Mountain coals, but the ash percentage is probably somewhat higher. The Bull Mountain Basin is subdivided into two areas -- Bull Mountain I and Bull Mountain II -- based primarily on degree of preservation of the coal-bearing formations. In Bull Mountain II, nearly the full thickness of the formation is preserved, whereas in Bull Mountain I, the formation is partly eroded (Tables A-59 and A-60).

The Powder River Basin contains nearly 90% of the resources in the Northern District, and accounts for almost 30% of the resources in the entire Rocky Mountain Province (Table A-61 and Figure 22). These coals are mainly of Tertiary age (Paleocene), and most of the seams are subbituminous. Sulfur content averages about 1% for the region, and ash content is reported to be rather low. Dips of the coal-bearing units are uniformly moderate. Aside from the major concentration of resources here, the most noteworthy features of the Powder River Basin are that about 40% of the resources lie within 2000 ft of the surface, and that about one-third of these coals occur in seams greater than 15 ft thick.

For purposes of resource estimation, the Powder River Basin is divided into two parts -- Powder River I and Powder River II (Figure 22 and Tables A-62 and A-63). Powder River I is characterized by thinner total coal as a result of both partial erosion of the coal-bearing formation, and thinner total coal within the coal-bearing unit. In Powder River II, the total coal thickness is very large, much of it being in very thick seams.

Original and remaining resources of the Northern District are shown on Table 14. The calculation of remaining resources assumes that recovery averaged about 60%, and that all mining was conducted under less than 2000 ft of cover in seams thicker than 28 in. These assumptions imply that less than 1.0 billion tons have been mined or lost in mining, and that the original resources are essentially intact (see Table 14). Of these resources, only about 10% are believed to occur under more than 4000 ft of cover, about half between 2000 and 4000 ft, and less than 1% in areas that are faulted, intruded or steeply dipping. Slightly over one-third of the tonnage is believed to lie within 2000 ft of the surface, with most of it in beds thicker than 42 in. Although these characteristics suggest a major resource, the poorly consolidated character of the interburden strata would probably restrict underground extraction.

4.5.9 Resources of the Front Range District

The Front Range District includes the Denver and Raton Basins which lie on the east flank of the Front Range of the Rocky Mountains. Total resources are small, amounting to only about 5% of the aggregate tonnage in the Rocky Mountain Province (Table A-64). Although the two basins have the same general geologic setting, they are quite different in other respects. The coals of the Raton Basin are Cretaceous in age (Mesaverde), and thus, comparable to the San Juan Basin lying to the west. In contrast, the resources of the Denver Basin are late Cretaceous and early Tertiary, and hence, similar to the coals of the Powder River Basin to the north. Sulfur content is reported to

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Table 14. Original and Remaining Resources of the Northern District of the Rocky Mountain Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	51 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥ 15° Faulted, and/or Intruded	Totals
Original Tonnage	19	57	111	21	15	224	39	185	329	68	4	625
Tonnage Mined/Lost	0.2	0.1	0.1	0.1	0	0.5	0.3	0.2	0	0	0	0.5
Remaining Tonnage[b]	19	57	111	21	15	224	39	185	329	68	4	625
Percent	3	9	18	3	2	35	6	29	53	11	0.5	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 60% recovery and the assumption that 40% of historical tonnage was derived from seams thicker than 50 ft, 20% from seams of 50 - 15 ft, 20% from seams of 15 ft - 42 in., and 20% from seams of 42 - 28 in.

be about 1% in both basins, but ash appears to be somewhat higher in the Raton Field. There is also a major difference in rank. Seams of the Denver Basin are lignite and subbituminous coals, ranging from 6,500 - 9,700 Btu/lb, whereas, the Raton seams are bituminous with a heating value of about 12,000 Btu/lb (Tables A-65 to A-70).

Resources of the Denver Basin are estimated in two blocks -- Denver I and Denver II, based on the rank of the coal (see Tables A-65 to A-67, and Figure 23). In Denver I the rank is subbituminous, but in Denver II the rank is mostly lignite. In other respects, however, the two parts of the basin are quite similar. The major resources occur in seams with low dips; few seams are faulted or intruded; most of the coals are above 2000 ft; and both blocks have about the same amount of tonnage in seams 15 ft - 42 in. thick.

Resources of the Raton Basin are estimated to be only about half those of the Denver Basin (Table A-68). For purposes of resource estimation, this field is also divided into two blocks -- Raton I and Raton II (see Tables A-69 and A-70 and Figure 23). Raton I is similar in some respects to other Rocky Mountain bituminous basins, with shallow dips and a greater percentage of tonnage in seams 15 ft - 42 in. thick. Raton II has all of its resources in seams which dip less than 15° and lie under less than 500 ft of cover.

Original and remaining resources of the Front Range District are shown on Table 15. Estimation of the remaining resources of the Front Range Province assumes that recovery was on the order of 45%, and that mining was conducted in seams greater than 28 in. thick at depths less than 2000 ft. Application of these assumptions to the original resource of 90 billion tons indicates that about 1% has been mined or lost in mining (Table 15). Of the remaining resources, 20% occur in beds that are steeply dipping, faulted, or intruded. Nearly 60% of these coals lie within 2000 ft of the surface, and many seams are reported to be rather thick.

4.5.10 Summary of Original and Remaining Resources in the Rocky Mountain Province

The Rocky Mountain Province clearly emerges as one of the major resource areas of the U.S., with roughly 2.2 trillion tons, or about 20% of the entire U.S. coal resources (see Tables A-71 and 16). Areas of steep dip, displacement faulting or igneous intrusion account for only a minor proportion of the total resources. However, there is some tendency for steep dips to be associated with seams lying on the basin margins under shallow cover. About two-thirds of the total resource occurs in areas where the coal is buried under more than 2000 ft of cover, and most of this is probably beyond the limit of extraction as it is now practiced in the U.S. Of the remaining one-third of the tonnage, probably only a fraction can be mined by underground methods because of physical weakness of the interburden materials. Of the resources under less than 2000 ft of cover, however, a very large proportion appears to occur in beds thicker than 42 in., with a quarter of the tonnage occurring in beds thicker than 15 ft. Such thicknesses make surface mining attractive, and also favor high productivity in underground mining where roof and floor conditions permit.

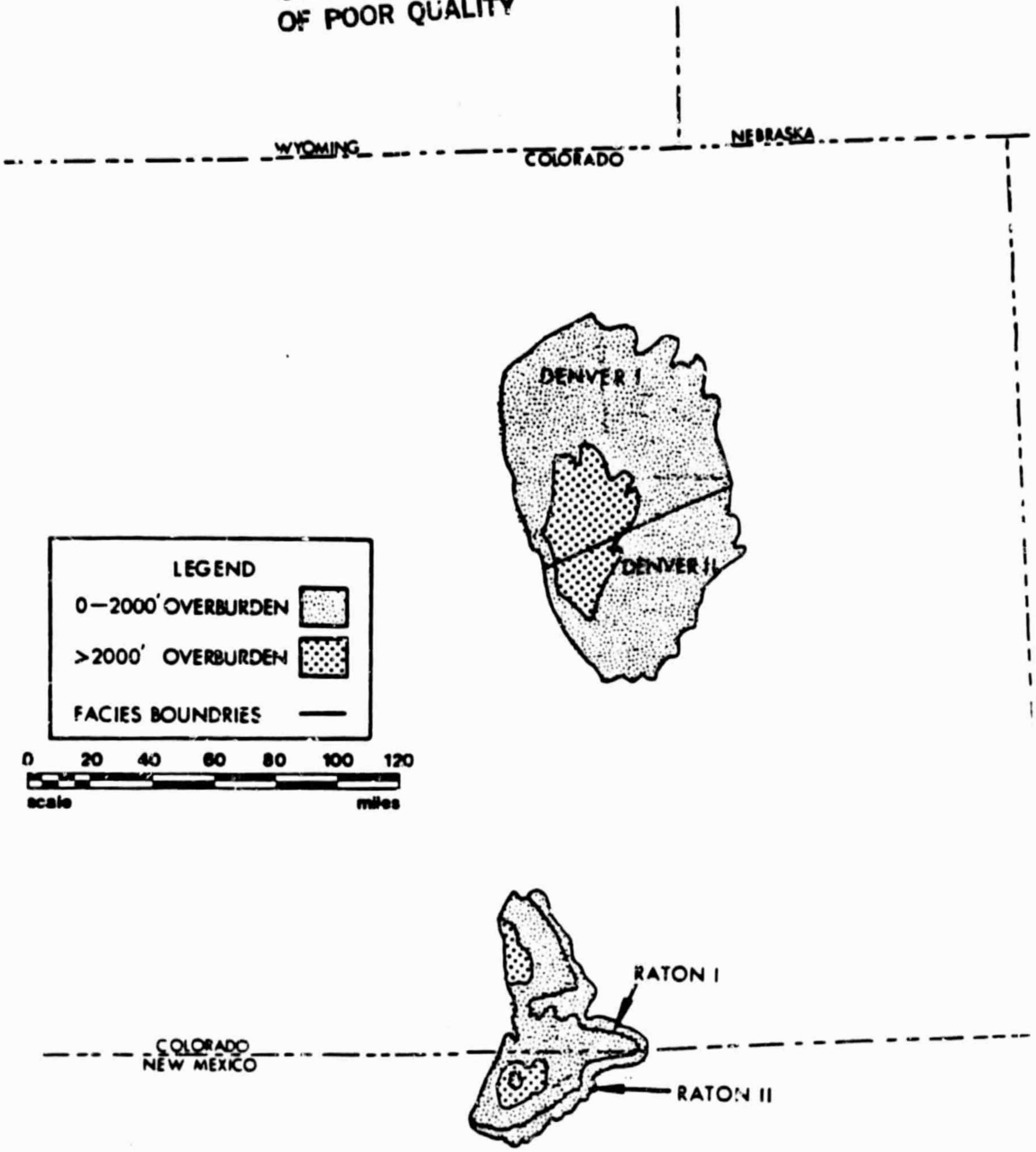

Figure 23. Location of Areas of Resource Estimation for the Front Range District of the Rocky Mountain Province (See Table A-65 for total resources in the Denver Basin area and Tables A-66 and A-67 for areas "Denver I" where the rank of coal is subbituminous, and "Denver II" where the rank is lignite. See Table A-68 for total resources for the Raton Area, and Tables A-69 and A-70 for areas "Raton I" where the coal seams are gently dipping and where a great percentage of tonnage occurs in seams 15 ft - 42 in. and "Raton II" in which the coal is gently dipping and has an overburden of less than 500 ft. Table A-64 shows resources for the district.)

Table 15. Original and Remaining Resources of the Front Range District of the Rocky Mountain Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft										Dip ≥ 15° Faulted, and/or Intruded	Totals
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	0	0	37	7	6	50	16	34	17	2	17	87
Tonnage Mined/Lost	0	0	0.5	0.5	0	1.0	0.5	0.5	0	0	0	1.0
Remaining Tonnage[b]	0	0	37	7	6	49	16	34	17	2	17	86
Percent	0	0	42	8	7	57	18	39	20	3	20	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on 45% recovery and the assumption that 50% of historical tonnage was derived from seams 15 ft - 42 in. thick, and 50% from seams of 42 - 28 in.

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Table 16. Summary of Original and Remaining Resources of the Rocky Mountain Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥ 15° Faulted, and/or Intruded	Totals
Original Tonnage	19	81	376	73	71	621	192	430	630	832	111	2195
Tonnage Mined/Lost	0.2	0.7	1.2	1.1	0	3.2	1.7	1.5	0	0	0	3.2
Remaining Tonnage[b]	19	80	375	72	71	618	190	428	630	832	111	2192
Percent	1	4	17	3	3	28	9	19	29	38	5	100

[a] Figures may not add to indicated totals due to round-off.

[b] Based on combination of Tables 12, 13, 14, and 15.

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Much of the Rocky Mountain coal is high-volatile bituminous and subbituminous with a low sulfur content, which makes it attractive for steam generation. In some areas, ash content is high and could conceivably present waste disposal problems at power plants where space is restricted.

4.6 NORTH ALASKA PROVINCE

4.6.1 Extent

The North Alaska Province extends from westernmost Alaska north of the Brooks Range to Barter Island in the northeastern part of the state (see Figures 1 and 24). The entire area lies north of the Arctic Circle.

4.6.2 Geology

Data necessary for geological study of the North Alaska Province are very sparse compared with other coal-bearing areas of the U.S. Discovery of oil and gas has led to some deep drilling, but very little detailed information is available for the study of coal resources. The general pattern of sedimentation and coal occurrence in North Alaska appears to be quite similar to that of the Rocky Mountain Province. In fact, the two provinces are probably related parts of a broad depositional structure which extends over the length of the North American continent, with intervening portions represented by the coals fields of the Canadian Rocky Mountains. The general depositional pattern of the coal-bearing formations is illustrated in Figure 25. Progradation appears to have been in a general northeastward direction, with major coals being formed in the shoreline position between a fluvio-deltaic sandstone facies on the southwest, and an offshore marine shale facies on the northeast. There were two major episodes of progradation, with the older represented by the Chandler Formation and the younger by the Prince Creek, both of which are late Cretaceous in age. There is some indication that Tertiary coals similar to those in the southern Rockies also occur here, but the available data are too insubstantial for inclusion in this report.

The general structure of the North Alaska Province appears to be relatively simple. Along the southwest edge, there are some broad open folds, exhibiting dips of less than 15°. To the northeast, these folds appear to die out, and the result is a gentle, uniform northeastward dip. Data are insufficient to define major areas impacted by either displacement faulting or igneous intrusion.

4.6.3 Coal Quality and Mining

Analytical data are not sufficient to indicate precise values for energy content, percent sulfur, and percent ash for the coals of the North Alaska Province, but it is probable that the coal is of subbituminous to bituminous rank. For the purposes of this report, it is assumed that there has been a negligible amount of mining in the North Alaska Province.

