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# COAL RESOURCE POTENTIAL OF THE NORTHWEST ALASKA RESOURCE MANAGEMENT AREA

By

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USERS GUIDE
ADGGS Public-data File 85-42-D
Northwest Alaska Coal Resource Evaluation

## INTRODUCTION

The map series for the northwest Alaska coal resource evaluation has been designed for use both by laymen and professional workers in the geologic and resource fields. The 1:250,000 scale maps that are provided are intended to be used as supplements to standard U.S. Geological Survey topographic base maps, and other resource or land status maps of the same scale. They do not include comprehensive geologic or geographic information. The purpose of the series is to indicate: A) the locations of known or reported coal occurrences; B) their areal extent, based upon available geologic information, including projections of continuity that rely upon the U.S. Geological Survey Coal Resource Classification System (U.S. Geological Survey Circular 891); C) a rating of the relative known or potential value of each occurrence as a resource; and D) a rating of all of the remaining land area within the quadrangle, including areas where the geologic setting is favorable for coal to occur, although none has been reported, and also including all areas where there is no possibility for a coal occurrence due to an unfavorable geologic setting (a rating of 1 on the map).

A total of 19 quadrangles at 1:250,000 scale fall within the Northwest Alaska Area Plan regional boundaries. Eighteen of the 19 quadrangles have been evaluated for coal resource potential. Only one quadrangle (Survey Pass Quadrangle) has no reported coal occurrence and too little geologic information available for a projection of possible coal-bearing rock units. For this reason, the Survey Pass Quadrangle has been omitted from the Coal Resource Evaluation series.

The 1:250,000 scale maps of this series are numbered as follows:

| Sheet no. | Quadrangle | Public-data file no. |
|---|---|---|
| 1 of 18 | Wainwright* | 85-42-D |
| 2 of 18 | Point Lay | " |
| 3 of 18 | Point Hope | " |
| 4 of 18 | De Long Mountains | " |
| 5 of 18 | Noatak | " |
| 6 of 18 | Baird Mountains | " |
| 7 of 18 | Ambler River | " |
| 8 of 18 | Shishmaref | " |
| 9 of 18 | Kotzebue | " |
| 10 of 18 | Selawik | " |
| 11 of 18 | Shungnak | " |
| 12 of 18 | Hughes | " |
| 13 of 18 | Teller | " |
| 14 of 18 | Bendeleben | " |
| 15 of 18 | Candle | " |
| 16 of 18 | Nome | " |
| 17 of 18 | Solomon | " |
| 18 of 18 | Norton Bay | " |

*Only the southern portion of the Wainwright Quadrangle falls within the study area.

Included with each map sheet in this series is an 'Explanation' section. This section incorporates the following information:

1) Coal Resource Rating Criteria; an explanation of the criteria used in rating the coal resource potential of each known or indicated coal occurrence, and in rating the 'barren' areas. These criteria were designed to be as comprehensive as possible, given the great variation in types of coal occurrences, kinds and levels of geologic data available, and differences in coal quality and rank. The evaluations based on these criteria are subjective to the extent that the data base must be supplemented with the experience and judgment of the authors.

2) Data confidence; a rating symbol, designating the confidence level of the available data upon which the rating of the area within a quadrangle is based, has been attached to each descriptive letter-qualifier accompanying a rating number in the Coal Resource Rating criteria.

3) Summary; a concise summary of the pertinent information available for each coal occurrence indicated. Each summary includes: A) the location(s) of the known or indicated coal occurrence(s); B) a short discussion of the geologic setting; C) a history of exploration and past use or development; D) a description of each individual occurrence; E) resource information, such as estimated reserves and coal quality, if available; and F) a brief comment upon the relative present or potential value of the coal occurrence(s).

4) Coal rank and some equivalents; an explanation of criteria upon which coal rank may be determined, with some equivalent values given for the heating value of coal expressed in Btu's/lb (British Thermal Units per pound).

5) Glossary; an abbreviated definition of some important terms used in discussing coal occurrences. This may be useful to users who are not familiar with geologic terminology, or with the specialized vocabulary of coal studies.

6) Types of coal; a description of the main types and uses of coal as determined by rank and other important characteristics.

7) Map symbols; a limited assortment of symbols used on the maps to indicate the type of coal occurrence that is being rated. These symbols are for quick reference only. More detailed information is contained in the Summary.

Included for handy reference are the Coal Resource Rating Criteria, and the Summary for each quadrangle. A bibliography of selected references used in the compilation of the maps is included at the end of this section.

Also included in this user guide (Appendix B) are excerpts taken directly from the U.S. Geological Survey Coal Resource Classification System publication, Geological Survey Circular 891, for users who desire a more complete glossary of coal and coal resource classification terminology than is given in the map explanations.

For users who wish to check references or acquire more detailed and specific information on individual coal occurrences, a reference file has been compiled for each of the 18 quadrangles and is available for public use at the Fairbanks office of ADGGS. In addition, geologic map compilations for each quadrangle, both for coal and general geology, are available for inspection.

A comprehensive bibliography of geologic references is on file at ADGGS, Fairbanks. It is titled 'Bibliography and index of northwest Alaska geology'; Public Data-file (PDF) 80-85. A xerox copy of this PDF may be purchased through ADGGS, Fairbanks, Publications Section, or examined on the premises.

## COAL RESOURCE RATING CRITERIA

The following resource rating criteria are organized on scale of 1 = low to 5 = high potential. A rating of 1 indicates virtually no possibility for substantial coal discoveries, and no known coal in the area. Categories 2 and 3 are for possible but unverified occurrences of coal. A 5 is the highest possible rating under this system. The letters 'a' through 'm' that may accompany the numbers 2 through 4 are meant to clarify and justify the number ratings assigned. In some cases, more than one letter is used, as in '2b,c.' These letters are only explanatory, like footnotes, and do not weight the ratings.

The areas outlined in heavy black on the map have been calculated according to the U.S. Geological Survey resource classification system (U.S.G.S. Circular 891), using available surface and subsurface data. The kinds and reliability of data available determine how the resource potential is calculated (see 'coal reserves,' Glossary and figure 7).

1. Very low to low possibility for substantial coal discoveries; sedimentary and other rock units not known to host coal; "barren" units vary from map to map; these ratings are based almost entirely on published general, broad-brush geological maps;

2. Low to medium possibility for substantial coal discoveries; these ratings based mostly on published general, broad-brush geology:

   a. units with very minor coal shows elsewhere; possibly favorable rocks but no coal known at location;

   b. queried rock unit or undifferentiated group (two or more rock units mapped together, so presence of coal-bearing unit is uncertain);

   c. cover of recent unconsolidated (Quaternary) sediments suspected of being underlain by coal-bearing formation;

   d. Tertiary basin; most of the coal on the Seward Peninsula is lignite (lower quality coal) found within Tertiary-aged sedimentary rocks confined in areas called basins (which may or may not be topographic depressions now); therefore, all such basins on the Peninsula potentially contain coal deposits;

e. unverified report of coal occurrence; off-hand reference to coal in published geological report, etc.

3. Medium to high possibility for substantial coal discoveries;

f. coal-bearing formation close to exposed coal, e.g. other end of basin(see 2d, above) from known coal deposits;

g. scattered, small surficial coal shows, float (loose fragments) that may be weathering out of a hidden deposit;

h. "mined out" or formerly subeconomic sites where future investigation may reveal usable coal resources;

i. Cretaceous basin (see 2d, above): composed of Cretaceous-aged rocks known elsewhere to contain medium to large tonnages of good quality (subbituminous) coal; rated higher than 2d both because of likely higher coal quality and because of high tonnage potential demonstrated, for example, by the large Cretaceous-aged Cape Beaufort coal field:

4. Known coal, lesser occurrences and/or less well studied than 5's;

j. marginal because of low rand (low Btu), low tonnage, structural complexity, thin beds (even if coal is good quality and present in large amounts, thin beds may mean too much admixed waste), etc.

k. indicated and inferred resources (3/4 mile radius and 3 mile radius, respectively) from 5's;

m. may include cases where drilling has disclosed some coal but where its extent is still unknown;

5. Known coal, medium to large measured (½ mile radius from coal drill hole or outcrop) resources of usable quality coal; there is a large size difference between smallest and largest but even the smallest is known to contain reserves that might be mineable under the right conditions. As an illustrative example, the Chicago Creek coal deposit, on the Seward Peninsula contains only one thick seam o coal and is confined to a linear trough feature. Estimated tonnages for this deposit are a fraction of those calculated for the Deadfall syncline. The rank of the Chicago Creek coal is Lignite, while the Deadfall syncline coal is of higher bituminous rank. Nevertheless, Chicago Creek coal rates a 5 as easily as Deadfall syncline, for it is a potentially marketable coal close to sea access, with an adequate tonnage.