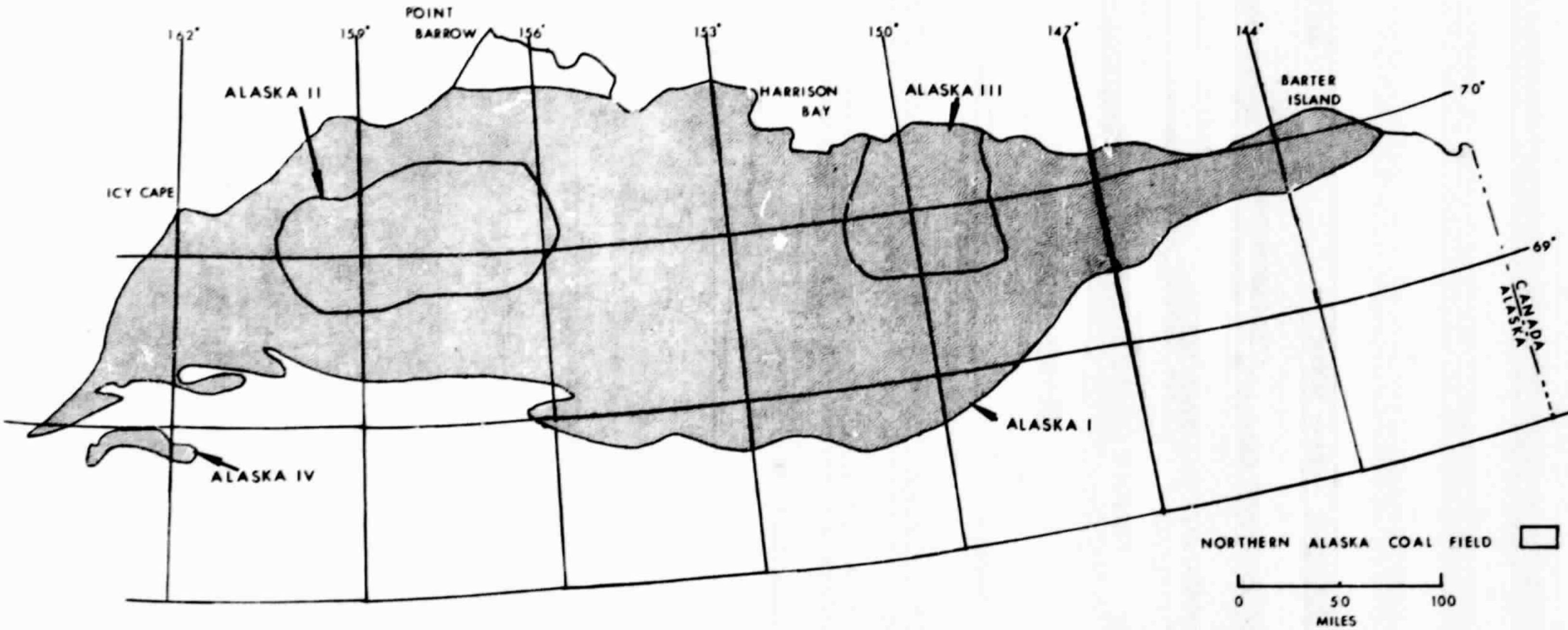

Figure 24. Location of Areas of Resource Estimation for the North Alaska Province (This area is subdivided at an enlarged scale on Figures 26 and 27. See Table A-72 for total resources.)

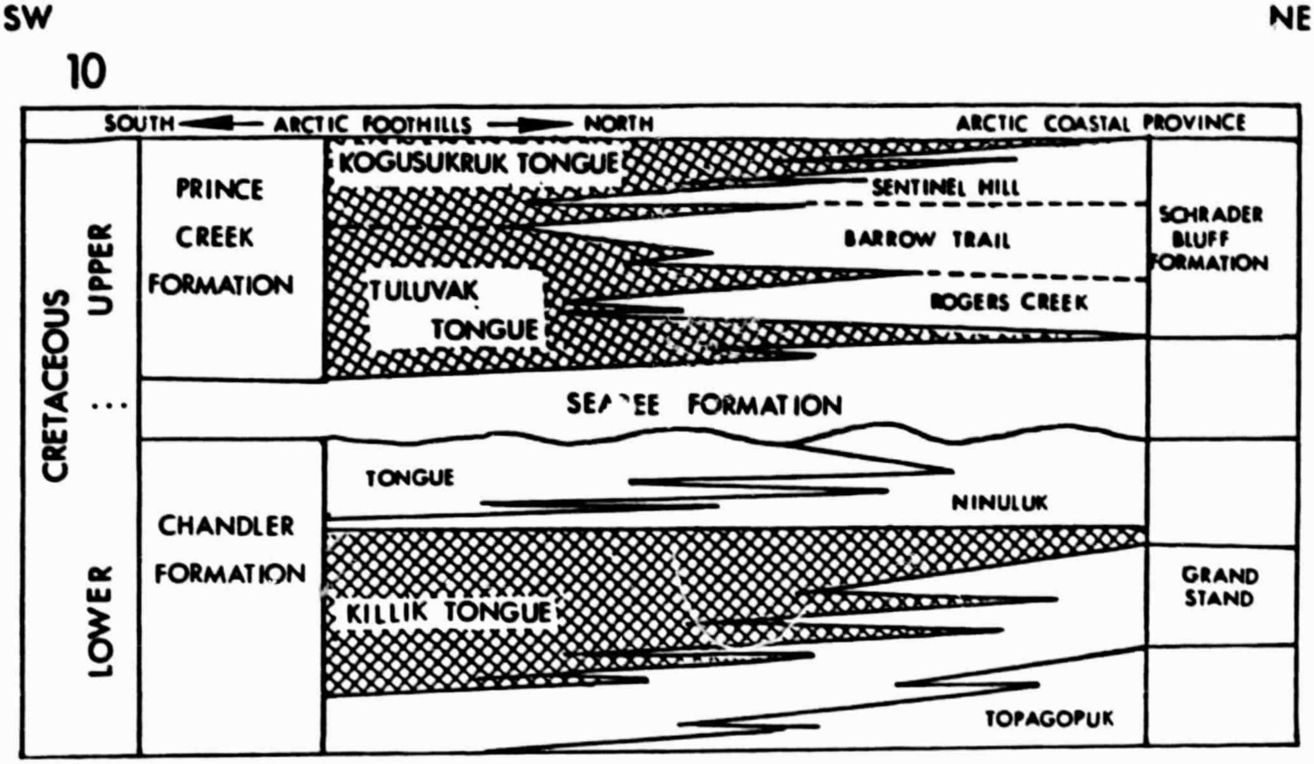

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Figure 25. Cross Section of Cretaceous Coal-bearing Strata in the North Alaska Province (See Figure 1 for location of this cross section.)

4.6.4 Resources of the North Alaska Province

Although data available for assessment of resources is extremely limited, it is clear that North Alaska is a major coal resource province, perhaps containing as much as one-third of the total U.S. coal tonnage (Table A-72). To estimate the resources of the North Alaska Province, the region was divided into four sub-provinces, in recognition of differences in data availability and overburden thickness. Figure 24 illustrates the four subprovinces, and Figures 26 and 27 show the eastern and western parts of the area in somewhat greater detail. Alaska I is the largest area, has the greatest number of data points (22), and contains resources from both the Chandler and Prince Creek Formations. The area of the Chandler Formation is shown on Figure 26, and that of the Prince Creek on Figure 27. Alaska II is an area of very deeply buried coal in the Chandler Formation. Information about Alaska III is based on a single drill hole in the Prince Creek Formation, which suggests a relatively modest total coal thickness. Alaska IV is a region in which the coal-bearing formation is partially eroded, and only a small total coal thickness has been preserved. Resource estimates for each area are given in Tables A-73 to A-76.

Since there has been no significant mining in the North Alaska Province, original and remaining resources are identical (Table 17). Although the province may contain as much as 30% of the total U.S. resources, the available data indicate that only about 10% or about 350 billion tons lies under less than 2000 ft of cover. Approximately 75% appears to be in seams greater than 42 in. thick, of which one-third may have seam heights greater than 15 ft. Steepness of dip and the presence of displacement faults are not sufficiently well known for precise description, but at present, there is no evidence that these anomalies are numerous enough to create significant extraction problems. However, the remoteness of the area and its hostile environment would pose serious obstacles to resource development.

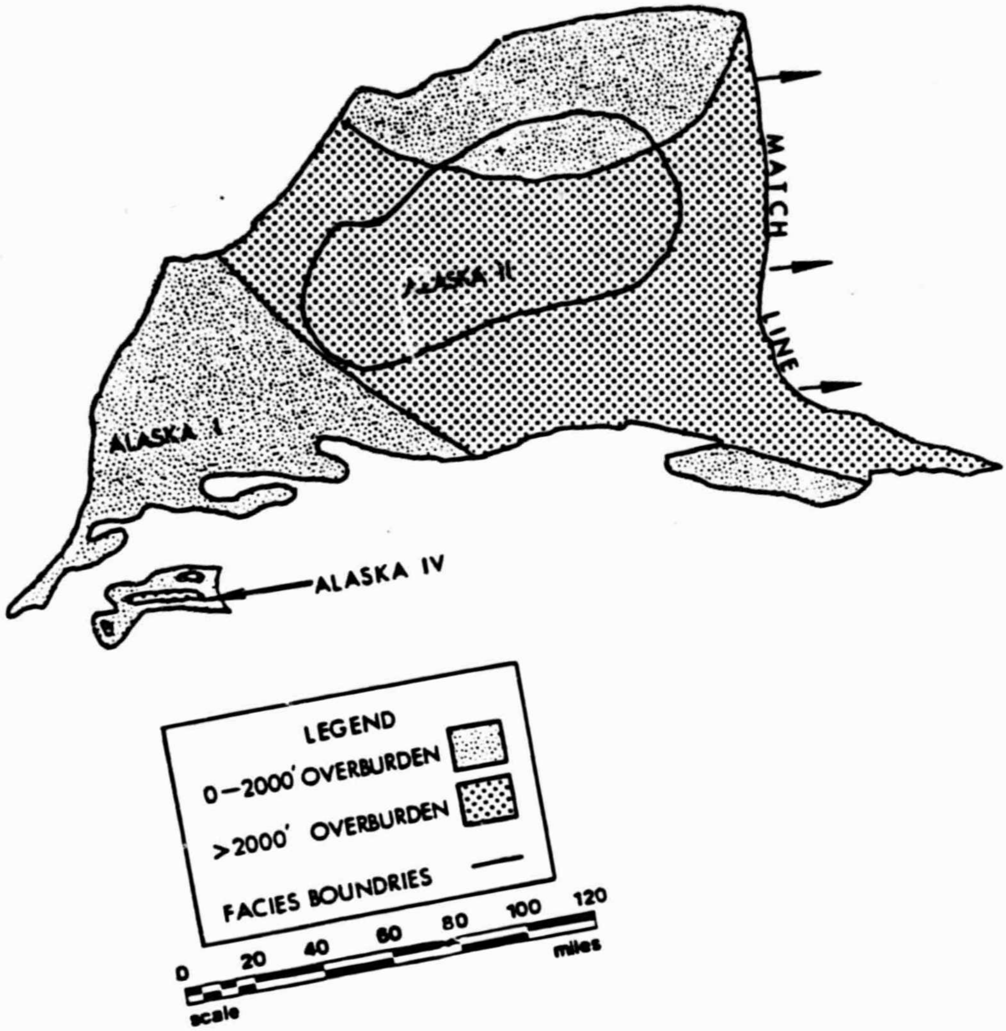

Figure 26. Location of Areas of Resource Estimation for the Western Portion of the North Alaska Province (See Table A-73 for resources for "Alaska I", an area of relatively high data density in the Chandler Formation; Table A-74 for "Alaska II", an area of deeply buried resources in the Chandler Formation; and Table A-76 for "Alaska IV", an area where the coal formations are partially eroded.)

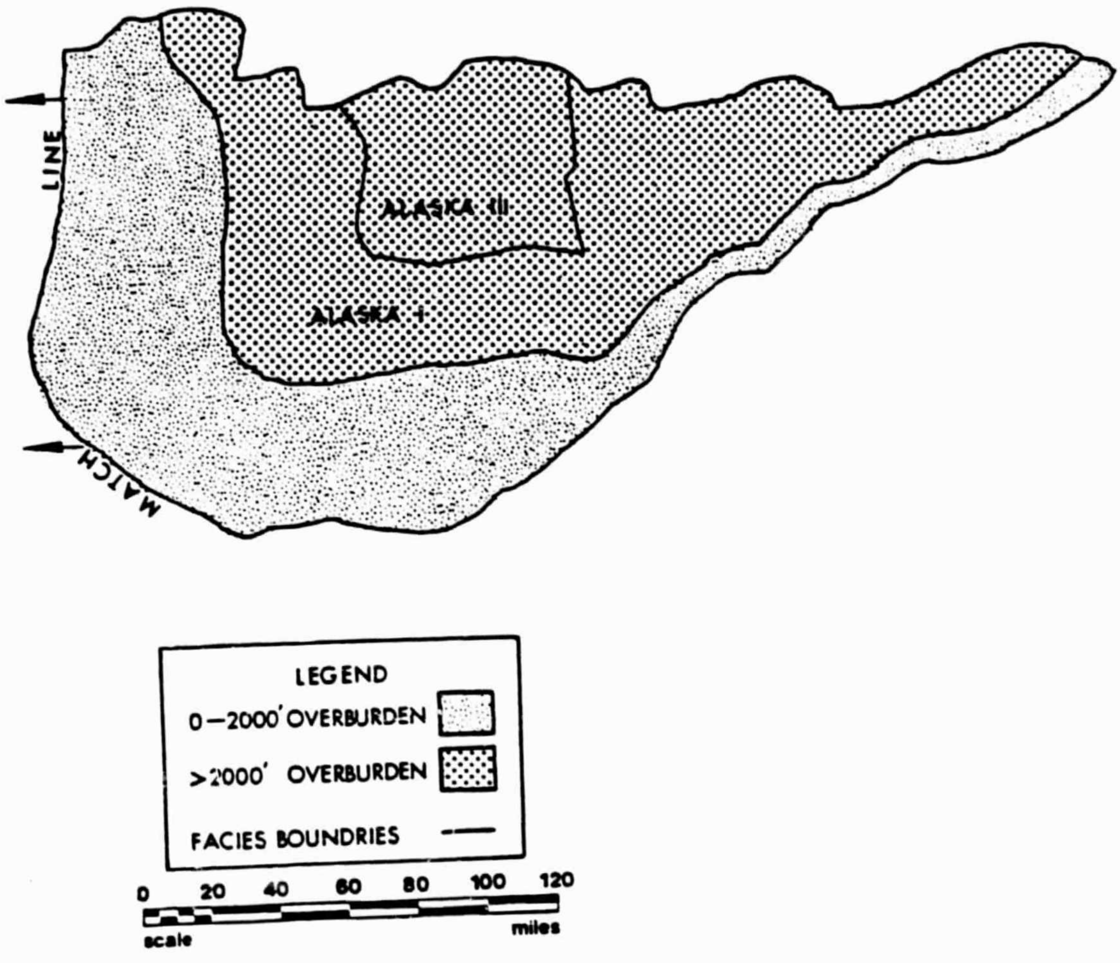

Figure 27. Location of Areas of Resource Estimation for the Eastern Portion of the North Alaska Province (See Table A-73 for resources for "Alaska I", an area of relatively high data density in the Prince Creek Formation; and Table A-75 for "Alaska III", an area of deeply buried coal and low data density.)

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Table 17. Summary of Original and Remaining Resources of the North Alaska Province

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions											
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft	Dip ≥ 15° Faulted, and/or Intruded	Totals
Original Tonnage	23	8[illegible]	177	37	45	366	14	352	1969	1180	0	3515
Tonnage Mined/Lost	-----	-----	-----	-----	-----	nil	-----	-----	-----	-----	0	nil
Remaining Tonnage[b]	23	83	177	37	45	366	14	352	1969	1180	0	3515
Percent	0.7	2	5	1	1	10	0.3	10	56	.34	0	100

[a] Figures may not add to indicated totals due to round-off.

[b] Because historical production is nil, the remaining resources are identical to the original tonnage.

SECTION 5

ANALYSIS OF MULTISEAM DEPOSITS

5.1 OBJECTIVES AND DISCUSSION OF PREVIOUS WORK

An examination of coal- and lignite-bearing sequences, together with an appreciation for the phenomena which created these rock series, shows that strata of coal (peat) and rock (mud or sand) commonly alternate in successive layers, and that the amount of noncoal material between the seams exhibits considerable variation. The intent of this chapter is to add some precision to this description, with the end objective being a gross quantitative characterization of major multiseam resource types. Current mining practice suggests that at least three resource types are worthy of attention:

(1) Isolated seams containing more than 50% coal by weight.
(2) Isolated seams containing less than 50% coal by weight.
(3) Multiple seams.

An isolated seam is so called because it is far enough removed from adjacent coals above or below, such that removal of this one seam has no material impact on subsequent mining of adjacent seams. Multiple seams are generally understood to be seams which are thick enough to be mined separately, but close enough vertically such that taking one will interfere with recovering the other. Quite often the rock layers in a multiseam sequence are very thin, raising the possibility of mining the sequence as one unit or "seam." Current mining practice indicates that seams with up to 50% rock by weight can be mined profitably.

Except for one previous study by Engineers International (1980), the authors are not aware of any published work describing these resources in a quantitative fashion. The study by Engineers International (EI) was devoted totally to describing the multiple seam resource type, and associated problems in exploitation; no examination was made of the resource type labeled "coal with rock partings." As Table 18 indicates, Engineers International estimated that in the aggregate, somewhat more than 50% of the demonstrated reserves may be classified as multiple seams, there being notable deviations from this figure both between and within geological provinces. Although limited to an estimate of multiple seam reserves, this study suggests that multiple seams also comprise a sizeable fraction of the aggregate coal resources, and are, by implication, a resource type of considerable importance to the United States.

Because of the brief description of the methodology used by Engineers International, it was very difficult to assess the adequacy of their analysis. However, the limited treatment of geology in EI's report indicated that the identification of multiple seam reserves was allocated a rather small portion of total study effort. Nevertheless, EI's work provided useful preliminary estimates for the current study, and identified the need to explain the apparent variations in multiple seam stratigraphy between and within provinces.

The data available to the current study included 932 borehole records and surface sections, thus permitting a much more detailed description of coal sequences than the map-oriented analysis conducted by EI. These logs contain a great deal of information about both coal measure geometry and lithology.

Table 18. Previous Estimate of Multiple Seam Reserves by State

Source: Economics of Multiple Seam Mining,
Engineers International, Inc. (1980)

(tonnage in billions)

	Total Original Reserves	Multiple Seam Reserves	Multiple Seam Percentage
Appalachia:			
Pennsylvania	75.1	52.2	69.5
West Virginia	116.7	83.5	71.6
Virginia	11.7	0	0
Ohio	46.6	12.6	24.0
East Kentucky	33.5	10.4	31.0
Tennessee	1.9	1.0	52.6
Alabama	13.8	4.2	30.4
Province Aggregate	299.3	163.9	54.7
Interior Province:			
Illinois	104.8	89.0	84.9
Indiana	37.3	25.3	67.8
West Kentucky	41.0	29.3	71.5
Iowa	7.2	2.5	34.7
Province Aggregate	190.3	146.1	76.9
Rocky Mountains:			
Colorado	99.3	30.0	30.2
Wyoming	33.5	10.5	31.3
Utah	39.3	12.0	30.5
Province Aggregate	172.1	52.5	30.5
U.S. Aggregate	661.7	362.5	54.8

In order to determine how to utilize these data in describing multiseams, one must understand the kinds of problems encountered in mining these resources. The bulk of this discussion will be devoted to multiple seams (as opposed to coal with rock partings) because it is much the more complex resource type.

5.2 MULTIPLE SEAM MINING TECHNIQUES AND ASSOCIATED IMPACTS

The description of multiple seam mining presented here is a condensed treatment of the phenomena covered by Stemple (1956), as summarized by Engineers International (1980). For simplicity of exposition, consider the extraction of two adjacent seams, where the intervening rock (interburden) is thin enough that the exploitation of one seam will interfere with the recovery of the other; the ideas presented below are extendable in a straightforward manner to operations extracting three or more contiguous coals. Stemple identifies three generic strategies for recovering these coals, with the choice of strategy depending upon (1) the overburden; (2) the lithology of the individual seams and the interburden (Stemple uses the term parting to denote interburden); and (3) the history of mining within the particular property of interest. These strategies are:

(1) Overmining, that is, "mining over" a seam which was previously removed (bottom seam first).

(2) Undermining, or "mining under" a previously extracted seam (top seam first).

(3) Simultaneous mining, in which the extraction of both seams proceeds in parallel, with operations in one seam inevitably being somewhat in advance of operations in the other.

All of these techniques are practiced with both room and pillar, and longwall methods, with room and pillar being more common in the United States.

5.2.1 Overmining (Bottom Seam First)

Overmining or taking the bottom seam first is thought to be both more difficult and more destructive to adjacent coals. Excavation of the lower seam causes caving of the immediate roof, and subsequently, subsidence of the overburden, which may extend all the way to the surface. Thus, at the minimum, overmining may encounter roof and floor fractures inherited from the underlying seam, greatly aggravating the hazard of rool falls. Very serious problems will occur under certain combinations of seam and interburden lithology. Whatever the mining method, removal of material from the lower seam will create stress concentrations in the overburden, often leading to separation of the upper seam along bedding planes. Frequently this will cause a roof support problem in the upper seam, particularly if the vertical displacement occurs precipitately. In addition, separation of the coal from the roof or floor can short-circuit the ventilating system, posing an explosion hazard. Finally, the disruption of the interburden opens pathways to groundwater and may, thereby, assist in keeping the floor of the upper seam dry, while causing flooding of the lower seam. All of these problems are made worse if the upper seam has a weak roof, and/or if pillars are left intact in the lower seam. On the other hand, problems of mining the upper seam are moderated if the lower seam is thin relative to the interburden thickness, and if the interburden has a favorable lithology. An example of a favorable lithology is the situation where the lower seam has an immediate roof of shale, overlain by a strong sandstone; the shale caves readily, filling voids effectively, while the sandstone acts as a beam to bridge any voids which remain, thus diminishing the upward influences of caving.

5.2.2 Undermining (Top Seam First)

Undermining or taking the top seam first is commonly regarded as posing fewer mining problems, and this is often the case unless the interburden is weak. More precisely, the nature of the impacts on the lower seam and resulting operational problems are a function of overburden, interburden thickness and strength, the composition of the roof and floor associated with the lower seam, and the extent of unrecovered pillars left in the upper seam. Indeed, most of the problems encountered in taking the lower seam are traceable to the stress concentrations caused by pillars left in the upper seam. Removal of the upper seam creates a zone of rubblization, which permits more of the overburden pressure to be transmitted to the strata acting as the main roof (load-carrying member) of the lower seam. Invariably the roof is weakened, leading to roof cracks (with heightened possibilities of falls and water flooding), floor heaves, and rib sloughing. The composition of the roof and floor will determine which problems are more severe: if both the roof and the floor are strong, roof falls and rib sloughing are more likely; if the roof is strong and the floor is weak, floor heaves will be troublesome; the consequences of a weak roof require no explanation. As in overmining, all of these problems are aggravated by a weak interburden and by partial extraction of the upper seam. An additional factor here is the increased loading on the lower seam which results from working at greater depths.

5.2.3 Simultaneous Mining

Simultaneous mining or parallel extraction of both seams is practiced occasionally in the United States, but is fairly common abroad in conjunction with longwall methods. In general, the impacts are a combination of overmining and undermining impacts, with the particular set of problems (falls, heaves, flooding, etc.) being a function of which seam is "ahead." Here again, the thickness and composition (strength) of the interburden is a key factor.

5.3 QUANTITATIVE DESCRIPTION OF MULTISEAMS

Clearly, the quantitative description of multiple seams is a challenging problem, both because the phenomena involved are complex and because our understanding of these pehnomena is at a very early stage in the United States. In the next section a preliminary, albeit crude attempt at quantitative characterization of resource properties is made by (1) defining impact measures, (2) describing how these measures were applied to the logs available to this study, and (3) discussing the numerical results obtained for coals under less than 2000 ft of cover -- the seams most likely to be exploited over the next 20 to 30 years.

5.3.1 Quantification of Multiseam Characteristics

As indicated in Section 5.1, multiseams may be grouped into two broad categories: (1) coal with rock partings, presumably mined as a contiguous unit; and (2) multiple seams, each of which is separately mineable, with some risk of adversely impacting adjacent seams. The coal/partings resource type is adequately described by the weight percentage of coal in the mineable unit because the expense of excavating and handling rock is the matter of primary concern to the operator.

A satisfactory description of the multiple seam resource is considerably more challenging. The discussion of Section 5.2 revealed three important clusters of variables:

(1) The loading upon the mined seam.
(2) The geometry of the seams and adjacent strata.
(3) The material properties of the strata.

In theory, a set of cores would provide the required elemental data, which, when combined with a dimensional analysis of the embedded loading problems, would produce nondimensional variables that could be used directly as multiple seam descriptors. We are not, however, in such a fortunate position. First, the data available to this study are logs not cores, with a log often being a rather undependable description of the rock type. Indeed, a procedure for the unambiguous classification of cores has only recently been published. Moreover, the rock types in this core book are specific to Appalachia (see Ferm and Weisenfluh, 1980); analysis of cores from another province would undoubtedly require an entirely new core book. Second, even if accurate descriptions of the cores were in hand, the sort of analysis outlined above would require measurements of material properties for each rock type. This is a large job which has not yet begun. Accordingly, material properties could not be included in the multiple seam descriptors used in this study.

Thus, the factors that are left are geometry and loading. Stemple's discussion of multiple seam mining impacts revealed two geometrical measures -- one for overmining ("upward zone of influence") and one for undermining ("interburden beam capacity"), defined as follows:

upward zone of influence = I/T

interburden beam capacity = D/I

where I: Interburden between the seams of interest.
T: Thickness of the subadjacent seam.
D: Depth of overburden to bottom of superadjacent seam.

The zone of influence parameter is well-known to mining engineers who routinely use this rule of thumb to gauge impacts on a superadjacent seam. Some feel that the influence of the lower seam effectively stops at an (I/T) of 15 to 20; others would advise using a figure of 25 to 30. In the analysis reported below, the cut-off value was 25. Thus, two adjacent seams were categorized as multiple seams, if they exhibited an (I/T) of 25 or less; and if the (I/T) exceeded 25, the top seam was labeled as isolated.

The parameter called "interburden beam capability" is not widely used in the mining community, but is no doubt familiar to those operators who practice multiple seam mining. Although very simple to calculate and readily obtainable from a log, (D/I) could not be used in this study because the logs typically failed to report overburden, and there was no convenient way to estimate it after the fact.

5.3.2 Description of Computational Procedure

The discussion of the preceding section identified two quantitative descriptors of multiseams used in this study: (1) coal weight percentage for coal/rock resources, and (2) the zone of influence parameter (I/T) for multiple seams. The required computations are easily done once the seams or mineable units are determined for each log.

A mineable unit is defined as a contiguous sequence of coal and rock which begins and ends with coal (i.e., coal on the top and bottom). Examination of any representative set of logs reveals that there is no unambiguous way of dividing the log into a mutually exclusive, collectively exhaustive set of units, such that every seam belongs to one and only one unit. After a number of different schemes were explored, the following algorithm was selected for defining mineable units because it was simple and it produced credible results:

(1) Select a cut-off value for the coal weight percentage in a mineable unit; for this purpose, 2 in. of coal was judged to weigh the same as 1 in. of rock (this corresponds to a coal weight of 80 lb/ft^3 and rock density of 160 lb/ft^3).

(2) Identify the uppermost seam not yet assigned to a mineable unit. Define this as the top coal.

(3) Identify the lowermost seam not yet assigned to a mineable unit. Define this as the trial bottom coal.

(4) Using the numerical assumptions in (1), compute the coal weight fraction lying between the top coal and the trial bottom coal. If the weight fraction exceeds the cut-off value, label all the seams between the top and current trial bottom coal as a new mineable unit, and go to (2). If the indicated weight fraction is less than the cut-off value, go to (5).

(5) Redefine the trial bottom coal as the seam immediately above the previous bottom coal. Go to (4).

This sufficed to partition a log into a nonoverlapping set of mineable units. After the entire set of logs had been processed in this manner, the flat-lying coals (mineable units) within each subarea were sorted into the following categories, and the tonnage was estimated for each in the manner described in Section 3.

(1) Thin seams, having a mineable unit height of 14 - 28 in.

(2) Isolated coal seams, having a mineable unit height in excess of 28 in., and containing at least 75% coal by weight.

(3) Multiple seams, in which each mineable unit exceeds 28 in., and has a coal weight fraction which varies from 75 - 100%.

(4) All mineable units not otherwise classified (in practice this category had negligibly small tonnage).

The results of this analysis are presented below in Section 5.3.3.

5.3.3 Discussion of the Results

Table 19 presents the results of the computational procedure described in Section 5.3.2. Note that this table focuses on the resources under less than 2000 ft of cover and excludes all coals that are thick, steeply dipping, or disturbed by faulting or igneous intrusion. The coals of Table 19 are subdivided into coals 14 - 28 in. thick and those 28 - 180 in. thick, with the latter being broken down into multiple seams and isolated seams, each exhibiting two different weight percentages of coal.

Examination of Table 19 leads to several useful generalizations about these five resource types. First, thin coals appear to be significant in Appalachia, the Interior, and portions of the Gulf Coast and the Rocky Mountains, but are much less important in the High Plains and North Alaska. However, this pattern may be an artifact of the data: in the latter three provinces, seams as thin as 28 in. go unrecorded in many logs because they are regarded as unmineable. Second, isolated seams containing less than 75% coal by weight (dirty coal) are a resource of minor proportions except in the Warrior Basin of Appalachia, and the Piceance and Hanna-Carbon Fields of the Rocky Mountains, where thin seams approximate 10% of subarea tonnage. Globally, dirty isolated seams appear to constitute about 1% of the national resources. This result, too, may be uncertain because seam measurements are not always made with great care, and in many cases all but the most conspicuous partings are ignored.