## DATA CONFIDENCE

Each number rating, 1 through 5, has typical typical levels of data confidence. A rating of 1 often implies limited geological data as well as a lack of coal potential. A rating of 3 usually implies more and better data, as well as greater coal potential. It is, however, possible to have a rating

of 1, signifying low or non-existent coal potential, based upon a high level of data. This is the case in parts of the Point Lay Quadrangle for example, where detailed geological mapping has shown that certain rock units are not coal-bearing. Conversely, it is also possible to have a high rating of 4 for which the data base is limited, but for which geologic conditions are highly favorable for significant coal resource potential, as in "4m". As a very general indication of the amount and depth of information upon which ratings are based, each rating above has been assigned one of the following confidence symbols:

○ Good data base △ Medium data base □ Poor or very general data base

These symbols are not meant as comments on the quality of work done by previous investigators, which in most cases is difficult to judge without rechecking the geology on the ground.

## TYPES OF COAL

The many types of coal in Alaska are classified, or ranked, according to physical and chemical properties. A coal's rank is determined by laboratory testing of its properties using ASTM standardized methods. Rank is based primarily on heating value (Btu/lb.) and content of certain physical components. The main coal rank classifications are: A) lignite = very low rank; B) subbituminous = low to medium rank; C) bituminous = medium to high rank; and D) semianthracite and anthracite = very high rank. Each of these rank classifications has discrete subdivisions (see below), and distinct properties that help to determine its optimum potential use. The uses that are appropriate for one type of coal may not be appropriate for another type.

Classification and use are determined by a coal's rank, its heating capacity, and its weathering characteristics (whether it remains compact or readily crumbles and decomposes under surface conditions). Lignites and subbituminous coals are often satisfactory for local use, such as home heating and power generation, but poor weathering behavior and low heating values typically make the long distance transportation and storage of low-rank coal impractical. Bituminous coals are of higher rank than lignites and subbituminous coals, and may be coking, caking or non-coking. Coking and caking coals soften and flow prior to ignition. The escape of volatile components, under heat in the absence of oxygen, results in a dull-grey, porous mass called "coke." This material, which has a high percentage of fixed carbon, is used in the production of steel. Caking and non-coking bituminous coals are not suitable for metalurgical use, but have high heating values, and do not weather as badly as lower rank coals. Long distance transportation and storage of these coals may therefore be feasible. Anthracite, the highest rank of coal, has the highest heating value per pound, with the fewest residual impurities, but there is very little anthracite coal in Alaska. At a very high fixed-carbon content, anthracite becomes graphite, which cannot be used for fuel.

Coal Rank - Based on Moist, Mineral Matter Free Btu/lb

Lignite: 6,000 to 8,300 Btu/lb.

Subbituminous: subbituminous-C = 8,300 to 9,500 Btu/lb.
subbituminous-B = 9,500 to 11,00 Btu/lb.

Bituminous: subbituminous-A to high volatile bituminous-C = 11,000 to 13,000 Btu/lb.
high volatile-B bituminous = 13,000 to 14,000 Btu/lb.
high volatile-A bituminous = 14,000 to 16,000 Btu/lb.

Coal Rank - Based on Dry, Mineral Matter Free Fixed Carbon %

| | BTU/Lb | Fixed Carbon % |
|---|---|---|
| Bituminous (medium volatile) | 11,000 to 16,000 Btu/lb | 69-78% |
| Bituminous (low volatile) | 16,000+ Btu/lb | 78-86% |
| Semi-anthracite | " | 86-92% |
| Anthracite | " | 92-98% |

SOME EQUIVALENTS

1 Btu (British thermal unit) equals 250 calories of heat. There are approximately 138,000 Btu to 1 gallon of fuel oil or diesel. 1 Kwh (kilowatt hours) equals approximately 3,400 Btu.

Therefore, using an average value of 12,000 Btu/lb for calculation:

1 ton of coal = 144 gallons of fuel for electric power
1 ton of coal = 176 gallons of fuel for home heating

Since the Btu value of coal varies considerably, 1 ton of a lower ranked coal, such as a lignite averaging 6,000 Btu/lb, is the equivalent of half as many gallons of fuel as a coal with an average of 12,000 Btu/lb. Conversely, 1 ton of 12,000 Btu/lb coal equals 176 gallons of fuel oil, but it would take 2 tons of 6,000 Btu/lb coal, or twice as much, to generate the same amount of heat.

GLOSSARY OF TERMS (MAP VERSION)

Coal — A compact, light weight dark brown to glossy black rock that is composed of vegetable material physically and chemically altered to a concentrated fixed carbon product.

Coking coal — A form of coal, usually of bituminous rank, where the coal material softens and flows when heated to just below the

point of ignition. During this process, volatile gasses escape and leave the dull-gray porous mass that is called coke.

Syncline — A rock structure that is formed from the large-scale folding of massive rock formations. The syncline is the 'U' shape of the downward folded portion of the rock.

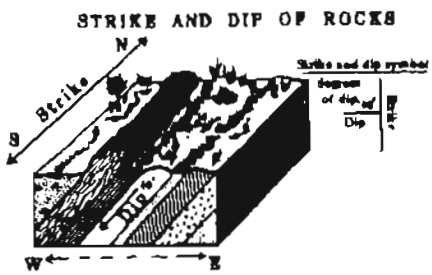
Dip of rocks — The angle from horizontal in which a rock unit lies.

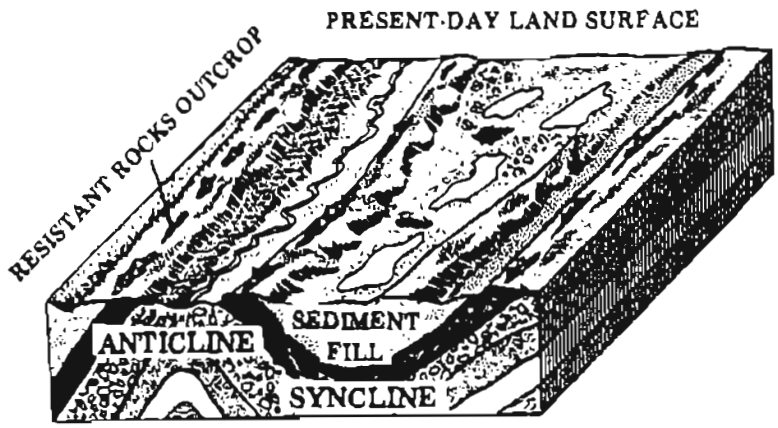
The dip of a rock unit can be the product of one or more deforming agencies, such as uplift, mountain building, fault movements or down-warping of rocks due to the weight of overlying sediments.

Strike of rocks — The strike is always perpendicular to the dip. If a rock unit is dipping at some angle toward the north, the strike will be east-west.

Deformation — Deformation is any physical change in attitudinal position or volume of rocks from the original configuration that they had when formed. Folding, tilting and warping are forms of deformation. So are compression (squeezing) and tension (stretching).

Anticline — A rock structure that is formed from the large-scale folding of massive rock formations. The anticline is the " _ " shape of the upward folded portion of the rock. Illustration:




FOLDED ROCKS

Btu — British thermal unit. One British thermal unit is the equivalent of the same amount of heat it takes to heat one pound of water one degree fahrenheit. This is the standard unit of heat used in describing the heating value of most fuels.

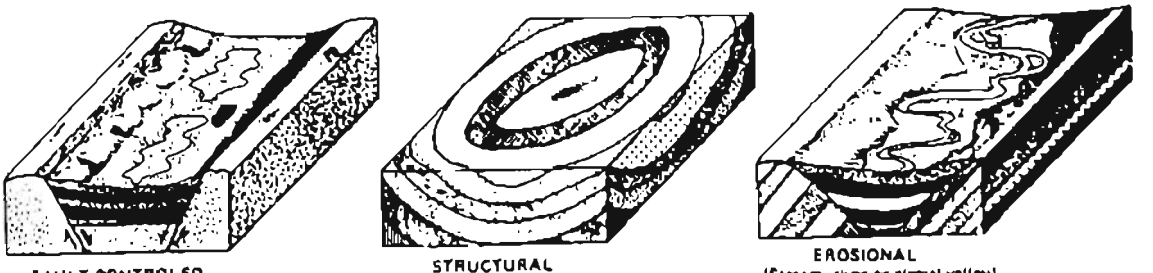
Bone coal — A coal that contains a high percentage of impurities such as clay, dirt, or rock fragments.

Ash — The residual mineral matter impurities left after the combustion of coal.

Coal float — Fragment of coal that have been displaced from the parent coal bed. This can occur through normal erosion. Coal fragments found in stream gravels, in rock and gravel talus at the base of a bluff, in landslide material and in other places removed from the in-place coal bed - are all called coal float.

Basin — Any structural depression in the earth's surface. Structural basins are where thick accumulations of sediments collect. Many such basins provide an environment whereby the thick layers of vegetable matter that may become coal can accumulate. Ancient basins that served as coal-forming environments may have undergone uplift and erosion through geologic time. In this case, what was at one time a basin may now be incorporated in a present-day topographically high area, such as a hill or mountain. Nevertheless, if it' original configuration was that of a basin, it will be described as such in geologic terms. Illustration:

**SOME TYPES OF BASINS**



FAULT CONTROLED
(Down-dropped block)

STRUCTURAL
(Doubly plunging syncline)

EROSIONAL
(Stream, river or glacial valley)

Coal rubble — Similar to coal float, but often the fragments of a fractured sub-surface coal bed being frost-jacked to the surface through freeze-thaw action, or the fractured and fragmented coal particles that accumulate from the weathering of a surface or near-surface coal exposure. Coal rubble is usually found close to the parent coal bed.