Third, multiple seams of 28 - 180 in. (defined as contiguous coals with an $I/T \leq 25$) are by far the most numerically important resource type for the coals under less than 2000 ft of cover. Like isolated seams, multiple seams where the mineable units contain at least 75% coal are more abundant than sequences in which the seams contain less than 75% coal. Moreover, multiple seams containing at least 75% coal dominate isolated seams containing a comparable coal percentage in all subareas except Southern Appalachia and the Warrior Basin, where the two resource types are of approximately equal importance. Throughout the Interior, most of the Gulf Coast, the High Plains, the Rocky Mountains, and North Alaska, multiple seams typically are 1.5 - 3 times more prominent than isolated seams, ranging up to 6 - 7 times more abundant for some basins in the Rocky Mountains. Examination of Table 19 reveals that the proportion of multiple seam resources varies considerably from province to province -- from a low of 37% in the Interior to a high of 76% in the High Plains.

Although there is considerable variation in the prominence of multiple seams within a province, the Warrior Basin and the Western Interior are the only significant fields where the multiple seam proportion drops below 30%.

The relatively low multiple seam proportion in the Warrior Basin, compared to the Gulf Coast and Rocky Mountain Provinces, may arise from the manner in which data are reported for the latter provinces. In all provinces the coal seams are clustered into coal-bearing rock units separated by thick layers of barren (noncoal-bearing) marine rock. (See Figures 3, 12, 13, 18, and 19). In the Warrior Basin, however, both barren marine and coal-bearing units are recorded on the logs, whereas, in the Rocky Mountains and Gulf Coast, only the coal-bearing formations are reported because the barren rock units are so thick. Hence, seams at the top and bottom of the coal-bearing formations in the Warrior Basin and those thin seams lying within the barren units will appear as isolated seams, whereas, similar beds in the Rocky Mountains and Gulf Coast are typically not recorded.

The low proportion of multiple seams in the Warrior Basin, relative to both the northern Appalachian and the Eastern Interior fields, probably represents a valid comparison because it is consistent with the diminishing thickness of the noncoal-bearing marine sequences in the Dunkard, Pocohantas, and Eastern Interior Basins.

The indicated low proportion of multiple seams in the Western Interior Basin, relative to the Eastern Interior, is probably a reflection of the diminishing thickness of coal beds westward from Illinois to Kansas. As the coal seams thin to 14 in. or less, the thickness of the intervening rock renders the remainder "isolated seams."

Variation in the proportion of multiple seams between subareas in the Rocky Mountains and Gulf Coast Provinces may reflect a balance between tectonic subsidence and sediment supply previously noted in the Rocky Mountain Province (see pages 60 and 63). Rapid progradation in absence of major sediment influx would favor the development of tabular, isolated seams, whereas, rapid influx of sediment, particularly in an area of rapid subsidence, would tend to produce split, multiple seams.

Finally, upon comparing the multiple seams percentages of Table 19 with corresponding figures developed by Engineers International (see Table 18), one concludes that the two studies accord the same level of importance to this resource. The multiple seam percentages presented here differ somewhat from those reported by EI; however, this is to be expected in light of the differences in the methods employed.

The findings of this analysis of multiseams may be summarized very briefly: (1) multiple seams of moderate thickness are a significant resource in all provinces; (2) isolated seams with less than 75% coal appear to be a minor resource; (3) isolated seams containing at least 75% coal, while prominent, constitute only about one-half the tonnage of multiple seams; and (4) thin seams of 14 - 28 in., although not as consistently prominent as thicker isolated coals, constitute substantial regional resources in Appalachia, the Interior, and parts of the Rocky Mountain Province.

Table 19. Percentage Breakdown of Flat-Lying, Undisturbed Coal Above 2000 ft and 14 in. - 15 ft Thick into Thin Seam, Isolated Seam, and Multiple Seam Resource Types

Province	Subarea	Original Tonnage (billions)	Seams 28 in. to 15 ft — Isolated Seams ≥ 75% Coal	Seams 28 in. to 15 ft — Isolated Seams <75% Coal	Seams 28 in. to 15 ft — Multiple Seams ≥ 75% Coal	Seams 28 in. to 15 ft — Multiple Seams < 75% Coal	Seams 14-28 in.
Appalachia	Allegheny	232	30%	2%	39%	3%	26%
	Monongehela	103	27	0	44	13	16
	S. Appalachia	336	29	6	26	12	27
	Warrior	167	17	8	14	7	54
Aggregate		838	27%	4%	30%	9%	30%
Interior	E. Interior	362	22	1	43	3	31
	W. Interior	348	6	3	23	5	63
Aggregate		710	14%	2%	33%	4%	47%
Gulf Coast	Texas	1153	38	0	55	4	3
	Louisiana, Arkansas	292	32	0	42	0	26
	Mississippi	394	38	0	39	1	22
	Alabama	82	15	0	65	17	3
Aggregate		1921	38%	0%	49%	3%	10%
High Plains		593	13%	0%	68%	8%	11%
Rocky Mountains	Alton-Kolob	7	0	4	64	25	7
	Kaiparowits	31	24	0	56	10	10
	Henry Mountains	1	13	0	72	15	0
	Black Mesa	52	16	0	71	6	7
	San Juan	113	32	1	37	8	22
	Emery	3	26	0	33	37	4
	Wasatch	23	10	0	70	13	7
	Uintah	6	0	0	0	89	11
	Piceance	54	12	13	38	23	14
	Green River	123	15	0	64	7	14
	Hanna-Carbon	8	18	9	56	6	11
	Wind River	2	26	2	54	0	18
	Big Horn	5	24	2	35	22	17
	Bull Mountain	11	0	0	54	6	40
	Powder River	213	10	0	63	22	5
	Denver Basin	50	25	0	65	0	10
	Raton Basin	13	14	0	36	28	22
Aggregate		715	16%	1%	58%	13%	12%
North Alaska		366	26%	0%	51%	10%	13%
Totals:		5143	26%	1%	46%	7%	10%

SECTION 6

SUMMARY AND CONCLUSIONS

6.1 DESCRIPTION AND COMPARISON OF RESULTS

A summary of the estimated tonnage for each of the major U.S. coal provinces is given in the last two columns of Table 20, which reports an aggregate resource of about 11.6 trillion tons. As Table 20 indicates, the total resources are not equally distributed. The bulk of the tonnage resides in the Gulf Coastal Plain and North Alaska, each having about 30% of the total; approximately 20% occurs in the Rocky Mountain Province; and the Appalachian Plateau, Interior, and High Plains Provinces each account for 5 - 7% of the aggregate tonnage. If it is assumed that most of the resources in the Gulf Coast and High Plains Provinces are lignite, it is clear that lignite comprises about 40% of the aggregate U.S. Resources, the remaining 60% being predominately subbituminous and high-volatile bituminous coal. Coals of higher rank occur, and a general description of them is to be found in section 2.2. However, it is felt that coals with a rank above high-volatile bituminous do not comprise more than about 1% of the total resources (see Table 1).

Table 20 also compares the detailed estimates of this report, both with the preliminary estimates made in Phase I of this study and with those published in the 1980 Keystone Coal Industry Manual. The most conspicuous feature of these data is that the 11.6 trillion ton aggregate estimate produced by this study is about three times greater than the other two, with the major differences arising from the addition of over 3.5 trillion tons each for the Gulf Coast and North Alaska Provinces. However, from the point of view of both quantity and quality of the basic data, the estimates for North Alaska and the Gulf Coast are not nearly so well controlled as those for the other provinces. Nonetheless, the results of this study do suggest that the importance of Alaska and the Gulf Coast Provinces has been seriously underestimated.

Although not so conspicuous, substantial increases in estimated tonnage were obtained for other provinces, particularly the Interior, Appalachian, and Rocky Mountains. Since the data used in preparing these estimates are probably very similar to the data used to produce the estimates reported by Keystone, the indicated discrepancies are undoubtedly a result of differences in methods. The Keystone data were based on reports published by various state and Federal agencies which, although somewhat variable in methods of estimation, all subscribe to some sort of geographic limit on extrapolation of the resource from data control points. The methods employed in the present study are not dependent on such constraints, but rather rely on the establishment of approximately homogeneous coal facies blocks, and the statistical treatment of thickness variation within blocks to quantify estimation uncertainty (see Section 3.2.4). Such methods permit larger areas to be included in the estimates, and not surprisingly, produce somewhat larger tonnage figures.

Another factor which could lead to overestimation in this study arises from the relatively small number of samples used in each analysis area, and

Table 20. Resource Estimates for U.S. Coal Provinces in Which Steep Dips, Faults, and Igneous Intrusions are not Major Characteristics

(Tonnage is Expressed in Billions)*

	1980 Keystone Estimates		University of Kentucky Estimate	
Province	Tonnage	Percent	Tonnage	Percent
Appalachian Plateau	400	11	810	7
Interior Basins	540	14	740	6
Gulf Coast	40	1	3790	33
High Plains	660	17	610	5
Rocky Mountains	1830	49	2190	19
North Alaska	290	8	3510	30
TOTAL	3760	100	11,650	100

*Tonnages may not add to totals shown elsewhere due to round-off.

from the character of the borehole data upon which the estimates are based. These data are almost exclusively derived from holes drilled for the commercial exploration of coal. When a number of such holes are drilled in any one mining district, areas of thin or no coal are established, and subsequent drilling avoids such areas. Hence, in any particular district, there is a preponderance of records from areas where the coal seams are thick, and as a result thin coal areas are underrepresented. Because all of the records for one analysis area are given equal weight, it is easy to see how a small sample of records drawn from the relatively thicker coals may indicate a greater coal thickness than is actually present within a district. This sort of bias could be avoided if records of holes of an entirely exploratory nature could be employed, but such data are neither generally available nor readily obtainable.

Speculation about the possible biases in the data or approach is useful because of the additional perspective it provides on the results of this study and similar studies in the future. The real question, however, remains -- is the tonnage estimated actually there? Strictly speaking, the only satisfactory way of assessing validity is comparison of the estimate produced by the methodology of this study with tonnages that have been precisely measured (or mined) in a variety of different coal districts. Such explicit comparisons were beyond the resources available for this study. However, some very preliminary comparisons of the results of this study with tonnages in carefully documented areas suggest a higher level of validity than one may initially suppose.

A recent paper by Ferm and Mathew (1981) may shed some light on this matter. In his study of the Texas lignites, Mathew prepared tonnage estimates for four depositional environments (alluvial plain, lower alluvial/upper delta transition, lower delta plain, and strandplain/lagoonal) using three different techniques: (1) manual estimates from hand-drawn isopach maps, (2) computer estimates from computer-drawn isopach maps, and (3) computer estimates, employing a mathematical model (Kriged thickness) of seam height. Not only were the three estimates in close agreement for each resource type, but the robustness of the estimates to decreases in data were quite impressive. In all cases, reducing the data by 75% (via random selection of logs) produced a variation in the tonnage estimate of no more than 15 - 20%. This implies that relatively little data may be used to make gross tonnage estimates. Because the present study blocked formations to yield areas of fairly homogeneous total coal thickness, the authors are encouraged to believe that the accuracy of these estimates may be of the same order as the variation in estimates described by Ferm and Mathew (1981).

6.2 RELEVANCE OF RESOURCE ESTIMATES TO ADVANCED MINING SYSTEMS

The primary objective of this study is the estimation of U.S. coal and lignite resources with a view to guiding future research on advanced mining systems. A companion study by Hoag, et al (1982) uses the tonnage estimates developed in this report to assess the commercial significance of various resource types, and subsequently, recommend resource targets for R&D on advanced mining systems. However, the tonnage estimates themselves, together with the geologic and geographic setting of the resources, have clear implications for mining R&D.

As practiced today, coal mining is a product of constraints imposed by both the material itself and mining methods established through long practice. Although new methods may be devised, the basic constraints remain. Section 2 identified the major constraints as the thickness of a mineable seam, its structural attitude or departure from the horizontal, the amount of overburden covering a seam, interburden or distance between adjacent seams, discontinuity of a seam produced by faulting or igneous intrusion, and the quality of the coal or lignite. Added to this list are the geographic location of the resource, and the average size of a mineable block (not examined in this study).

This study has shown that the attributes of structural attitude and discontinuity due to faulting or igneous intrusion probably do not constitute major constraints in the total body of U.S. coal resources. Preliminary tonnage estimates for all coal provinces indicate that only about 3% of the total U.S. resources occur in fields where a large fraction of the seams are inclined at angles greater than 15°, or rendered discontinuous by faulting or igneous intrusion (see Table 1). Moreover, within those basins or fields in which such features are relatively less abundant, it is estimated that tonnages affected in this way probably do not exceed 1% of the total (see Table 21). Hence, in evaluating total coal and lignite resources, the major constraints are depth of cover, seam thickness, and the geographic area of occurrence.

6.2.1 Depth of Cover

In order to describe current U.S. practice and give a feeling for the extreme ground pressures surrounding the very deepest coals, the cateogries used to describe depth of cover were 0 - 500 ft, 500 - 2000 ft, 2000 - 4000 ft, and greater than 4000 ft. Extraction by surface methods at depths of up to 500 ft is envisioned, and subsurface mining at depths up to 2000 ft is currently practiced. Mining at depths of 2000 - 4000 ft is possible, but only with increasing difficulty and expense. Resources at depths greater than 4000 ft are probably not extractable as solids, but are candidates for in situ combustion or similar processes. Viewed this way, slightly over 40% of the U.S. resources are extractable via currently available or readily foreseeable mining methods, and nearly 60% occur at depths where mining is difficult or impossible (see Table 21). Of the 40% of the resource under less than 2000 ft of cover, about one-quarter is available for surface mining at depths down to 500 ft, and the remainder is within the range of underground mining.

However, because of the rock materials in which these resources occur, easily mineable coals total somewhat less than 40% of the aggregate. In particular, the 2 trillion tons at depths of 500 - 2000 ft in the Gulf Coast and High Plains Provinces are probably not available for underground mining because of the unconsolidated character of the materials which enclose these lignite bodies; i.e., these resources could be placed in the category of "extractable only with great difficulty." Consequently, readily mineable U.S. resources are probably about one-quarter of the total, with the remaining three-quarters recoverable only by unconventional methods.

Table 21. Summary of Original and Remaining Resources by Seam Thickness, Depth of Cover, and Degree of Disturbance

(All tonnage expressed in billions)[a]

	Dipping less than 15°, and No Faults or Intrusions										Dip ≥15° Faulted, and/or Intruded	Totals
	0 - 2000 ft											
	50 ft	50 - 15 ft	15 ft - 42 in.	42 - 28 in.	28 - 14 in.	0 - 2000 ft	0 - 500 ft	500 - 2000 ft	2000 - 4000 ft	4000 ft		
Original Tonnage	56	260	2862	911	959	5048	1226	3822	4081	2469	124	11,722
Tonnage Mined/Lost[b]	0	1	51	19	3	74	37	37	0	0	0	74
Remaining Tonnage	56	259	2811	892	956	4974	1189	3785	4081	2469	124	11,648
Percent	0.5	2	24	8	8	43	10	33	35	21	1	100

[a]Figures may not add to indicated totals due to round-off.

[b]Aggregation of tonnage mined or lost in mining as reported for the six major coal provinces studied in this report.

Therefore, one of the major directions in R&D on resource exploitation should be development of technology for exploiting the resources for which ground control is the paramount technological constraint -- deeply buried bituminous and subbituminous coals, and deep mineable lignites surrounded by rock of very low competence.

Of the readily extractable 3 trillion tons, about one-third can be considered available for surface mining methods, the remainder being suitable for underground mining. Of the coals that can be surface mined, the bulk appear to be located mainly in the Gulf Coast Province and to a lesser degree in the Appalachian Plateau, the Interior Basin, and the Rocky Mountain Province. However, until more definitive data are available for the Gulf Coast, all of these four provinces should be regarded as roughly equal in resources available for surface mining, leading to a conservative estimate of surface mineable resources of about 250 billion tons. Any consideration given to enhancement of surface mining techniques in these provinces should recognize the major differences among them. Rocks enclosing the lignites of the Gulf Coast are very poorly consolidated relative to the other provinces, and can be readily excavated. However, for the same reasons, highwall and spoil pile stability could present serious problems, further aggravated by the proximity of large quantities of subsurface water. On the other hand, the rather level character of the Gulf Coastal Plain topography, combined with the low structural inclination of the seams, enhance the possibilities of surface mining, as do similar conditions in the Interior Province. Surface mining in the more rugged terrain of the Appalachian Plateau or Rocky Mountain Province could be aided by development of improved methods for handling highly variable thicknesses of overburden occurring in close geographic proximity.

Tonnages readily available for underground mining at depths of 500 - 2000 ft amount to about 10 - 15% of the total U.S. resources if the lignites in the poorly consolidated rocks of the Gulf Coastal Plain and High Plains are excluded (Table 22). These readily mineable underground resources, together with the roughly 250 billion tons conservatively available for surface mining, comprise the easily extractable coal resources of the United States. Virtually all of this coal is of at least subbituminous rank, and some includes medium- and low-volatile bituminous deposits. These resources are located in the Rocky Mountain, Interior, and Appalachian Plateau Provinces, with each province having roughly the same magnitude of resource potential. Since mining conditions and methods, as currently practiced, are about the same in each of these three provinces, advanced extraction techniques developed in one area would probably be applicable to another.

6.2.2 Seam Thickness

Seam thickness, as a mining constraint, is of importance primarily in underground mining. In surface mining the governing factor is the ratio of total coal to the volume of the rock to be removed. Thus, unless only a single seam is to be mined, the thickness of any one seam is of little importance. The thickness categories used in this study reflect the approximate relationship of seam thickness to underground mining methods currently being employed. Some European collieries practice multiple slice longwalling of thick coals, and recent reports indicate the availability of

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Table 22. Remaining Resources in Beds not Faulted or Intruded and Dipping less than 15°, by Depth of Cover and Coal Province

(Tonnage is Expressed in Billions)[a]

Province	0 - 500 ft Tonnage	0 - 500 ft Percent	500 - 2000 ft Tonnage	500 - 2000 ft Percent	2000 - 4000 ft Tonnage	2000 - 4000 ft Percent	4000 ft Tonnage	4000 ft Percent	TOTAL Tonnage	TOTAL Percent
Appalachian Plateau	236	2.1	545	4.7	28	0.2	0	0.0	809	7.0
Interior Basin	288	2.5	408	3.5	31	0.3	0	0.0	727	6.3
Gulf Coast	402	3.5	1,519	13.2	1,409	12.2	456	3.9	3,786	32.8
High Plains	59	0.5	534	4.7	14	0.1	0	0.0	607	5.3
Rocky Mountains	190	1.7	428	3.7	630	5.5	832	7.2	2,080	18.1
North Alaska	14	0.1	352	3.1	1,969	17.1	1,180	10.2	3,515	30.5
TOTALS	1,189	10.4	3,786	32.9	4,081	35.4	2,468	21.3	11,524	100.0

[a]Tonnages may not add up to totals shown due to round-off.

powered shields which can support a 20 ft roof. However, there is, at present, no accepted technique for mining North American seams much in excess of 15 ft, and as a rule, a substantial fraction of the coal in thick American seams is left on the roof and floor. The probable range of seam thickness for current underground mining is 15 ft - 42 in. Fifteen feet slightly exceeds an optimum of 6 - 9 ft for most commercially available equipment, and 42 in. represents a tolerable lower limit for commonly used mining machines. Seams less than 42 in. high can be categorized as difficult to mine, and seams thinner than 28 in. are currently mined only under special circumstances.

Table 23 shows the distribution of U.S. resources by thickness category for those seams which are gently inclined, not faulted or intruded, and lying under less than 2000 ft of overburden -- i.e., resources that are most suitable for underground mining. Table 23 indicates that in this category of resources, seams in excess of 15 ft represent a very small proportion of the total, with about half of these occurring in either the Gulf Coast or High Plains Provinces, where weakness of the surrounding strata would very likely preclude the possibility of significant underground extraction. Moreover, the attractiveness of thick seams as an R&D target diminishes when one recognizes that it is at least theoretically possible to mine the bulk of the resource over 15 ft with a two-pass, top slicing longwall, leaving at most a few feet of coal between slices (a state-of-the-art technique in Europe). Hence, primary interest must be focused on seams with thicknesses of less than 15 ft. About half of these resources are in seams 15 ft - 42 in. thick, and the remainder, in thin seams of 42 - 14 in. However, over half of the tonnage in the 15 ft - 42 in. category is located in the Gulf Coast or High Plains Provinces, and is probably not suitable for extraction by underground methods. In addition, thin seam resources in the High Plains, Rocky Mountain, and Gulf Coast Provinces have probably been underestimated because beds of this thickness are generally not regarded as mineable in those regions, thus discouraging the exploration of these coals as well as the careful reporting of thin coals in recorded logs. Hence, in order to evaluate seam thickness data in the context of underground mining, data from the Gulf Coast and High Plains should be excluded, and thin seam tonnages for the Rocky Mountain Province should be regarded as underestimated.

Accordingly, data from Table 23 are recast into Table 24 which excludes seams thicker than 15 ft as well as all Gulf Coast and High Plains coal. Table 23 shows that, overall, about half of the "adjusted" underground tonnage occurs in seams from 15 ft - 42 in. thick, and half in seams of 42 - 14 in. If the Rocky Mountain and North Alaskan tonnages have been underestimated, then it may be expected that a substantial body of readily available underground tonnage occurs in the thin seam category. At first glance, these data appear to have clear implications for the development of advanced underground mining systems. Thicker coals are widely regarded as easier and cheaper to mine; moreover, any thin coal must generally compete with closely adjacent thicker coals, under the assumption that nearby thick coals have not been seriously depleted. This logic implies that R&D efforts should be channeled into systems suitable for mining seams 15 ft - 42 in. thick, and indeed, most research in underground mining is concentrated in this range of seam thickness.

Table 23. Remaining Resources in Beds not Faulted or Intruded, Dipping Less Than 15° and Lying Under Less Than 2000 ft of Cover, by Seam Thickness and Coal Province

(Tonnage is Expressed in Billions)

Province	50 ft Tonnage	50 ft Percent	50 - 15 ft Tonnage	50 - 15 ft Percent	15 ft - 42 in. Tonnage	15 ft - 42 in. Percent	42 - 28 in. Tonnage	42 - 28 in. Percent	28 - 14 in. Tonnage	28 - 14 in. Percent	TOTAL Tonnage	TOTAL Percent
Appalachian Plateau	0	0.0	0	0.0	321	6.5	207	4.2	253	5.0	781	15.7
Interior Basins	0	0.0	0	0.0	228	4.7	137	2.7	331	6.6	695	14.0
Gulf Coast	14	0.3	32	0.6	1306	26.2	376	7.6	193	3.9	1921	38.6
High Plains	0	0.0	63	1.3	404	8.1	63	1.2	63	1.3	593	11.9
Rocky Mountains	19	0.4	81	1.6	375	7.5	72	1.5	71	1.4	618	12.4
North Alaska	23	0.5	83	1.7	177	3.5	37	0.8	45	0.9	366	7.4
TOTALS	56	1.2	259	5.2	2811	56.5	892	18.0	956	19.1	4974	100.0

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Table 24. Remaining Resources in Beds 15 ft to 14 in. Thick, which Are Not Faulted or Intruded and Lie Under Less than 2000 ft of Cover, in All Provinces Except the Gulf Coast and High Plains (Tonnage is Expressed in Billions)[a]

Province	15 ft - 42 in. Tonnage	15 ft - 42 in. Percent	42 - 28 in. Tonnage	42 - 28 in. Percent	28 - 14 in. Tonnage	28 - 14 in. Percent	TOTAL Tonnage	TOTAL Percent
Appalachian Plateau	321	14.2	207	9.2	253	11.2	781	34.6
Interior Basins	228	10.1	137	6.1	331	14.6	696	30.8
Rocky Mountain	375	16.6	72	3.2	71	3.2	518	23.0
North Alaska	177	7.8	37	1.7	45	2.1	259	11.6
TOTALS	1101	48.7	453	20.2	700	31.1	2254	100.0

[a]Tonnages may not add to indicated totals due to round-off.

On the other hand, methods of mining seams thinner than 42 in. appear to be adaptations of procedures used in the thicker seams, and the smaller interest in commercial development of thin seams would appear to reflect, at least in part, a lack of suitable technology for rapid and efficient extraction of coal from low seams. This, coupled with the fact that a large proportion of readily available underground resources occurs in thin seams, suggests that development of totally new thin seam technology could yield great benefits.

6.2.3 Multiseams

As explained above in Section 5.0, the juxtaposition of rock and coal in a sedimentary sequence leads to two kinds of mining problems. If the strata are relatively thin, then a sequence of coal and rock layers may be mined as one unit (or seam) so long as the proportion of rock is small enough to be economic. Current practice averages 25 - 30% reject in dirty seams, with 50% rock being regarded as the outer limit of profitability. A higher proportion of rock leads to excessive machine wear, more intensive product preparation, and generally higher handling costs per ton of coal mined.

If the coal beds are more widely separated, and if each seam is thick enough to be mineable by itself, the removal of one coal may hinder the subsequent removal of another. These so-called multiple seams, although not widely mined in the United States, pose a multitude of operational problems which vary with the order in which the seams are removed. Such problems include roof falls, rib sloughing, floor heaves, water flooding, and disruption of the ventilation system. Contrary to popular opinion, removing the top seam first does not necessarily simplify the extraction of subadjacent seams. A choice between taking the top seam first, the bottom seam first, or mining the seams simultaneously is a complex function of overburden, seam thickness, roof and floor quality for each seam, and the structural strength of the rock mass between the seams.

The identification of multiseam resources required a reanalysis of the logs used to estimate tonnage for the more familiar resource categories, and this analysis was reported separately in Section 5.0. Table 25 places those results within the broader context of the aggregate national resource. This summary tabulation indicates that multiple seams comprise over 50% of the aggregate flat-lying coals of moderate thickness under less than 2000 ft of cover, and about 21% of the total resource. No attempt was made to isolate multiple seams within the categories of steeply dipping, thin, exceptionally thick, or very deep coal. However, one could safely assume that a similarly large proportion of these more challenging resource types may be classified as multiple seams as well. Examination of Table 25 reveals that almost 40% of the shallow multiple seams are concentrated in the Gulf Coast, the remainder of this resource type spread being fairly evenly over the other five provinces. Comparison of multiple seam and isolated seam tonnages indicates that multiple seams dominate by a factor of 1.5 to 3 in all provinces, expanding to a ratio of 5:1 or more in the High Plains and some basins in the Rocky Mountains. Section 5.0 suggests some reasons for the apparent stratigraphic differences between provinces.

Table 25. Remaining Resources by Major Resource Category and Coal Province

(Tonnage is expressed in billions)[a]

Province	Thick, Steeply Dipping, or Intruded; No Depth or Thickness Limitations[b]		Flat-Lying, Under 180 in., and Below 2000 ft		Flat-Lying and Above 2000 ft						TOTAL	
					14-28 in.		28-180 in.					
							Isolated Seams		Multiple Seams			
	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent	Tonnage	Percent
Appalachian Plateau	0	0.0	28	0.2	239	2.0	244	2.1	298	2.6	809	6.9
Interior Basin	13	0.1	31	0.3	326	2.8	112	1.0	258	2.2	740	6.4
Gulf Coast	46	0.4	1865	16.0	191	1.6	686	5.9	998	8.5	3786	32.5
High Plains	63	0.6	14	0.1	56	0.5	72	0.6	402	3.4	607	5.2
Rocky Mountains	210	1.8	1462	12.6	65	0.6	97	0.8	358	3.1	2192	18.8
North Alaska	106	0.9	3149	27.0	32	0.3	68	0.6	160	1.4	3515	30.2
TOTALS	438	3.8	6549	56.2	909	7.8	1279	11.0	2474	21.2	11,649	100.0

[a]Tonnages may not add to totals shown elsewhere due to round-off.

[b]Severely faulted or intruded beds of significance are found in the Rocky Mountains and the Interior Province, with an estimated tonnage of 89.9 billion.

These numbers must be considered order of magnitude estimates, since they depend upon a particular definition of a mineable unit and upon a particular quantification of the zone of interference, which is itself only the crudest approximation to a very complex reality. Perhaps the real import of these numbers is the light it sheds on the problem of coal conservation, and thus, the value of developing mining systems which minimize the impact on adjacent coals.

6.3 GEOLOGICAL TARGETS FOR ADVANCED MINING SYSTEMS

The results of this study offer clear guidance for the development of advanced mining systems to enhance the exploitation of U.S. coal and lignite resources. Firstly, there is strong evidence that the total resources have been underestimated by at least 100%, and that a substantial body of coal and lignite occurs at depths greater than 2000 ft. A large fraction of these deposits are found below depths where coal is currently mined in the United States, with the deep coals occurring mainly in the Gulf Coast and North Alaska, and to a lesser extent, in the Rocky Mountain Province. The poorly consolidated character of the rocks in the Gulf Coast and the extreme depths of much of the North Alaskan coals suggest that utilization of these deeply buried resources is best accomplished by unconventional techniques, probably involving in situ comminution or conversion. However, the state-of-the-art in solution mining, in situ combustion, and related technology is not well developed, and benefits from these modes of exploitation appear likely only in the long-term.

Secondly, the data indicate that 1.2 trillion tons of resources lie within 500 ft of the surface, and thus, within the ordinary range of surface mining. These resources are roughly equally distributed across the coal provinces of the contiguous United States and, hence, comprise a readily available short-term resource. Extraction technology in this area is similar to that utilized in other excavation enterpises and has benefitted greatly from the transfer of technology. Although technological evolution may be expected to continue, development of totally novel surface extraction methods appears both unnecessary and unlikely.