Coal resources — Naturally occurring concentrations or deposits of coal in the earth's crust, in such forms and amounts that economic extraction is currently or potentially feasible.

Coal reserves — Identified, recoverable coal resources.

sub-categories
1. measured reserves...accessed and virgin coal reserves having the highest degree of geologic assurance
2. indicated reserves...categories of virgin reserves having a moderate degree of geologic assurance.
3. inferred reserves...categories of virgin coal reserves having a low degree of geologic assurance.

Mississippian — The lower ½ of the geologic period called the carboniferous. The carboniferous period was a time when many of the world's coal deposits formed. It spans the time from 360 million years ago to 185 million years ago. The Mississippian subdivision spans the time from 360 million years ago to 320 million years ago, a total of 40 million years.

Cretaceous — The geologic period spanning the time from 140 million years ago to 65 million years ago. Many of Alaska's coals were formed during the Cretaceous period.

Tertiary — The geologic period spanning the time from 65 million years ago to 1.5 million years ago. Many of Alaska;s coals are Tertiary in age.

Quaternary — The geologic period spanning the time from the end of the Tertiary through the present, or the last 1.5 million years.

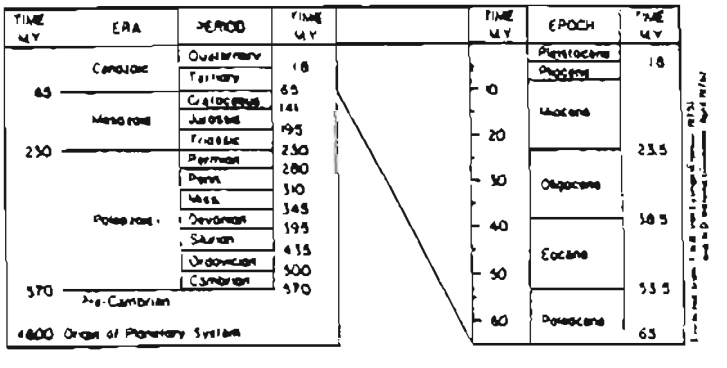



Figure 1. Geologic time scale.

## APPENDIX A - SUMMARIES

### Summary: Wainwright Quadrangle (1 of 18)

The coal-bearing rock unit in the Wainwright Quadrangle is called the Corwin Formation. Outcrops of this unit are generally restricted to exposures along the Kuk and Kugrua Rivers and along the beaches around Wainwright and Peard Bay within the National Petroleum Reserve, Alaska.

The Cretaceous Corwin Formation is a clastic sedimentary assemblage of interbedded claystone, siltstone, sandstone, ironstone, conglomerate, coal, and minor bentonite. The formation is folded and faulted along east-west axes that generally parallel the northern front of the Brooks Range. Intensity of deformation decreases northward from tight, asymmetric folds with steep dips and many faults in the southern part of the foothills belt, to broad open folds with flat dips and few faults under the coastal plain (Barnes, 1967). The Corwin Formation underlies most of the north slope beneath Pleistocene and younger surficial deposits. Data from seismic work and three deep exploratory wells suggests that the unit is roughly divided into three zones (Callahan and Martin, 1980). Lower zone coal is generally thin and laterally continuous up to 12 miles. Coal of the upper zone is generally thicker, but thins and splits over short distances. Coal beds in the middle, transitional zone are 6 to 10 feet thick and laterally persistent for as much as 6 miles. Beds in the northern part of the quadrangle tend to be thin and laterally continuous, while beds to the south are thicker but more discontinuous (Callahan and Martin, 1980).

Coal along the coast at Wainwright Inlet and on the banks of the Kuk River was first reported in 1889 by H.D. Woolfe, who described it as cleaner and of better quality than Cape Lisburne coal (Schrader, 1904; Collier, 1906). In 1901, F.C. Schrader of the U.S. Geological Survey (USGS) studied and sampled coal at several localities in the Wainwright Inlet area. Easily accessible beds have since been mined by primitive methods to supplement local fuel needs (Smith and Mertie, 1930).

Three mines on Kuk Lagoon southeast of Wainwright operated from the turn of the century, with most production in the 1930's (Lounsbury, 1974). The best known outcrops of Cretaceous coal-bearing strata in the Wainwright Quadrangle occur along the Kuk and Kugrua Rivers in the vicinity of these mines. Coal in the shaft of the mine closest to the village of Wainwright (Kuk River #1) could not be measured because it was flooded but the surrounding strata strike S. 3° E. and dip 7° W. The coal bed that was mined here is known to extend 1,000 feet along the shoreline (Toenges and Jolley, 1947). The Kuk River #2 mine has three separate beds 2.2 to 5.0 feet thick that strike S. 28° W. and dip 5° E. Two beds 5.2 feet and 3.8 feet thick at the Kuk River #3 mine strike S. 40° E. and dip 5° W. These three mines have produced a few hundred tons of coal for local use (Plangraphics, 1983). One mile past the Kuk River #3 mine, two coal beds 5.5 and 6 feet thick are probably extensions of the ones at the mine and continue for at least a mile along strike away from the mine (Lounsbury, 1974).

Acute fuel shortages in Barrow during World War II spurred interest in north slope coal deposits. In 1943-44 and in 1946, U.S. Bureau of Mines (USBM) geologists measured and sampled deposits at Peard Bay and on the Kuk River (Sanford and Pierce, 1946; Toenges and Jolley, 1947). In 1951, the U.S. Navy, as part of a petroleum exploration program in the Naval Petroleum Reserve (now called National Petroleum Reserve, Alaska), drilled a 7,000-foot test well near the Kaolak River, five miles south of the Wainwright Quadrangle. Though dry, the Kaolak test hole intersected 4,000 feet of coal-bearing Corwin Formation containing 36 coal beds between 3 and 26 feet thick (Collins, 1958). In the 1970's, two additional test wells, one near Peard Bay and the other near the Tunalik River, penetrated at least 2,600 feet of coal-bearing strata (Rao and Smith, 1983). These test wells and numerous closely spaced seismic measurements by the USGS and private industry have demonstrated that fairly continuous coal beds occur widely throughout the subsurface of the Wainwright Quadrangle (Callahan and Martin, 1980).

Two other abandoned mines occur along the east bank of the Kugrua River south of Peard Bay. Coal beds between 5 and 6 feet thick at the Kugrua River #1 mine have been sampled from prospect pits by the USBM, as has a 6-foot bed at the Kugrua River #2 mine (Sanford and Pierce, 1946). Other minor occurrences in the Wainwright Quadrangle include coal float on the beach near the village of Wainwright. This coal may be derived from eroding offshore beds, or may be brought from outcrops elsewhere on the coast by longshore sediment transport. Thin coal beds on the Kaolak River and considerable amounts of coal float on river bars suggest that other beds may be concealed nearby under surficial material (Smith and Mertie, 1930). Several beds up to 3 feet thick are poorly exposed on the Avalik River a short distance above a place the natives call Kangik. Coal beds are recognized at a number of other places on the Avalik but most are less than one foot thick (Smith and Mertie, 1930).

Analyses of coal from outcrops in the Wainwright Quadrangle yield moderate moisture, low ash and sulfur, and an apparent rank from lignite to subbituminous A, with subbituminous B most abundant (Callahan and Martin, 1980). Subsurface coals increase in rank from subbituminous B near the surface to subbituminous A at depth. Heating values for these coals (as received) average 9,500 Btu/lb.

Although geological evidence suggests that coal beds in the Wainwright Quadrangle are fairly continuous, no reserve estimates are available for this quadrangle. Significant coal resources discovered anywhere near the Kuk and Kugrua Rivers could be developed as a local source of fuel for the settlements of Wainwright and Barrow.

Summary: Point Lay Quadrangle (2 of 18)

Coal resource potential in the Point Lay Quadrangle is not as restricted to specific locations as it is in some other quadrangles of the Northwest Alaska study area. Much of the north slope of the Brooks Range, especially the western part, is underlain by the coal-bearing Corwin Formation folded into a series of east-west synclines. Although subsurface exploration has been confined primarily to the Deadfall and Liz-A Synclines, geologic mapping

has identified the coal-bearing formation in all exposed structural basins. The northern half of the Point Lay Quadrangle is covered by recent sediments, but exposures in cutbanks of the Kukpowruk and Kokolik Rivers show that coal-bearing rocks of the Corwin Formation occur here in synclines like those mapped further south.

Most known coal exposures in the Point Lay Quadrangle occur in creek and river cutbanks, and in beach cliffs along the coast, with a few outcrops in the Deadfall and Liz-A Synclines. Exploration has been concentrated in these areas, and the highest coal ratings are found where drilling programs have provided subsurface data. Nonetheless, all areas containing mapped or probable Corwin Formation have been rated to reflect the fact that this unit is commonly coal-bearing.