Thirdly, these data indicate that substantial resources of bituminous and subbituminous coal occur at depths suitable for underground mining (less than 2000 feet), with shallow inclination, and absence of faults and igneous intrusions -- all of which simplify underground operations. These bodies of coal occur mainly in the Rocky Mountain, Interior, and Appalachian Provinces where an infrastructure already exists for underground extraction. Within these areas, efforts toward the enhancement of extraction technology should be directed to seams in the range of 15 ft - 42 in. since only a small proportion of the resources occur in seams thicker than 15 ft. It appears that technological advancement in mining coals 15 ft - 42 in. thick would be best directed toward improving the capability of existing systems for the extraction of isolated (non-interfering) seams. However, a potential for major technological innovation exists in the recovery of multiple seam deposits and thin coals. The relatively small indicated tonnage of seams which can be mined in isolation has strong implications for resource conservation. As mining proceeds in Appalachia and the older coal fields of other provinces, depletion of the resource will occur at a rate much higher than may be apparent because of inattention to the mutual interference of closely adjacent coal beds. Accordingly, multiple seams are regarded as a resource of long-term national importance, and of short-term importance in those coal fields where mining has been intensive.

Finally, this study has shown that only a relatively small proportion of the U.S. resources occur in steeply dipping, faulted, or intruded bodies. Consequently, although some of this coal is of good to excellent quality, the technical problems associated with it, relative to the total volume available, place it in a position of secondary importance compared with coals that can be more easily extracted.

APPENDIX A

DETAILED RESOURCE DATA ON BASINS AND SUB-BASINS

Table A-1. Original Resources of the Dunkard Basin (See Figure 4 for location of area of estimate.)

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(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
329.1 - 339.5	335.2	59

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
335.2			335.2

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
130.9	204.3				335.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		156.1	102.8	76.3	335.2

Quality

SULFUR	ASH	BTU	RANK
.4%-6%	3% - 15%	10,400 - 15,000	BIT

Area of Resource Estimate 20,712 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-2. Original Resources of the Monongahela Formation in the Dunkard Basin (See Figure 4 for location of area.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
100.3 - 105.2	102.8	23

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
102.8			102.8

Tonnage Which is Faulted or Intruded

	TOTAL
	0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
59.0	43.8				102.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		68.8	17.5	16.5	102.8

Quality

SULFUR	ASH	BTU	RANK
.4% - 16%	3% - 15%	10,400-15,000	BIT

Area of Resource Estimate	
	6,051 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-3. Original Resources of the Partially Eroded Monongahela Formation in the Dunkard Basin (See "Monongahela I" on Figure 4.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
58.7 - 74.2	66.4	15

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
66.4			66.4

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
52.0	14.4				66.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		38.4	13.9	14.1	66.4

Quality

SULFUR	ASH	BTU	RANK
.4% - 16%	3% - 15%	10,000 - 15,000	BIT

Area of Resource Estimate 4,874 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-4. Original Resources of Area of Full Thickness of the Monongahela Formation in the Dunkard Basin (See "Monongahela II" on Figure 4.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
29.2 - 43.4	36.4	8

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
36.4			36.4

Tonnage Which is Faulted or Intruded

	TOTAL
	0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
7.0	29.4				36.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		30.4	3.6	2.4	36.4

Quality

SULFUR	ASH	BTU	RANK
.4% - 6%	3% - 15%	10,000 - 15,000	BIT

Area of Resource Estimate

1,177 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-5. Original Resources of the Allegheny Formation in the Dunkard Basin (See Figure 5 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

$\leq$ μ $\leq$	$\bar{x}$	n
195.7 - 269.1	232.4	36

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
232.4			232.4

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
71.9	160.5				232.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		87.2	85.3	59.9	232.4

Quality

SULFUR	ASH	BTU	RANK
.4% - 7%	3% - 15%	10,400 - 15,000	BIT

Area of Resource Estimate	
	20,670 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-6. Original Resources of the Pocahontas Basin
(See Figure 6 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
333.2 - 336.5	335.5	69

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
335.5			335.5

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
111.7	223.8				335.5

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		174.1	71.8	89.6	335.5

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate	11,721 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-7. Original Resources of Thin Breathitt Coals in the Eastern Kentucky Portion of the Pocahontas Basin (See "P-1" on Figure 6.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
21.8 - 47.5	34.6	8

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
34.6			34.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
17.3	17.3				34.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		12.5	9.5	12.6	34.6

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate

Area of Resource Estimate	6,236 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-8. Original Resources of Thick Coals in the Upper and Lower Parts of the Breathitt (Eastern Kentucky) - Kanawha Formation (West Virginia) in the Pocahontas Basin (See "P-II" on Figure 6.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
109.4 - 186.0	141.7	27

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
141.7			141.7

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
47.2	94.5				141.7

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		69.5	34.4	37.8	141.7

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate 8,353 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-9. Original Resources of Thin Coals in the Lower Breathitt and Upper New River (Lee) Formations in the Pocahontas Basin (See "P-III" on Figure 6.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
44.7 - 88.4	66.6	10

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
66.6			66.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
16.4	50.2				66.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		34.0	14.6	18.0	66.6

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate	6,269	SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-10. Original Resources of Subcrop Pocahontas Coals Overlain by Thin New River Coals in the Pocahontas Basin (See "P-IV" on Figure 6.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
5.9 - 19.5	12.6	6

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
12.6			12.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
4.2	8.4				12.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		1.9	2.4	8.3	12.6

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate 1,291 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-11. Original Resources of Outcrop Pocahontas Coals Overlain by Thin New River Coals in the Pocahontas Basin (See "P-V" on Figure 6.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{X}$	n
3.6 - 6.8	5.2	6

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
5.2			5.2

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
1.7	3.5				5.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		3.2	1.2	.8	5.2

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate 485 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-12. Original Resources of Thin Lower Kanawha and Thick Upper Kanawha Coals Outcropping in the Central West Virginia Portion of the Pocahontas Basin (See "P-VI" on Figure 6.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
22.1 - 47.8	34.9	9

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
34.9			34.9

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
11.6	23.3				34.9

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		21.5	6.1	7.3	34.9

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate 2,783 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-13. Original Resources of Subcrop Thin Kanawha and Thick Upper Kanawha Coals in the Central West Virginia Portion of the Pocahontas Basin (See "P-VII" on Figure 6.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
15.1 - 65.1	39 9	3

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
39.9			39.9

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
13.3	26.6				39.9

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		31.5	3.6	4.8	39.9

Quality

SULFUR	ASH	BTU	RANK
.5% - 6%	.5% - 26%	10,094 - 15,800	BIT

Area of Resource Estimate 3,512 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-14. Original Resources in the Warrior Basin (See Figure 7 for location of area estimate.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
184.4 - 203.1	194.2	35

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
194.2			194.2

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
21.8	144.8		27.6		194.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		30.1	46.7	89.7	166.5

Quality

SULFUR	ASH	BTU	RANK
.7% - 3.1%	2.5% - 15.9%	12,210 - 14,310	BIT

Area of Resource Estimate

Area of Resource Estimate	13,258 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-15. Original Resources in Areas in the Warrior Basin Where All Seams are Represented (See "Warrior I" on Figure 7.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
79.5 - 163.3	121.4	7

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
121.4			121.4

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
11.5	109.9				121.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		18.5	36.7	66.2	121.4

Quality

SULFUR	ASH	BTU	RANK
.7% - 3.1%	2.5% - 15.9%	12,210 - 14,310	BIT

Area of Resource Estimate

4,267 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-16. Original Resources in Areas of the Warrior Basin Where the Coal Seams in the Lower Two-Thirds of the Total Sequence are Present (See "Warrior II" on Figure 7.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
50.7 - 88.7	69.7	25

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
69.7			69.7

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
8.6	34.7		26.4		69.7

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		11.7	10.0	21.6	43.3

Quality

SULFUR	ASH	BTU	RANK
.7% - 3.1%	2.5% - 15.9%	12,210 - 14,310	BIT

Area of Resource Estimate 7,533 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-17. Original Resources in Areas of the Warrior Basin Where Only the Lower Seams are Present (See "Warrior III" on Figure 7.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
2.4 - 3.8	3.1	3

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
3.1			3.1

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
1.7	.1		1.3		3.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
				1.8	1.8

Quality

SULFUR	ASH	BTU	RANK
.7% - 3.1%	2.5% - 15.9%	12,210 - 14,310	BIT

Area of Resource Estimate 1,457 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-18. Original Resources of the Eastern Interior Basin

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{X}$	n
369.3 - 380.1	376.7	90

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
376.7			376.7

Tonnage Which is Faulted or Intruded

	TOTAL
	12.6

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
223.7	149.3		3.7		376.7

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		176.9	81.0	115.1	373.0

Quality

SULFUR	ASH	BTU	RANK
1.16 - 3.13	6.3 - 12.2	10,900-11,590	BIT

Area of Resource Estimate

31427 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-19. Original Resources of the Eastern Interior Basin Where the Major Coal-Bearing Formations are Present (See "Eastern Interior Thick" on Figure 10.)

(All data in billions of tons)

Total Tonnage		
$\leq \mu \leq$	$\bar{x}$	n
311.3 - 395.3	353.3	74

Tonnage By Degree Of Dip			
< 15°	15°-45°	>45°	**TOTAL**
353.3			353.3

Tonnage Which is Faulted or Intruded	**TOTAL**
	11.5

Tonnage by Overburden Thickness					
0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	**TOTAL**
200.3	149.3		3.7		353.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet					
>50'	50-15'	15'- 42"	42"-28"	28" - 14"	**TOTAL**
		174.6	75.8	99.8	349.6

Quality			
SULFUR	ASH	BTU	RANK
1.16-3.13	6.3 - 12.2	11,000-15,000	BIT

Area of Resource Estimate	
	26,413 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-20. Original Resources of the Southeastern Portion of the Eastern Interior Basin Where Older Coal-Bearing Formations Contain Mineable Seams (See "Eastern Interior Thin" on Figure 10.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
16.4 - 30.6	23.4	16

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
23.4			23.4

Tonnage Which is Faulted or Intruded

TOTAL
1.1

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
23.4					23.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		2.9	5.2	15.3	23.4

Quality

SULFUR	ASH	BTU	RANK
1.16- 3.13	6.3 - 12.2	10,900-11,590	BIT

Area of Resource Estimate

5014 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-21. Original Resources of the Western Interior Basin (See Figure 11 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
318.7 - 435.5	377.2	68

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
377.2			377.2

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
71.7	276.2		29.3		377.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		64.6	63.0	220.3	347.9

Quality

SULFUR	ASH	BTU	RANK
2.2 - 8.9	5.9 - 17.2	11,470-15,210	BIT

Area of Resource Estimate

56,260 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-22. Original Resources of the Texas Portion of the Gulf Coast Lignite Province Where the Lignites are Relatively Thin (See "Texas I" on Figure 14.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{X}$	n
827.5 - 1584.5	1206.0	23

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
1206.0			1206.0

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
322.8	657.1		192.2	33.9	1206.0

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		793.2	162.1	24.6	979.9

Quality

SULFUR	ASH	BTU	RANK
.4 - 5.77	2.3 - 58.6	6158-11221	LIG

Area of Resource Estimate 25935 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-23. Original Resources of the Texas Portion of the Gulf Coast Lignite Province Where the Lignites are Relatively Thick (See "Texas II" on Figure 14.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
577.0- 1249.0	913.0	7

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
913.0			913.0

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
4.4	168.4		439.2	301.0	913.0

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		148.7	19.6	4.5	172.8

Quality

SULFUR	ASH	BTU	RANK
.4 - 5.77	2.3 - 58.6	6158-11221	LIG

Area of Resource Estimate 6737 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-24. Original Resources Where Lignites are Under 500 ft or Less Cover in the Louisiana Portion of the Gulf Coast Lignite Province (See "Louisiana I" on Figure 15.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
11.2 - 15.8	4.1	69

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
4.1			4.1

Tonnage Which is Faulted or Intruded — TOTAL 0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
4.1					4.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		1.3	1.1	1.7	4.1

Quality

SULFUR	ASH	BTU	RANK
.3 - 1.9	3.8 - 55.6	2730-10120	LIG

Area of Resource Estimate 2,952 SQ.MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-25. Original Resources Where Lignites are Under Cover Greater Than 500 ft in the Louisiana Portion of the Gulf Coast Lignite Province (See "Louisiana II" on Figure 15.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
353.3 - 521.3	437.2	0

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
437.2			437.2

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
	212.3		193.2	31.7	437.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		110.4	58.1	43.8	212.3

Quality

SULFUR	ASH	BTU	RANK
.3 - 1.9	3.8 - 55.6	2730-10120	LIG

Area of Resource Estimate 14702 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-26. Original Resources in the Arkansas Portion of the Gulf Coast Lignite Province (See "Arkansas" on Figure 15.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	x̄	n
		0

Tonnage by Degree of Dip

< 15°	15°-45°	>45°	TOTAL
89.3			89.3

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
13.6	62.1		13.6		89.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		23.7	21.1	30.9	75.7

Quality

SULFUR	ASH	BTU	RANK
			LIG

Area of Resource Estimate 19,489 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-27. Original Resources Where Lignites are Under 500 ft or Less Less Cover in the Mississippi Portion of the Gulf Coast Lignite Province (See "Mississippi I" on Figure 15.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
8.6 - 18.57	13.6	0

Tonnage By Degree Of Dip

$< 15^\circ$	15°-45°	$>45^\circ$	TOTAL
13.6			13.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
13.6					13.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		3.8	3.4	6.4	13.6

Quality

SULFUR	ASH	BTU	RANK
			LIG

Area of Resource Estimate 2988 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-28. Original Resources Where Lignites are Under Cover Greater Than 500 ft in the Mississippi Portion of the Gulf Coast Lignite Province (See "Mississippi II" on Figure 15.)

(All data in billions of tons)

Total Tonnage

≤ µ ≤	$\bar{x}$	n
840.86 - 1239.74	1040.3	31

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
1040.3			1040.3

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
	380.2		570.5	89.6	1040.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		197.7	104.0	78.5	380.2

Quality

SULFUR	ASH	BTU	RANK
			LIG

Area of Resource Estimate 34984 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-29. Original Resources Where Lignites are Relatively Thin in the Alabama Portion of the Gulf Coast Lignite Province (See "Alabama I" on Figure 16.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
21.53 - 44.25	32.9	35

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
32.9			32.9

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
17.0	15.9				32.9

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	6.0	19.0	5.4	2.5	32.9

Quality

SULFUR	ASH	BTU	RANK
.31 - 3.74	2.9 - 42.23	2300-6185	LIG

Area of Resource Estimate 4262 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-30. Original Resources Where Lignites are Relatively Thick in the Alabama Portion of the Gulf Coast Lignite Province (See "Alabama II" on Figure 16.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
22.39 - 76.93	49.6	12

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
49.6			49.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
27.0	22.6				49.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
13.5	26.5	8.4	1.2		49.6

Quality

SULFUR	ASH	BTU	RANK
.31 - 3.74	2.9 - 42.23	2300-6185	LIG

Area of Resource Estimate 2154 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-31. Original Resources of the High Plains Lignite Province
(See Figure 17 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
593.5 - 620.6	606.6	81

Tonnage by Degree of Dip

< 15°	15°-45°	>45°	TOTAL
606.6			606.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
58.4	534.2		14.0		606.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	63.3	403.8	62.5	63.0	592.6

Quality

SULFUR	ASH	BTU	RANK
.3% - 1.9%	3.7% - 12.7%	6,020 - 8,422	LIG

Area of Resource Estimate: 3,028 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-32. Original Resources in Areas Where the Lignite-Bearing Formation is Partially Eroded in the High Plains Lignite Province (See "High Plains I" on Figure 17.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
31.17 - 54.39	42.8	15

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
42.8			42.8

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
39.2	3.6				42.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		26.7	4.6	11.5	42.8

Quality

SULFUR	ASH	BTU	RANK
.3 - 1.9	3.7 - 12.7	6020-8422	LIG

Area of Resource Estimate 5425 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-33. Original Resources in Areas Where the Full Sequence of the Lignite-Bearing Formation is Present in the High Plains Lignite Province (See "High Plains II" on Figure 17.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
453.24 - 674.3	563.8	66

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
563.8			563.8

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
19.2	530.6		14.0		563.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	63.3	377.1	57.9	51.5	549.8

Quality

SULFUR	ASH	BTU	RANK
.3 - 1.9	3.7 - 12.7	6020 - 8422	LIG

Area of Resource Estimate 24857 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-34. Original Resources of the Southwest District of the Rocky Mountain Province (See Figure 20 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
286.8 - 298.0	292.1	77

Tonnage By Degree of Dip

< 15°	15°-45°	>45°	TOTAL
272.3	19.8		292.1

Tonnage Which is Faulted or Intruded

	TOTAL
	8.7

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
114.2	89.3		82.8	5.8	292.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	7.0	141.3	23.1	32.1	203.5

Quality

SULFUR	ASH	BTU	RANK
.5% - 5.8%	3.4% - 50.8%	5,119 - 12,060	BIT SUBBIT

Area of Resource Estimate 16,441 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-35. Original Resources of the Kolob-Alton Area of the Southwest District of the Rocky Mountain Province (See Figure 20 for location.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
10.9 - 19.3	15.1	13

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
15.1			15.1

Tonnage Which is Faulted or Intruded

TOTAL
.3

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
2.0	4.7		5.9	2.5	15.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	.7	5.5	.1	.5	6.8

Quality

SULFUR	ASH	BTU	RANK
.64 - 5.8	7.7 - 13.6	7,935-10,492	BIT

Area of Resource Estimate 910 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-36. Original Resources of the Kaiparowits Area of the Southwest District of the Rocky Mountain Province (See Figure 20 for location.)

(All data in billions of tons)

Total Tonnage

$\le \mu \le$	$\bar{x}$	n
8.1 - 79.9	44.2	4

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
41.6	2.6		44.2

Tonnage Which is Faulted or Intruded

TOTAL
.8

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
20.3	11.1		10.8	2.0	44.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	5.2	19.8	3.3	3.1	31.4

Quality

SULFUR	ASH	BTU	RANK
.68 - .88	7 - 11.1	9,309-11,210	BIT

Area of Resource Estimate 1071 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-37. Original Resources of the Henry Mountains Area of the Southwest District of the Rocky Mountain Province (See Figure 20 for location.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
.96 - 1.77	1.4	5

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
1.4			1.4

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.2	.8		.4		1.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		.7	.3		1.0

Quality

SULFUR	ASH	BTU	RANK
.87-1.8	9.5 - 10.7	11,000-11,253	BIT

Area ot Resource Estimate 189 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-38. Original Resources of the Black Mesa Area of the Rocky Mountain Province (See Figure 20 for location and Tables A-39 and A-40 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
48.3 - 54.7	51.6	19

Tonnage By Degree of Dip

< 15°	15°-45°	>45°	TOTAL
51.6			51.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
22.2	29.4				51.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		45.1	2.8	3.7	51.6

Quality

SULFUR	ASH	BTU	RANK
.5% - 2.2%	3.4% - 50.8%	5,119 - 12,060	SUBBIT

Area of Resource Estimate	4,023 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-39. Original Resources of the Dakota Coals of the Black Mesa Area (See "Dakota" on Figure 20.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
17.2 - 33.0	25.1	12

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
25.1			25.1

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
3.3	21.8				25.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		21.4	1.6	2.1	25.1

Quality

SULFUR	ASH	BTU	RANK
.5 - 2.29	11 - 30.74	5,119 - 10,550	SUBBIT

Area of Resource Estimate 2,795 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-40. Original Resources of the Mesaverde Coals of the Black Mesa Area (See "Mesaverde" on Figure 20.)

(All data in billions of tons)

Total Tonnage

≤	μ	≤	$\bar{x}$	n
17.0		35.8	26.5	7

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
26.5			26.5

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
18.9	7.6				26.5

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		23.7	1.2	1.6	26.5

Quality

SULFUR	ASH	BTU	RANK
.5 - 1.3	3.4 - 50.8	5,430 - 12,060	SUBBIT

Area of Resource Estimate 1,228 . SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-41. Original Resources of the San Juan Area of the Rocky Mountain Province (See Figure 20 for location and Tables A-42 and A-43 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{X}$	n
175.3 - 184.6	179.8	36

Tonnage By Degree Of Dip

$< 15^{\circ}$	$15^{\circ}-45^{\circ}$	$>45^{\circ}$	TOTAL
162.6	17.2		179.8

Tonnage Which is Faulted or Intruded

TOTAL
7.7

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
69.5	43.3		65.7	1.3	179.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	1.1	70.2	16.6	24.9	112.8

Quality

SULFUR	ASH	BTU	RANK
.6 - .86	15 - 20.4	8900-10,200	SUBBIT

Area of Resource Estimate 10,248 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-42. Original Resources of the Area of Partially Eroded Coal Formations of the San Juan Area (See "San Juan I" on Figure 20.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
45.7 - 68.8	57.3	15

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
49.3	8.0		57.3

Tonnage Which is Faulted or Intruded

TOTAL
1.6

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
8.2	9.5		38.3	1.3	57.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	1.1	13.1	1.4	2.1	17.7

Quality

SULFUR	ASH	BTU	RANK
.6 - .86	15 - 20.4	8,900-10,200	SUBBIT

Area of Resource Estimate 2996 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-43. Original Resources of the Area Where a Full Sequence of the Coal-Bearing Formations is Present in the San Juan Area (See "San Juan II" on Figure 20.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
97.4 - 147.6	122.5	21

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
113.3	9.2		122.5

Tonnage Which is Faulted or Intruded

TOTAL
6.0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
61.3	33.8		27.4		122.5

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		57.1	15.2	22.8	95.1

Quality

SULFUR	ASH	BTU	RANK
.6 - .86	15 - 20.4	8,900 - 10,200	SUBBIT

Area of Resource Estimate 7,252 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-44. Original Resources of the West Central District of the Rocky Mountain Province (See Figure 21 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

$\le \mu \le$	$\bar{x}$	n
1169.6 - 1211.4	1190.8	94

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
1138.9	45.3	6.6	1190.8

Tonnage Which is Faulted or Intruded

TOTAL
35.2

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
49.9	122.7	44.3	217.1	756.8	1190.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	20.8	134.8	32.1	29.2	216.9

Quality

SULFUR	ASH	BTU	RANK
31% - 5.5%	2.2%- 15.3%	7980-19,430	BIT SUBBIT

Area of Resource Estimate

30,729 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-45. Original Resources of the Emery Area of the West Central District of the Rocky Mountain Province (See Figure 21 for location.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
14.5 - 21.7	18.1	7

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
18.1			18.1

Tonnage Which is Faulted or Intruded

TOTAL
1.0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.7	2.00		4.5	10.9	18.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		2.2	.4	.1	2.7

Quality

SULFUR	ASH	BTU	RANK
.39 - 5.5	5.5 - 13.8	11,400-14,380	BIT

Area of Resource Estimate	
	1036 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-46. Original Resources of the Wasatch Area of the West Central District of the Rocky Mountain Province (See Figure 21 for location.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
72.0 - 119.7	95.8	27

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
94.7	1.1		95.8

Tonnage Which is Faulted or Intruded

TOTAL
3.8

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
10.1	13.0		18.2	54.5	95.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	3.7	15.1	2.7	1.6	23.1

Quality

SULFUR	ASH	BTU	RANK
.49 - 1.09	6.1 - 7.0	11,727 - 12,825	BIT

Area of Resource Estimate

5307 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-47. Original Resources of the Uinta Area of the West Central District of the Rocky Mountain Province (See Figure 21 for location.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
14.7 - 25.4	20.0	6

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
18.1	1.9		20.0

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
1.8	3.9		3.5	10.8	20.0

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		4.5	.6	.6	5.7

Quality

SULFUR	ASH	BTU	RANK
.8 - 2.1	6.44 - 13.26	10,690-12,200	BIT

Area of Resource Estimate 3562 SQ.MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-48. Original Resources of the Piceance Area of the West Central District of the Rock Mountain Province (See Figure 21 for location and Tables A-49 through A-52 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{y}$	n
191.6 - 211.0	201.4	18

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
182.6	13.5	5.3	201.4

Tonnage Which is Faulted or Intruded

TOTAL 9.5

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
9.4	4.0	40.7	43.1	104.2	201.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	11.4	25.9	8.1	8.7	54.1

Quality

SULFUR	ASH	BTU	RANK
.4 - 1.9	3.2 - 9.15	11,040-14,170	BIT

Area of Resource Estimate

7665 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-49. Original Resources of the Piceance Area Where the Coal-Bearing Formations have been Substantially Eroded (See "Piceance I" on Figure 21.)

(All data in billions of tons)

Total Tonnage						
≤ μ ≤		$\bar{x}$		n		
27.3 - 42.9		35.1		4		
Tonnage By Degree Of Dip						
< 15°		15°-45°		>45°		TOTAL
35.1						35.1
Tonnage Which is Faulted or Intruded						TOTAL 6.6
Tonnage by Overburden Thickness						
0-500'	500-2000'	0-2000' *1	2000-4000'		>4000'	TOTAL
7.1	2.9		12.3		12.8	35.1
Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet						
>50'	50-15'	15'- 42"	42"-28"	28" - 14"		TOTAL
		5.5	2.5	2.0		10.0
Quality						
SULFUR		ASH	BTU		RANK	
.4 - .75		5.53 - 9.15	11,040-11,490		SUB BIT	
Area of Resource Estimate			1361 SQ. MI.			

*1 applies where areas 0'-500' are too small for measurement.

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Table A-50. Original Resources of the Piceance Area Where the Full Sequence of the Coal-Bearing Formations is Present (See "Piceance II" on Figure 21.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
57.5 - 104.8	81.2	10

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
71.9	4.0	5.3	81.2

Tonnage Which is Faulted or Intruded

TOTAL
2.3

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.2	.8	10.6	17.1	52.5	81.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		8.6	1.4	1.5	11.5

Quality

SULFUR	ASH	BTU	RANK
.4 - .75	5.53 - 9.15	11,040-11,490	BIT

Area of Resource Estimate

4986 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-51. Original Resources of the Piceance Area Where the Coal-Bearing Formations have been Substantially Eroded (See "Piceance III-A" on Figure 21.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
1.8 - 3.0	2.4	2

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
2.4			2.4

Tonnage Which is Faulted or Intruded

TOTAL
.5

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
2.1	.3				2.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		2.2		.2	2.4

Quality

SULFUR	ASH	BTU	RANK
.4 - 1.9	3.2 - [illegible].1	11,400-14,170	BIT

Area of Resource Estimate

93 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-52. Original Resources of the Piceance Area Where the Full Sequence of the Coal-Bearing Formations is Present (See "Piceance III-B" on Figure 21.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
65.9 - 99.8	82.7	2

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
73.2	9.5		82.7

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
		30.1	13.7	38.9	82.7

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	11.4	9.6	5.1	4.0	30.1

Quality

SULFUR	ASH	BTU	RANK
.4 - 1.9	3.2 - 9.1	11,400-14,170	BIT

Area of Resource Estimate 1,224 SQ.MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-53. Original Resources of the Green River Area of the West Central District of the Rocky Mountain Province (See Figure 21 for location.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
768.5 - 843.2	806.3	28

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
787.5	17.5	1.3	806.3

Tonnage Which is Faulted or Intruded

TOTAL
15.7

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
27.1	96.3		136.5	546.4	806.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	3.2	83.4	19.7	17.1	123.4

Quality

SULFUR	ASH	BTU	RANK
.42 - 5.4	2.2 - 15.3	7980-12447	SUB BIT

Area of Resource Estimate 11778 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-54. Original Resources of the Hanna-Carbon Area of the West Central District of the Rocky Mountain Province (See Figure 21 for location.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
31.8- 66.6	49.2	8

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
38.0	11.2		49.2

Tonnage Which is Faulted or Intruded

TOTAL
5.2

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.8	3.5	3.6	11.3	30.0	49.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	2.5	3.9	.6	.9	7.9

Quality

SULFUR	ASH	BTU	RANK
.31 - 1.35	5.54 - 10.74	9640-11,000	SUB Bit

Area of Resource Estimate	1381 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-55. Original Resources of the Northern District of the Rocky Mountain Province (See Figure 22 for location.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
611.9 -634.7	624.6	115

Tonnage By Degree of Dip

< 15°	15°-45°	>45°	TOTAL
613.2	10.9	.5	624.6

Tonnage Which is Faulted or Intruded

	TOTAL
	2.1

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
41.5	185.9	4.2	325.5	67.5	624.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
18.5	59.6	115.3	22.6	15.6	231.6

Quality

SULFUR	ASH	BTU	RANK
1.7% - 2.21%	3.15% -55.4%	3850-14,020	BIT SUBBIT

Area of Resource Estimate

25,127 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-56. Original Resources of the Wind River Area of the Northern District of the Rocky Mountain Province (See Figure 22 for location.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
10.9 - 20.7	15.8	30

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
12.4	2.9	.5	15.8

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.3	.4	1.5	1.2	12.4	15 8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	.3	.9	.6	.4	2.2

Quality

SULFUR	ASH	BTU	RANK
.32 - 1.23	3.15 - 15.2	6080-13,310	SUB BIT

Area of Resource Estimate 3308 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-57. Original Resources of the Big Horn Area of the Northern District of the Rocky Mountain Province (See Figure 22 for location.)