The geology of the Point Lay Quadrangle is comparatively well known, though recent sediments cover the northern part. Four formations, all of Cretaceous age, occur in the region: the Fortress Mountain, Torok, and Kukpowruk Formations are all primarily of marine origin and barren of coal; rocks of the Corwin Formation are predominantly non-marine, and contain at least 146 coal beds, of which 28 are potentially mineable (Chapman and Sable, 1960).

The Corwin Formation thins southward toward the Brooks Range, and thickens to the north. Inland from the coast, this unit is found in a series of east-west-trending synclines. Folding is more intense close to the foothills of the Brooks Range and much gentler to the north. Coal is best exposed in sea cliffs, as at Corwin Bluff (Delong Mountains Quadrangle), and in the banks of the Kukpowruk and Kokolik Rivers. Estimated cumulative thickness of the coal-bearing Corwin Formation rocks is between 11,353 and 15,494 feet (Chapman and Sable, 1960).

Coal in arctic northwest Alaska was first officially reported by A. Collie, a member of the Beechey expedition to the Arctic Ocean in 1826-27. Coal beds exposed in the coastal sea cliffs at Corwin Bluff, east of Cape Lisburne, were exploited during the late 1800's and early 1900's to replenish the fuel supplies of whaling ships. Coal was also mined from several different beds for use at Nome in 1900-1901. A total of 1,000 tons was produced and shipped during that time.

Geologic study of the Corwin Formation began in 1904 when A.J. Collier of the U.S. Geological Survey (USGS) led a mapping expedition to the Utukok-Corwin region. The area between Cape Lisburne and Cape Beaufort was an important part of this study (Collier, 1906). Following the establishment of Naval Petroleum Reserve No. 4 in 1923, the USGS extended geological reconnaissance as much as 40 miles inland from the coast, up the Kukpowruk, Kokolik, and Utukok Rivers. In the summer of 1946, U.S. Bureau of Mines (USBM) engineers investigated a number of reported coal occurrences to determine the feasibility of small-scale coal mining as a fuel source for native villages in the region. A 20-foot bed of coal that they examined and sampled on the Kukpowruk River later became the target of more detailed investigations. During 1947, and from 1949 to 1953, the USGS studied the geology of the Utukok-Corwin region to evaluate the petroleum potential of 'Pet 4' and sample numerous coal beds (Chapman and Sable, 1960).

In 1954, J.S. Robins and Associates, under contract to the Morgan Coal Company, drove a 70-foot adit into the 20-foot coal bed on the Kukpowruk River for bulk sampling. In 1961 and 1963, Union Carbide sampled this same bed for coking tests. Results from both of these testing programs are confidential. However, during the summers of 1962 and 1963, the USBM sampled this same bed and several others along the Kukpowruk River for testing, which showed that this coal could produce an almost metallurgical-grade coke if blended with as little as 15 percent low volatile coking coal from other sources (Warfield and others, 1966).

From 1978 to 1980 the USGS, in cooperation with Huskey Oil Company and Geophysical Services Inc., used several kinds of geophysical techniques to obtain shallow subsurface data on coal bed thickness and distribution. In 1983 the State of Alaska Division of Geological and Geophysical Surveys (ADGGS) and the USGS explored in the Cape Beaufort/Liz-A Syncline region for accurate information on the thickness, continuity, and quality of selected coal beds. This program included auger and core drilling of 21 holes, and downhole geophysics.

In 1984, Arctic Slope Consulting Engineers, under contract to Alaska Native Foundation and sponsored by the State of Alaska Department of Community and Regional Affairs, began a project in the Cape Beaufort/Liz-A Syncline and Deadfall Syncline areas. During geologic mapping and coal sampling, 74 new drill holes up to 110 feet deep were completed. This work was done to evaluate the coal resources at Cape Beaufort and the Deadfall Syncline as a potential substitute for the fuel oil presently used for space heating and power generation in western arctic villages (Arctic Slope Consulting Engineers, 1984).

Within the most extensively explored areas, a total of 141 holes were drilled between 1966 and 1984. Along the Kukpowruk River between Point Lay and the Deadfall Syncline, estimates are for 235,100,000 tons of indicated, and 2,767,200,000 tons of inferred, coal resources. These coals range between 12,000 and 14,000 Btu/lb (dry, mineral-matter free), and are high-volatile bituminous C or B.

The logs of 18 holes drilled by the USBM and USGS during 1966 and 1972 in the Cape Beaufort/Liz-A Syncline area show 26 coal beds over 1 foot thick in some 4,000 feet of Corwin Formation rocks. Onshore coal resources for the Liz-A Syncline are calculated at 35,000,000 tons measured, mostly with a favorable 10:1 stripping ratio; 312,000,000 tons indicated; and 186,000,000 tons inferred. Hypothetical additional resources of the 26 major seams have been estimated to be as high as 500 million tons, though this figure includes coal that is not necessarily mineable, let alone strippable, because it is too deep or for other reasons (Arctic Slope Consulting Engineers, 1984). Measured reserves for the Deadfall Syncline, at the 10:1 stripping ratio, total about 15,810,000 tons, with additional reserves of about 59 million tons inferred (Arctic Slope Consulting Engineers, 1984).

Hundreds of drill hole and outcrop samples from 8 beds 4.3 to 13.1 feet thick in the Deadfall syncline analyzed between 10,675 and 13,209 Btu/lb. Subbituminous and bituminous coals found in the Point Lay Quadrangle have

less moisture, a lower ash content, and a higher Btu value than many Alaskan coals. In addition, they are more compact and do not decompose badly when exposed to weathering. For example, coals from the Kukpowruk River area commonly contain between 1 and 3 percent moisture, between 2 and 4 percent ash, and an average heating value of 14,000 Btu/lb (dry mineral-matter free).

Chances appear to be very good for additional sizeable coal discoveries wherever the Corwin Formation has been mapped. So far, with so much coal already known, there has been little incentive for 'wildcat' drilling in the Corwin Formation except near known coal outcrops.

Summary: Point Hope Quadrangle (3 of 18)

The coal-bearing formation of interest in the Point Hope Quadrangle is called the Kapaloak Formation. This unit, located on the Lisburne Peninsula, consists of Lower Mississippian-age nonmarine sandstone, mudstone, shale, and coal, with minor conglomerate and marine limestone. It lies directly below the base of the Lisburne Group, a sequence of Mississippian-age marine limestone and dolomite. The coal deposits occur on land claimed by the Tigara Native Corporation of Point Hope.

The structure of the Kapaloak Formation coal-bearing sediments is complex due to extensive faulting, shearing, contorted folding, and crumpling along east-trending fold axes. This results in erratic dip angles ranging from horizontal to vertical. The deformation of the coal-bearing rocks, with their tendency to weather and erode rapidly, has resulted in coal beds that are difficult to locate or trace. The lack of continuity of beds due to deformation may limit the scale of any future mining endeavors.

The coal occurring along the coast south of Cape Lewis to below Cape Dyer on the Lisburne Peninsula, was first formally noted in 1831 (Collier, 1906). Whaling ships and revenue cutters for many years replenished their fuel supplies from the easily accessible coal beds exposed along the sea cliffs. The fact that the coals exposed south of Cape Lewis are much older than those elsewhere in Alaska was first recognized by Maddren in 1900 (Tailleur, 1965). These coals were formed during the Mississippian Period, between 340 and 315 million years ago. Most of Alaska's coal is much younger, being either Cretaceous or Tertiary in age. The greater heat and pressure generated during deformation of the older strata have produced a coal that ranks as low volatile bituminous, whereas elsewhere in Alaska lignite, subbituminous, and bituminous high volatile coals are more common.

The largest outcrops of Mississippian coal-bearing strata occur in the sea cliffs 1½ miles south of Cape Lewis and along Kapaloak Creek south of Cape Dyer. Several small beds and a 4-foot 'considerably crushed' coal bed south of Cape Lewis strike N. 75° E. and dip north at 40° (Collier, 1906). In the sea cliffs south of Kapaloak Creek, Tailleur (1965) found 13 coal beds from 2.5 to 11 feet thick, exposed in 2,200 feet of measured section. The upper 1,900 feet (to the north) is coal-bearing but the lower 300 feet, marine in origin, is barren. The coal-bearing section at Kapaloak Creek has an overall dip to the south, with moderate to steep attitudes. This section is the type section by which the Kapaloak Formation was named. Other isolated

occurrences of Mississippian coal are: 1) at Niak Creek, 5 miles south of Cape Lisburne, where a 4- to 5-foot bed of coal, sampled near the turn of the century by C. Washburne (Collier, 1906), dips north at 60°; 2) on the Kukpuk River, ¼ mile west of the mouth of Iglupak Creek, where Conwell and Triplehorn (1976) studied and sampled a 6-foot coal bed in a hand-dug pit; this bed strikes easterly and dips 23° to the south; 3) at Cape Thompson, 25 miles southeast of Point Hope, where Conwell and Triplehorn (1976) observed two near-vertical beds of coal, each about 1 foot thick. One of the beds analyzed contained 27.8 percent ash, which means it is of poor quality. Since there has been no drilling in the area, continuity of the Mississippian coal seams cannot be determined.

Another area of interest in the Point Hope Quadrangle is the intermittant exposure of coal beds in the sea cliffs east of Cape Lisburne. These Cretaceous coals extend into the De Long Mountains Quadrangle in the most westerly extension of the Corwin Formation. This unit is widespread from the northern foothills of the Brooks Range to the southern Arctic Plain, from Corwin Bluff on the west to the Utukok River on the east. Coal was first formally reported in the Corwin Bluff area in 1826 by the Beechey Arctic Expedition (Collier, 1906). Whaling ships and revenue cutters also used this coal for fuel, and 1,000 tons was used at Nome in 1900 and 1901. Some small-scale coal mining was attempted during the late 1800's and early 1900's at various localities along Corwin Bluff, most notably at the Corwin and Thetis Mines. Coals in the Corwin Bluff area are quite numerous. Barnes (1967) cites 58 coal beds greater than 14' thick from field observations made during a Naval Petroleum Reserve Study for oil and gas reserves. The thickest bed reported is 9 feet thick. Bedding in the Corwin Formation strikes N. 75° W. and dips about 40° SE in the western part of the area, with changes of strike and dip to N. 60° W. and 20° SW in the east.

Analyses of the Mississippian coals shows them to be low volatile bituminous in rank, although Conwell and Triplehorn (1976) suggest a semi-anthracite rank for the Kukpuk River coals. Numerous analyses from different authors show these coals to be low in moisture, ash, and sulfur, with high heating values (Btu). The Cretaceous Corwin Bluff coals are also shown by various analyses to be low in moisture and sulfur, variable in ash, and high, though generally below the Mississippian coals, in heating value; their rank has been determined to be high volatile bituminous.

In recent years, the coal beds of the Lisburne Peninsula have come under increasing scrutiny for possible steam generation and domestic heating in local villages, especially nearby Point Hope. In 1983, geologists from the State of Alaska Division of Geological and Geophysical Surveys (ADGGS) investigated both known and previously unreported coal occurrences of the western Peninsula for preliminary evaluation of the area's development potential. Results suggest that the complex structure of coal beds near the coast rules out any state-funded drilling program for the present. There is simply too little surface geological information to effectively target drill holes. Exposed coal could, however, be used for domestic heating with forced draft blowers to enhance combustion (since these coals are harder than most Alaskan coals). Currently, Point Hope and other northwestern Alaska villages import oil and coal from the coterminous United States, a costly dependency which

could make development of the area's coal attractive in the future. The Corwin Bluff coals, in contrast, enjoy a less deformed structure, more numerous beds, and a seacoast exposure, which makes these coals accessible and potentially useful in both the domestic and foreign markets.

Summary: De Long Mountains Quadrangle (4 of 18)

The coal-bearing formation of interest in the De Long Mountains Quadrangle is called the Corwin Formation. Outcrops of this unit are generally restricted to the northern half of the quadrangle along the Chukchi Sea coast or along river-cut exposures. The quadrangle, which lies directly east of the Lisburne Peninsula, includes the De Long Mountains to the south and the Arctic Coastal Plain to the north. Subsurface mineral rights are presently being conveyed to the Arctic Slope Regional Corporation.

The Cretaceous Corwin Formation is a clastic sedimentary assemblage of interbedded claystone, siltstone, sandstone, ironstone, conglomerate, coal, and minor bentonite. The structure is folded and faulted along eastward-trending axes generally parallel to the northern front of the Brooks Range. The formation is best exposed in the axes of major synclines. Intensity of deformation decreases northward, from tight asymmetric folds with many faults in the southern part of the foothills belt, to broad open folds with few faults under the coastal plain (Barnes, 1967). The Corwin Formation is thickest in the southwest and thins toward the north and northeast. Its type section at Corwin Bluff in the southwest corner of the quadrangle comprises 15,494 feet of coal-bearing strata (Chapman and Sable, 1960). This type section is subdivided into 7 distinct stratigraphic members according to dominant rock types, with the thickest coals occurring in the bentonitic clay member near the top of the formation. Bedding also shows a trend, from moderately to steeply dipping in the south and southwest, to nearly horizontal under the coastal plain to the north. The Corwin Formation shows similar structural trends in adjacent quadrangles (Point Hope and Point Lay).

Coal was first discovered near Corwin Bluff in 1826 by the Beechey Arctic Expedition. During the latter part of the nineteenth century, it became a refueling source for ships, particularly whalers and U.S. revenue cutters. One thousand tons of this coal was sold in Nome during 1900 and 1901 (Collier, 1906). In 1904 A.J. Collier of the U.S. Geological Survey (USGS) made the first reconnaissance geologic study of the coal-bearing area between Cape Thompson and Cape Beaufort, including the Mississippian-aged Lisburne Peninsula coals. Financed by the Department of the Navy, the USGS continued these studies into the 1920's in the newly established Naval Petroleum Reserve. In 1947 and the early 1950's, USGS geologists renewed their investigation of the stratigraphy and structure to evaluate the the region's petroleum possibilities. All of these studies concentrated on accessible outcrops of the Corwin Formation along the coastal region and major interior waterways. Local formations, including the Corwin Formation, were mapped during these later studies, but only from outcrop data with no drilling. In 1966 and 1972, an 18-hole drilling program was conducted in the Cape Beaufort area by the USGS and the U.S. Bureau of Mines (USBM) (Callahan and Sloan, 1978). It was determined from these holes that over 4,000 feet of the Corwin section near Cape Beaufort is coal-bearing.

The sedimentary rocks of the Corwin Formation contain 146 known coal beds, of which 28 are potentially mineable by conventional methods, which means they should be at least 14 inches thick and have less than 1,000 feet of overburden. Most exploration efforts have concentrated on three main areas within the De Long Mountains Quadrangle: 1) the Cape Beaufort - Liz-A Syncline area; 2) the Corwin Bluff area; and 3) the Coke Basin area. In the Cape Beaufort - Liz-A Syncline area, 26 coal beds one foot thick or greater have been identified. The majority of these beds are relatively thin or of limited extent. The thickest beds, no. 7 (15-17 feet), no. 8 (12-13 feet), no. 10 (8 feet), and no. 15 (9 feet), contain most of the reserves for the Cape Beaufort area (Dames and Moore, 1980). Dips of between 14° and 20° were determined from the drill holes. In the Corwin Bluff area, 80 coal beds greater than one foot thick, and 17 between 2.5 and 9 feet thick, have been measured from outcrops (Chapman and Sloan, 1960). Known coal beds in the Thetis Syncline dip from 45° to 52° S. near Corwin Bluff, to between 16° and 24° S. at the Thetis Mine. The third major occurrence of coal in this quadrangle is at Coke Basin, a structural depression located along the Kukpowruk River, where 10,000 feet of Corwin Formation is exposed (Chapman and Sable, 1960). Beds dip steeply on the flanks of this elliptical basin and flatten abruptly near the center. There are six coal beds ranging from 1 to 3 feet thick, with the thickest coal exhibiting good coking qualities. Minor exposures of coal-bearing Corwin Formation strata are found in the De Long Mountains Quadrangle in the Pitmeagea, Seaview, and Tupikchak synclines. These synclines may contain coal of mineable thickness but little is known about them.

Existing drill hole data suggest that the Corwin Formation coals are laterally continuous. Total hypothetical coal reserves for the North Slope are estimated at around 3.7 trillion tons for this one formation (Tailleur and Brosge, 1976). Onshore coal resources for the Cape Beaufort/Liz-A Syncline area are calculated by Callahan (1976) to be 35,000,000 tons measured, 312,000,000 tons indicated, and 186,000,000 tons inferred. Strip mining is the preferred mining method for this region, considering that dips are between 14° and 20° and that a stripping ratio of 10:1 has been projected. Coal resources for the Corwin Bluff area show no actual measured tonnages but Barnes (1967) estimates 48,700,000 tons indicated and 848,400,000 tons inferred. Steeper dips of 45° to 52° at Corwin Bluff and thrust faulting at the Thetis Mine area suggest that strip mining here may not be as feasible as at Cape Beaufort and underground mining may be the best alternative. Coke Basin coal resources stand at 11,400,000 tons indicated and 8,400,000 tons inferred (Barnes, 1967). Strip mining would be the preferred method here.

Analyses from various authors on the three main areas within the De Long Mountains Quadrangle show the coals to be high volatile bituminous A if found lower in the stratigraphic section, and high volatile bituminous B if found higher in the section (Dames and Moore, 1980). Moisture and sulfur values tend to be low, ash is variable depending on the proportion of shaly partings included, and heating values range from 12,260 to 14,910 Btu/lb. The Coke Basin coking coal sampled has an extremely low moisture value of 0.8 percent (as received) and a heating value of 15,300 Btu/lb., so deformation or nearby igneous intrusion may have caused some upgrading since the coal originally formed.