(All data in billions of tons)

Total Tonnage

≤	μ ≤	$\bar{x}$	n
17.2	32.9	27.7	30

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
23.4	4.3		27.7

Tonnage Which is Faulted or Intruded

TOTAL
0.2

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.8	1.8	2.7	3.6	18.8	27.7

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
	.8	2.3	1.3	.9	5.3

Quality

SULFUR	ASH	BTU	RANK
.4 - .6	4.3 - 10.9	9800- 10970	SUB BIT

Area of Resource Estimate

4528 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-58. Original Resources of the Bull Mountain Area of the Northern District of the Rocky Mountain Province (See Figure 22 for location and Tables A-59 and A-60 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
10.2 - 11.6	11.0	14

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
11.0			11.0

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
3.8	7.2				11.0

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		4.5	2.1	4.4	11.0

Quality

SULFUR	ASH	BTU	RANK
.17 - 2.21	3.3 - 55.4	3850 - 14.020	BIT

Area of Resource Estimate

1019 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-59. Original Resources of the Bull Mountain Area Where the Coal-Bearing Sequence has been Partially Eroded (See "Bull Mountain I" on Figure 22.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
5.29 - 10.0	7.6	10

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
7.6			7.6

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
2.8	4.8				7.6

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		3.0	1.3	3.3	7.6

Quality

SULFUR	ASH	BTU	RANK
.17 - 2.21	3.3 - 55.4	3850-14,020	BIT

Area of Resource Estimate 901 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-60. Original Resources of the Bull Mountain Area Where the Full Coal-Bearing Sequence is Present (See "Bull Mountain II" on Figure 22.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
3.13 - 3.35	3.3	4

Tonnage By Degree Of Dip

$< 15^\circ$	15°-45°	$>45^\circ$	TOTAL
3.3			3.3

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.9	2.4				3.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		1.4	.8	1.1	3.3

Quality

SULFUR	ASH	BTU	RANK
.17 - 2.21	3.3 - 55.4	3850-14020	BIT

Area of Resource Estimate

118 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-61. Original Resources of the Powder River Area of the Northern District of the Rocky Mountain Province (See Figure 22 for location and Tables A-62 and A-63 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage

$\le \mu \le$	$\bar{x}$	n
551.1 - 588.0	570.1	41

Tonnage By Degree of Dip

< 15°	15°-45°	>45°	TOTAL
566.4	3.7		570.1

Tonnage Which is Faulted or Intruded

TOTAL
.4

Tonnage by Overburden Thickness

0-500'[1]	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
36.6	176.5		320.7	36.3	570.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
18.5	58.5	107.6	18.6	9.9	213.1

Quality

SULFUR	ASH	BTU	RANK
.34%-1.5%	4.3% - 11.4%	7884-9710	SUB BIT

Area of Resource Estimate	16271 SQ. MI.

[1] applies where areas 0'-500' are too small for measurement.

Table A-62. Original Resources of the Powder River Area Where the Coal is Thinner and the Coal Formation is Partially Eroded (See "Powder River I" on Figure 22.)

(All data in billions of tons)

Total Tonnage

≤	μ ≤	$\bar{x}$	n
134.3	201.9	168.2	24

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
164.5	3.7		168.2

Tonnage Which is Faulted or Intruded

TOTAL
.4

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
16.0	51.7		64.2	36.3	168.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		47.6	12.3	7.8	67.7

Quality

SULFUR	ASH	BTU	RANK
.34 - 1.5	4.3 - 11.4	7,884-9710	SUB BIT

Area of Resource Estimate 12,807 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-63. Original Resources of the Powder River Area Where Coal is Thick and the Full Sequence of the Coal-Bearing Formation is Present (See "Powder River I" on Figure 22.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
294.3 - 509.3	401.9	17

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
401.9			401.9

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
20.6	124.8		256.5		401.9

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
18.5	58.5	60.0	6.3	2.1	145.4

Quality

SULFUR	ASH	BTU	RANK
.34 - 1.5	4.3 - 11.4	7884-9710	SUB BIT

Area of Resource Estimate 3464 SQ.MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-64. Original Resources of the Front Range District of the Rocky Mountain Province (See Figure 23 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
83.5 - 90.2	87.3	40

Tonnage By Degree of Dip

< 15°	15°-45°	>45°	TOTAL
72.9	14.4		87.3

Tonnage Which is Faulted or Intruded — TOTAL 5.9

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
17.0	46.3		21.8	2.2	87.3

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		45.6	10.0	7.7	63.3

Quality

SULFUR	ASH	BTU	RANK
.4%-1.7%	6.0%-18.5%	6500-12700	LIG SUBBIT BIT

Area of Resource Estimate — 9828 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-65. Original Resources of the Denver Basin Area of the Front Range District of the Rocky Mountain Province (See Figure 23 for location and Tables A-66 and A-67 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage					
≤ μ ≤	$\bar{x}$	n			
57.6-63.6	60.4	19			
Tonnage By Degree of Dip					
< 15°	15°-45°	>45°			TOTAL
49.8	10.6				60.4
Tonnage Which is Faulted or Intruded					TOTAL
					2.7
Tonnage by Overburden Thickness					
0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
13.2	37.1		10.1		60.4
Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet					
>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		38.2	7.3	4.8	50.3
Quality					
SULFUR	ASH	BTU	RANK		
.4%-1.7%	6.0%-9.0%	6500-9700	LIG SUBBIT		
Area of Resource Estimate			4868 SQ. MI.		

*1 applies where areas 0'-500' are too small for measurement.

Table A-66. Original Resources of the Portion of the Denver Basin Area Containing Subbituminous Coal (See "Denver I" on Figure 23.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
26.71 - 43.48	35.0	13

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
28.2	6.8		35.0

Tonnage Which is Faulted or Intruded

TOTAL
2.1

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
8.8	21.8		4.8		35.0

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		19.4	6.6	4.2	30.2

Quality

SULFUR	ASH	BTU	RANK
.4 - .6	6.0 - 7.0	8200 - 9700	SUB BIT

Area of Resource Estimate 3022 SQ.MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-67. Original Resources of the Portion of the Denver Basin Area Containing Lignite (See "Denver II" on Figure 23.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
17.45 - 33.21	25.4	6

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
21.6	3.8		25.4

Tonnage Which is Faulted or Intruded

TOTAL
.6

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
4.8	15.3		5.3		25.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		18.8	.7	.6	20.1

Quality

SULFUR	ASH	BTU	RANK
.4 - 1.7	8.0 - 9.0	6500 - 7500	LIG

Area of Resource Estimate 1846 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-68. Original Resources of the Raton Area of the Front Range District of the Rocky Mountain Province (See Figure 23 for location and Tables A-69 and A-70 for resource breakdowns.)

(All data in billions of tons)

Total Tonnage					
≤ μ ≤		$\bar{x}$	n		
22.3 - 31.4		26.9	21		
Tonnage By Degree of Dip					
< 15°		15°-45°	>45°		TOTAL
23.1		3.8			26.9
Tonnage Which is Faulted or Intruded					TOTAL 3.2
Tonnage by Overburden Thickness					
0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
3.8	9.2		11.7	2.2	26.9
Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet					
>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		7.4	2.7	2.9	13.0
Quality					
SULFUR	ASH	BTU	RANK		
.6%-.7%	11.6%-18.5%	11,890-12,700	BIT		
Area of Resource Estimate			4960 SQ. MI.		

*1 applies where areas 0'-500' are too small for measurement.

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Table A-69. Original Resources of the Portion of the Raton Area in which Seams are Mostly Gently Dipping and a Great Percentage of Tonnage is in Seams 15-ft to 42-in. Thick (See "Raton I" on Figure 23.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
15.49 - 30.83	23.2	12

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
19.4	3.8		23.2

Tonnage Which is Faulted or Intruded

TOTAL
1.4

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
.1	9.2		11.7	2.2	23.2

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		6.2	1.6	1.5	9.3

Quality

SULFUR	ASH	BTU	RANK
.6 - .7	11.6 - 18.5	11,890 - 12,700	BIT

Area of Resource Estimate 1635 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-70. Original Resources of the Portion of the Raton Area in Which Seams are Gently Dipping, and Under Less Than 500 ft of Overburden (See "Raton II" on Figure 23.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
2.49 - 4.98	3.7	9

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
3.7			3.7

Tonnage Which is Faulted or Intruded

	TOTAL
	1.8

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
3.7					3.7

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
		1.2	1.1	1.4	3.7

Quality

SULFUR	ASH	BTU	RANK
.6 - .7	11.6 - 18.5	11,890-12700	BIT

Area of Resource Estimate 3325 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-71. Original Resources of the Rocky Mountain Province

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
2186.2 - 2204.8	2194.8	326

Tonnage By Degree of Dip

< 15°	15°-45°	>45°	TOTAL
2097.3	90.4	7.1	2194.8

Tonnage Which is Faulted or Intruded

TOTAL 77.3

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'	2000-4000'	>4000'	TOTAL
222.6	444.2	48.5	647.2	832.3	2194.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
18.5	87.4	437.0	87.8	84.6	715.3

Quality

SULFUR	ASH	BTU	RANK
.17%-5.8%	2.2%-55.4%	3850-19430	BIT SUBBIT LIG

Area of Resource Estimate

82,125 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-72. Original Resources of the North Alaska Province (See Figures 24, 26 and 27 for location of area of estimate.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
INSUFFICIENT DATA		27

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
3515.4			3515.4

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
13.6	352.2		1969.4	1180.2	3515.4

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
23.2	83.1	177.0	37.3	45.2	365.8

Quality

SULFUR	ASH	BTU	RANK
INSUFFICIENT DATA			SUB-BIT

Area of Resource Estimate 45524 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-73. Original Resources for Areas of Relatively High Data Density in the Chandler and Prince Creek Formations in the North Alaska Province (See "Alaska I" on Figures 26 and 27.)

(All data in billions of tons)

Total Tonnage

$\leq \mu \leq$	$\bar{x}$	n
1032.73- 1967.0	1500.1	22

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
1500.1			1500.1

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
	68.6		924.2	507.3	1500.1

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
4.5	1.4	29.6	13.2	19.9	68.6

Quality

SULFUR	ASH	BTU	RANK
INSUFFICIENT DATA			SUB-BIT

Area of Resource Estimate 36,162 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-74. Original Resources of Deeply Buried Coal with Low Data Density in the Chandler Formation (See "Alaska II" on Figure 26.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
INSUFFICIENT DATA		3

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
1610.8			1610.8

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
	271.6		1040.3	298.9	1610.8

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
17.1	75.9	135.0	21.5	22.1	271.6

Quality

SULFUR	ASH	BTU	RANK
INSUFFICIENT DATA			SUB-BIT

Area of Resource Estimate 5161 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

Table A-75. Original Resources of the Deeply Buried Coal with Low Data Density in the Prince Creek Formation (See "Alaska III" on Figure 27.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
INSUFFICIENT DATA		1

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
374.0			374.0

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000'*1	2000-4000'	>4000'	TOTAL
				374.0	374.0

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL

Quality

SULFUR	ASH	BTU	RANK
INSUFFICIENT DATA			SUB-BIT

Area of Resource Estimate 4127 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

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Table A-76. Original Resources of Areas of Partially Eroded Coal Formations in the North Alaska Province (See "Alaska IV" on Figure 26.)

(All data in billions of tons)

Total Tonnage

≤ μ ≤	$\bar{x}$	n
INSUFFICIENT DATA		1

Tonnage By Degree Of Dip

< 15°	15°-45°	>45°	TOTAL
30.5			30.5

Tonnage Which is Faulted or Intruded

TOTAL
0

Tonnage by Overburden Thickness

0-500'	500-2000'	0-2000' *1	2000-4000'	>4000'	TOTAL
13.6	12.0		4.9		30.5

Tonnage by Seam Thickness Where Overburden is Less than 2000 Feet

>50'	50-15'	15'- 42"	42"-28"	28" - 14"	TOTAL
1.6	5.8	12.4	2.6	3.2	25.6

Quality

SULFUR	ASH	BTU	RANK
INSUFFICIENT DATA			SUB-BIT

Area of Resource Estimate 74 SQ. MI.

*1 applies where areas 0'-500' are too small for measurement.

APPENDIX B

DERIVATION OF CONFIDENCE INTERVALS

FOR AN AGGREGATION OF SUBAREAS

Calculation of a confidence interval appropriate for describing the precision of estimated coal tonnage in a subarea of a basin involves a straightforward application of the t-distribution, as described in Section 3.2.3 of the text. This appendix extends the concept of a confidence interval for tonnage to the aggregate coal resources within a basin. Begin by defining the following seams:

R = total coal resources in tons

X_i = feet of coal in region i

X_{ij} = jth sample value of X_i

A_i = area of region i in sq mi

ρ = tons of coal/sq mi-ft

N = number of regions

n_i = number of samples in region i

In addition, it is convenient to define the two statistical parameters:

$$\mu_i = E(X_i) \qquad \sigma_i^2 = V(X_i)$$

and two other quantities which simplify the expressions for the mean and variance,

$$A = \sum_{i=1}^{N} A_i \qquad W_i = A_i/A$$

Expressions for R, μ_R, and σ_R^2 may be readily written with use of the above definitions:

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$$R = \rho A \sum_{i=1}^{N} W_i X_i$$

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$$\mu_R = E(R) = \rho A \sum_{i=1}^{N} W_i \mu_i$$

$$\sigma_R^2 = V(R) = (\rho A)^2 \sum_{i=1}^{N} W_i^2 \sigma_i^2$$

Now,

$$\bar{X}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} X_{ij}$$

$$\bar{R} = \rho A \sum_{i=1}^{N} W_i \bar{X}_i$$

Thus,

$$\mu_{\bar{R}} = E(\bar{R}) = \rho A \sum_{i=1}^{N} W_i \mu_i = \mu_R$$

$$\sigma_{\bar{R}}^2 = V(\bar{R}) = (\rho A)^2 \sum_{i=1}^{N} W_i^2 \sigma_i^2/n_i$$

$$\hat{\sigma}_i^2 = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_i)^2$$

$$\hat{\sigma}_{\bar{R}}^2 = (\rho A)^2 \sum_{i=1}^{N} W_i^2 \hat{\sigma}_i^2/n_i$$

If $X_i \sim N(\mu_i, \sigma_i^2)$, then

$$\frac{\bar{R} - \mu_R}{\hat{\sigma}_{\bar{R}}} \sim t\left(\sum_{i=1}^{N} n_i - N\right)$$

$$\Pr\left\{ \left| \frac{\bar{R} - \mu_R}{\hat{\sigma}_{\bar{R}}} \right| < t_{\alpha/2} \right\} = 1 - \alpha$$

$$\Pr\left\{ \bar{R} - t_{\alpha/2}\, \hat{\sigma}_{\bar{R}} < \mu_R < \bar{R} + T_{\alpha/2}\, \hat{\sigma}_{\bar{R}} \right\} = 1 - \alpha$$

In consequence, the 100 $(1 - \alpha)$% confidence interval for μ_R is $(\bar{R} - t_{\alpha/2}\, \hat{\sigma}_{\bar{R}}\ ,\ \bar{R} + t_{\alpha/2}\ {}_{\bar{R}})$.

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