The possibility of future use of the De Long Mountains Quadrangle coals is enhanced by their favorable location at or near tidewater, and their good quality. Substantial reserves at relatively shallow depth are already known, and potential for expanding these reserves in the future is quite favorable.

Summary: Noatak Quadrangle (5 of 18)

Coal-bearing strata in the Noatak Quadrangle have only been found along the Noatak River. No formation name for them has yet been designated. Known occurrences of these rocks are located within the Noatak National Park.

The Noatak coals are interbedded with poorly indurated, nonmarine conglomerate, sandstone, and clayey siltstone (Ellersieck and others, 1979). These rocks are interpreted as being Upper Cretaceous or Tertiary in age and are approximately 300 feet thick (Dames and Moore, 1980). The exposure is covered by extensive Quaternary material that precludes tracing of the rocks away from the river. Of this 300-foot section, the lower 150 feet was not accessible to field workers but appears from a distance to be composed of blue-gray siltstone and claystone (Ellersieck and others, 1979). The upper 150 feet is composed of approximately 60 percent siltstone and claystone, 35 percent sandstone (locally concretionary), and 5 percent conglomerate. Structurally speaking, the presence of Upper Cretaceous and Tertiary rocks in the Noatak Valley is significant because it is evidence for a basin of relatively low-density strata. This in turn causes a significant gravity low that may relate this basin with the Point Hope Basin under the Chukchi Sea to the west (Ellersieck and others, 1979). However, additional geologic mapping is needed to test this theory and to correlate these sedimentary rocks with similar ones in neighboring quadrangles.

Although the Noatak River was first discovered in the early 1800's and first explored in 1885 by S.B. McLenegan in the revenue-marine steamer Corwin (Smith 1913), coal was not discovered anywhere along its course until 1978. Smith (1913) does note a deposit of dark brown material, used for fuel by prospectors near the mouth of the Noatak, that was not coal but was composed entirely of large fern spores ('cannel'). It did, however, burn readily, giving considerable smoke and oil and leaving practically no ash, like natural asphalt (Dames and Moore, 1980). In 1978 the U.S. Geological Survey noticed 'silty, shaley, low-rank coal in which flattened branches are visible,' (Ellersieck and others, 1978) in an outcrop along the Noatak River farther from the village of Noatak.

This is the only known coal location in the Noatak Quadrangle and occurs on the north bank of the Noatak River about 4 miles upstream from the confluence of the Kelley River. One 2-inch coal bed, among partings of carbonaceous material in the poorly indurated coal-bearing strata, helps define planar stratification and ripple marks. Some of the sediments contain rootlets or impressions of plant material and lenses as thick as 2 inches. The coal-bearing strata dip 30° to 75° to the west-southwest. The extent of the coal-bearing strata is not known, however, since the area has not been mapped in detail and because no drilling has been done. The occurrence of the dark brown material, resembling 'cannel coal' or 'natural asphalt,' at the mouth of the Noatak is unusual and deserves some further investigation.

Analysis of the coal found in the exposure along the Noatak River in the Noatak quadrangle has not been attempted. From visual inspection, however, the coal appears to be lignitic, quite high in ash and presumably moisture as well.

Due to lack of recognizable coal beds of substantial size, exposed coal-bearing strata, and general geologic information, lateral continuity and reserve estimates for the Noatak Quadrangle coal cannot be accurately projected. Their favorable location near the native settlement of Noatak makes local fuel use of the coals a possibility.

Summary: Baird Mountains Quadrangle (6 of 18)

Coal-bearing strata in the Baird Mountains Quadrangle occur near the confluence of the Kallarichuk and Kobuk Rivers in the southeastern corner of the quadrangle. No formation name has yet been designated for these rocks, which are located within and near the western edge of the new Kobuk Valley National Park. The NANA Regional Corporation has selected several pieces of land containing the coal-bearing rocks.

The Baird Mountains coals are interbedded with Cretaceous conglomerates, sandstones, and mudstones (Patton and Miller, 1968). These nonmarine rocks are found as isolated exposures along the Kobuk River in the Baird Mountains and Selawik Quadrangles, with the best exposure at Hotham Peak in the Selawik Quadrangle. Here an estimated 3,000 feet of section contains four known coal beds (Patton and Miller, 1968).

Coal-bearing sections in the Baird Mountains Quadrangle occur farther upstream on the Kobuk River near the Kallarichuk River. A potassium-argon age of 83.4 ± 2.2 million years from an ash-fall tuff agrees with well preserved plant fossils in verifying a Late Cretaceous age for these rocks (Patton and Miller, 1968). From limited geologic information from scant outcrops, the structure of the area is thought to be a broadly folded, NE-trending marginal trough (called the Kobuk/Koyukuk Basin) dissected by numerous high-angle faults (Patton, 1973). Isolated pockets of Cretaceous coal-bearing strata occur in the neighboring Noatak, Ambler River, and Selawik Quadrangles, but correlation is uncertain.

Coal was first discovered in the Kobuk River area in 1884 by Lieutenant G.M. Stoney during exploration work for the Navy Department (Smith, 1913). He reports successfully using bituminous coal from a 2-3 foot bed for his steam launch's furnace (Smith, 1913). Lieutenant J.C. Cantwell also visited the area later in 1884 but found the coal unsatisfactory for his launch. The first U.S. Geological Survey (USGS) expedition to the coal-bearing area in 1901 reported numerous small beds of coal that 'are of poor quality, and burn slowly, yielding abundant ash and disagreeable gases' (Mendenhall, 1902). In 1908 a mine on the Kobuk at its confluence with the Kallarichuk was opened by a Captain Theilen to fuel placer gold operations on nearby Squirrel River. A reported 150 tons was mined at this and several smaller nearby mines during 1918. In 1929, Alexander Haralan reopened the main mine, which became known as the Haralan Mine, and supposedly produced a total of 35 tons of coal during the peak year of 1932. According to an unpublished report by Reed

(1931), the Kobuk River Mine, about 5 miles downstream from the Haralan, also operated during the Squirrel River gold stampede, producing 100 tons of coal that was later lost during spring breakup. Reed (1931) believes that it was from this mine that Stoney and Cantwell obtained coal for their launches. Little more was done in the area until 1960 when Russell Chadwick revisited the area of the two mines and found a number of shallow pits, now caved in, at the Haralan and piles of coal on the river bank at the Kobuk River Mine. In 1968, Patton and Miller of the USGS determined the extent of the coal-bearing strata while doing regional geologic mapping on both sides of the Kobuk River. In 1979 and 1982, the Alaska Division of Geological and Geophysical Surveys (ADGGS) did a reconnaissance study of the area to select potential drilling sites for the northwest coal resource study. This group could not locate either of the mines but did discover coal-bearing strata on the nearby Kallarichuk River and its south fork (Eakins, 1979; Clough and others, 1982).

There are several coal occurrences in the vicinity of the Kallarichuk and Kobuk Rivers. The main occurrences are on the Kobuk River: 1) at the confluence of the Kallarichuk River; 2) two miles downriver from the confluence; and 3) five miles downriver from the confluence. At the confluence of the Kallarichuk River, there are numerous coal beds up to 3 feet thick but most seams are much thinner (Dames and Moore, 1980). Eakins (1979) reports the attitude of the beds as striking N. 60° E. and dipping 50° to the south. Two miles down the Kobuk River and 1 mile past the Haralan Mine, Eakins (1979) describes five or six coal beds ranging from a few inches to 18 inches thick, in bedding that strikes N. 60°E. and dips 25° to the south. Five miles further down the Kobuk River a number of poorly exposed thin seams of coal have about the same strike and dip (Eakins, 1979). Chadwick (1960) reported piles of coal here, presumably from the old Kobuk River Mine, but Eakins (1979) and Sanders (1984a,b) found no such evidence. Minor occurrences of coal are also found on both forks of the Kallarichuk River. Patton and Miller (1968) report bituminous coal float on the south fork of the Kallarichuk but no coal beds. Clough and others (1982) also describe blocky and relatively unweathered coal in cutbanks on the south fork and a nearby creek. Although coal seams reportedly do occur in the bed of the creek, they were covered by high water at the time of the visit (Clough and others, 1982). The other small occurrences are roughly 1 mile upstream from the confluence of the two forks of the Kallarichuk River. Two coal beds 1 foot and 2 feet thick exposed here strike N. 45° E., dip 45° W., and are of poor quality with high ash contents.

Coal analyses from various authors give low to moderate moisture and sulfur levels, high variability in ash contents, and a rank of high volatile bituminous C. Generally their quality is equal to or slightly below that of Cretaceous coals farther north at Corwin Bluff and Cape Beaufort. Due to lack of geologic information and scarcity of exposed coal-bearing strata, lateral continuity and reserve estimates for the coals of the Baird Mountains Quadrangle cannot be accurately projected. The location of the coal along the Kobuk and Kallarichuk Rivers makes them readily accessible for development as a local fuel source.

Summary: Ambler River Quadrangle (7 of 18)

Coal-bearing sedimentary rocks occur in the southern part of the Ambler River Quadrangle along the lower Ambler and Hunt Rivers. No formation name for them has yet been designated. The sedimentary rocks on the lower Ambler River are on lands that are native selected or under interim conveyance, while those farther upstream are on state selected land. Along the lower Hunt River, the land with coal potential is within the Kobuk Valley National Park.

The Ambler River coal is interbedded with nonmarine quartz conglomerate, sandstone and mudstone, which generally occur beneath unconsolidated Quaternary deposits. They are exposed by stream erosion in places, but only in areas too small to show on 1:250,000-scale maps. Therefore, coal locations appear to be mapped as Quaternary deposits by Patton and others (1968). These coal-bearing strata are assigned a late Cretaceous age because of their similarity to potassium-argon dated rocks in the adjoining Baird Mountains and Selawik Quadrangles (Patton and Miller, 1968). Correlation between these quadrangles is uncertain at present, however. The structure of the area has been interpreted as a broadly folded, NE-trending marginal trough (called the Kobuk/Koyukuk Basin) dissected by numerous high angle faults (Patton, 1973).

Coal was first discovered in the Ambler River Quadrangle in 1902 by W.C. Mendenhall (U.S. Geological Survey), who reported finding coal just below the mouth of the Hunt River and for several miles along its lower course. P.S. Smith (1913) also refers to coal float on the lower part of the Ambler River, as does Barnes (1967). The U.S. Bureau of Mines, in their Mineral Appraisal study (1979), mention coal along the Ambler River, but give no further information about the occurrences. Because so little mapping of the coal-bearing strata has been done, other than the reconnaissance work by Patton and Miller (1968), not much is known of the the Hunt River and Ambler River coal occurrences, and no drilling has been attempted in the area.

Just below the mouth of the Hunt River, on the Kobuk River, coal fragments occur in an outcrop of hard quartz conglomerate. This quartz conglomerate, as described by prospectors to Mendenhall (1902), may extend for several miles on the lower Hunt. This conglomerate is inferred from the geologic description to be part of the nonmarine conglomerate, sandstone, mudstone and coal unit of Patton and Miller (1968), even though only Quaternary units have been mapped in this area (Dames and Moore, 1980). The other occurrences of coal are on the lower 40 miles of the Ambler River above its confluence with the Kobuk River. Here coal float occurs in four separate places, both north and south of the river, in Cretaceous coal-bearing rocks similar to those observed on the lower Hunt River and in neighboring quadrangles. As along the Hunt River, the coal-bearing rocks are not mapped separately from Quaternary deposits, so their full extent has not been reported.

No analysis of the coals in the Ambler River Quadrangle has been attempted because they have been sampled only as isolated and weathered float fragments. However, assuming a source in strata similar to those observed in neighboring quadrangles, a high volatile bituminous coal might be predicted.

Lateral continuity and reserve estimates for these coals cannot be projected due to lack of recognizable coal beds, exposed coal-bearing strata, and general geologic information. More geologic studies in the Ambler River Quadrangle might be useful if good target areas can be more definitely identified. The favorable location of the coal-bearing strata along the Hunt and Ambler Rivers near the native settlements of Ambler, Shungnak, and Kobuk, means that any coal beds discovered might find a local market.

Summary: Shishmaref Quadrangle (8 of 18)

Coal-bearing strata in the Shishmaref Quadrangle are suspected to occur in the subsurface because isolated coal float has been found in several places south of Shishmaref, near the Serpentine River (Dames and Moore, 1980). Land status in the area is complex, with the Bureau of Land Management and the Bering Land Bridge National Park having substantial holdings, and the Bering Straits Native Corporation controlling selected and interim conveyed land.

In the Shishmaref Quadrangle coal is thought to be interbedded with conglomerate, sandstone and shale in the subsurface (Dames and Moore, 1980). This interpretation is based on data from two Standard Oil Company of California drill holes completed during the winter of 1974-75 in the neighboring Kotzebue Quadrangle (Forbes, 1980). The two wells (Cape Espenberg #1 and Nimiuk Point #1) show that up to 8,000' of Tertiary-aged strata, a substantial portion of which is coal-bearing, underlie much of the Kotzebue Quadrangle. According to Barnes (1977), these Tertiary sedimentary rocks create a large east-west trending gravity low that stretches from Selawik Lake on the east across the Shishmaref Quadrangle to the northern Seward Peninsula on the west. From this gravity data, the data from the two Standard Oil Company wells, and scattered coal float south of Shishmaref, it is presumed that coal-bearing rocks are present in the subsurface in the Shishmaref Quadrangle.

No analyses of coal in the Shishmaref Quadrangle has been attempted because it has so far been found only as float near the Serpentine River. However, judging from the well logs, from the character of coal float in the Kotzebue Quadrangle, and from similar coal observed in the neighboring Selawik Basin, coal in the Shishmaref Quadrangle is probably lignite.

Due to lack of recognizable coal beds on the surface, and the general lack of detailed geologic information, lateral continuity and reserve estimates for the coals in the Shishmaref Quadrangle cannot be projected. Study of mud logs and electric logs from the two existing holes, in the Kotzebue Quadrangle, would be useful to determine coal thickness, quality, and related information about the coal-bearing strata.

Summary: Kotzebue Quadrangle (9 of 18)

Coal-bearing strata in the Kotzebue Quadrangle are suspected to occur in the subsurface, based on evidence from oil drilling logs, gravity maps, and isolated coal float. The two wells in the quadrangle were drilled on land that is either native or state selected, and coal float has been found in Bering Land Bridge National Park.

The Kotzebue Quadrangle coals are found in the subsurface interbedded with conglomerate, sandstone, and shale. These coal-bearing rocks, in turn, overlie interbedded tuffaceous volcanics, basalt, conglomerate, sandstone, and siltstone, but are barren of coal (Dames and Moore, 1980). The upper coal-bearing unit shows a decrease in conglomerate and coal up section (Forbes, 1980). The two wells, Cape Espenberg #1 and Nimiuk Point #1, show that crystalline basement is first penetrated at 8,000 feet and 6,000 feet respectively. Patton (1973) has postulated that Cretaceous and younger sediments in the Kotzebue Sound area may be as much as 10,000 feet thick. In the Kotzebue Quadrangle area, Forbes (1980) places a Tertiary age on the rocks overlying the crystalline basement rocks, and these Tertiary sediments create a large east-west trending gravity low throughout the Kotzebue Sound area (Barnes, 1977). It is suggested that this gravity low accentuates a large basin that may extend from Selawik Lake on the east to the northern Seward Peninsula on the west (Dames and Moore, 1980). Thus, the subsurface coals in Kotzebue Quadrangle may correspond with the coals observed in the Selawik Quadrangle at Elephant Point and Mangoak River.

There is still very little known about the coal-bearing sequence in the Kotzebue Quadrangle. Prior to 1974, only isolated coal float on the surface hinted at the possibility of coal-bearing strata in the subsurface. Coal float had been reported from south of Shishmaref in the Shishmaref Quadrangle to the Goodhope River in the Kotzebue Quadrangle, and along Fish River and Rock Creek south of Devil Mountain. At Devil Mountain Lake, float of peat and petrified wood is reported in volcanic ejecta in the maar (Dames and Moore, 1980). During the winter of 1974-1975, the Standard Oil Company of California drilled two wells in the Kotzebue Quadrangle, the Cape Espenberg #1 and the Nimiuk Point #1. Both were 'dry holes' (lacking oil), but showed the presence of a rather thick section of coal-bearing Tertiary rocks which contain salt water-bearing aquifers and a geothermal gradient which is above normal (Forbes, 1980). The Cape Espenberg #1 well, drilled to a depth of about 8,400 feet, encountered numerous lignite beds between 2,500 feet and 4,000 feet depth. The Nimiuk Point #1 well was drilled to a depth of 6,300 feet, intercepting a thin bed of low-grade coal at 2,700 feet (Dames and Moore, 1980). Although little additional information is available on these coals, either from the wells or from coal float, and though no analyses have been published, the coal is thought to be lignitic.

Due to lack of recognizable coal beds on the surface, and the general lack of detailed geologic information, lateral continuity and reserve estimates for the coals in the Kotzebue Quadrangle cannot be projected. If coal were found near Kotzebue, Shishmaref, or other coastal native settlements, it might be used locally for fuel.

Summary: Selawik Quadrangle (10 of 18)

Unnamed coal-bearing sedimentary rock units occur in the northern part of the Selawik Quadrangle in the Hockley Hills and Singauruk River areas and also in the southern part of the quadrangle near Elephant Point and the Mangoak River. The northern coal-bearing rocks are within the Selawik National Wildlife Refuge and on land selected by the NANA Regional Corporation. The southern rocks are located either on NANA Regional Corporation selected or

state selected land, or on federal land managed by the Bureau of Land Management.

Cretaceous coals, interbedded with nonmarine conglomerate, sandstone, and mudstone, occur in the northern part of the quadrangle (Patton and Miller, 1968). These rocks are best exposed at Hotham Peak, where the 3,000 feet of section lacks significant coal beds (Patton and Miller, 1968). A potassium-argon age of 83.4 ± 2.2 m.y. agrees with a Late Cretaceous age from well preserved plant fossils. The structure of the area is interpreted to be a broadly folded, NE-trending trough (called the Kobuk/Koyukuk Basin) dissected by numerous high angle faults (Patton, 1973). Attitude measurements show that the coal-bearing strata may be near the nose of a regional syncline (Patton and Miller, 1968) that plunges 40° to the northwest (Burand, 1959). Isolated pockets of similar Cretaceous coal-bearing strata occur in the neighboring Ambler River and Baird Mountains Quadrangles, but correlation is uncertain at present.

Coal in the southern part of the quadrangle is interbedded with up to 500 feet of poorly consolidated conglomerate, sandstone, siltstone and clay with a Tertiary age based on pollen identifications (Patton, 1973). Deposits are confined to small structural or topographic basins, which may be a part of a graben up to 6 miles wide, south of the main Selawik basin. Similar Tertiary coal-bearing strata occur to the south in the Bendeleben and Candle Quadrangles.

Coal was first discovered in the Kobuk River area in 1884 by Lieutenants G.M. Stoney and J.C. Cantwell during exploration work for the Navy Department (Smith, 1913). The area south of the Kobuk River into the Selawik basin was explored by Stoney and Cantwell in 1886 and by Mendenhall (USGS) in 1901. These investigators do not mention coal, but in 1907 and 1908 L.S. Quackenbush, on an expedition to collect mammoth fossils for the American Museum of Natural History, discovered minor amounts of coal and peat along Eschscheltz Bay, near Elephant Point, and on the south side of Hotham Inlet. In 1959, Willow Burand of the Alaska Division of Mines and Minerals sampled a coal occurrence 16 miles northwest of Selawik on the Singauruk River. Local natives had for some time been using this coal in their stoves without much success. Chadwick (1960) examined coal on the northern flank of the Hockley Hills and again on the Singauruk River near the southwest edge of the Waring Mountains. Patton and Miller (1968) studied these areas further, mapping the coal-bearing rocks as volcanics, calcareous graywacke, and mudstone. These authors report scattered Tertiary gravel and sand south of the Selawik basin, but do not mention coal. In 1982, Alaska Division of Geological and Geophysical Surveys (ADGGS) geologists located and sampled the occurrences north of the Hockley Hills and on the Singauruk River (Clough and others, 1982).

There are two Cretaceous coal occurrences in the Selawik Quadrangle. North of the Hockley Hills, beds containing very thin coal layers can be traced across several north-flowing creeks (Dames and Moore, 1980). Clough and others (1982) describe numerous 1-inch coal streaks in bedding that strikes N. 20° E. and dips 40° W. No coal of potential commercial value was found here, but Chadwick (1960) speculates that the coal of Singauruk River is probably in the same stratigraphic position as the thin streaks at Hockley

Hills. Burand (1959) reports that four coal seams at the Singauruk River occurrence range from 2 to 3.5 feet thick, separated by zones of shale, mudstone, and poorly consolidated sandstone. Chadwick (1960) also reports several coal beds up to 2.5 feet thick, not counting partings, which total 13 feet in a 24-foot exposed section. Clough and others (1982) agree that there are 4 main beds, but find they range from 3 to 6 feet thick, and include many thin shaley partings, which results in high ash content. Bedding of the coal-bearing strata at this locality strikes N. 40° E. and dips 30° W. Coal may occur in the 3,000 feet of sedimentary section on Hotham Peak, at the extreme western part of the Hockley Hills, (Patton and Miller, 1968), but none has been reported.

Of two known Tertiary coal deposits in the Selawik Quadrangle, one occurs on the beach bluffs about 2 miles south of Elephant Point on Eschscholtz Bay. A 2-foot coal bed was reported here in the early 1900's (Quackenbush, 1909), but at present only a 4-inch bed is exposed at low tide (Dames and Moore, 1980). The coal-bearing sequence here is generally flat-lying, with a total onshore extent of probably only several square miles (Dames and Moore, 1980). About 31 miles south of the village of Selawik up to 500 feet of Tertiary coal-bearing sedimentary rocks are exposed along the east fork of the Mangoak River. These strata strike NE to NW and dip between N. 10° W. and S. 30° W. (Dames and Moore, 1980). Coal has been found in this area only as float so far, but up to 10,000 feet of Cretaceous through Tertiary coal-bearing section is predicted to occur throughout the Selawik Basin (Patton, 1973).

Due to lack of geologic information and scarcity of exposed coal-bearing strata, lateral continuity and reserve estimates for the coals in the Selawik Quadrangle cannot be accurately projected. If mining ever were to occur in this area, strip mining would be the preferred method considering the thinness of the beds and the relatively shallow dips.

Analyses show variable rank for the Selawik Cretaceous coals. Both Burand (1959) and Chadwick (1960) rank the coals as subbituminous C, while Clough and others (1982) assign them a rank of high volatile bituminous C. However, it is agreed that the coals have moderate moisture, low sulfur, and high ash content. High ash coal has been known to give an apparent rank, when determined from heating values, that is lower than actual rank. The only way to accurately determine the rank of coal that is high in ash is to use the float-sink technique to remove the ash, or measure vitrinite reflectances. Generally, though, these coals resemble those along the Kobuk River in the Baird Mountains Quadrangle, and compare in quality with Cretaceous coal found farther north at Corwin Bluff and Cape Beaufort. No analysis of the Tertiary coal in the southern part of the Selawik Quadrangle has been attempted, because it has been found only as float, but it is described as lignitic by various authors.

The favorable location of the coal along the Singauruk River, at an average distance of 16 miles from the villages of Selawik and Kiana, makes future development as a local fuel source a possibility if useful reserves are found. The various coal float occurrences here and throughout the Selawik Quadrangle need further study to locate the source beds.

Summary: Shungnak Quadrangle (11 of 18)

Coal-bearing strata are found in the northern part of the Shungnak Quadrangle along the Kogoluktuk River and in the Sheklukshuk Hills. Along the Kogoluktuk River these unnamed rocks occur on lands that are native selected or state selected, or under interim conveyance, while in the Sheklukshuk Hills similar rocks are on either native selected land or federal land managed by the Bureau of Land Management. Rock units of the Lockwood Hills and north of the Kobuk River have, for the sake of consistency, been given the same coal-potential ratings as rocks in the adjacent Hughes Quadrangle with which they are continuous, even though the level of geological information differs somewhat between the two quadrangles, and though these rocks have not been reported to host significant coal in the Shungnak Quadrangle.

The Cretaceous Shungnak coals, interbedded with nonmarine quartz conglomerate, sandstone, and mudstone, generally are covered by unconsolidated Quaternary deposits. Locally these coal-bearing rocks are exposed by stream erosion, but only in areas too small to show on 1:250,000-scale maps. Therefore, coal locations appear to be mapped as Quaternary deposits by Patton and others (1968). These coal-bearing strata are assigned a Late Cretaceous age because of their similarity to potassium-argon dated rocks in the adjoining Baird Mountains and Selawik Quadrangles (Patton and Miller, 1968). Correlation of rocks between these quadrangles is uncertain at present, however. The structure of the area has been interpreted as a broadly folded, NE-trending marginal trough (called the Kobuk/Koyukuk Basin) cut by numerous high angle faults (Patton, 1973).

Coal was first reported in the Shungnak Quadrangle by Phillip S. Smith and Henry M. Eakin of the U.S. Geological Survey (Smith, 1913). During a traverse of the mountains between the Koyukuk and Kobuk Rivers in 1910, these geologists noticed coal float along the Kogoluktuk River, in the Sheklukshuk Hills, and the northern lowland of the Kobuk River. These authors state that much of the Sheklukshuk Hills area is underlain by Cretaceous-age conglomerate and sandstone derived from sedimentary rocks. Later, however, Patton and others (1968) mapped the same rocks as Cretaceous volcanic conglomerate and graywacke, thus leaving the origin of the rocks, if not the coal, in some dispute. Barnes (1967) mentions coal float on the Kogoluktuk, but offers no further information about it. Very little else is known of these occurrences because the coal-bearing strata have not been mapped in detail. Besides the reconnaissance mapping by Patton and others (1968), little geologic work has been done in this quadrangle since 1910, and there has been no drilling.

Coal float has been reported on the Kogoluktuk River, which flows into the Kobuk River about 5 miles east of the village of Kobuk. This coal float is thought to originate in the unnamed quartz conglomerate, sandstone, and mudstone unit of Patton and others (1968), which, in the area of the Kogoluktuk, is sheared and dynamically metamorphosed. The other coal occurrence is supposed to be exposed in the Sheklukshuk Hills west of the Pah River in the problematic Cretaceous conglomerate and sandstone unit. This coal, though reported by Smith and Eakin in 1911, has not been found again since. No intact coal beds have been reported at either of the Shungnak Quadrangle occurrences.

The coals of this quadrangle have not been analyzed since only isolated and weathered coal float has been found here. However, assuming a source in strata similar to those in neighboring quadrangles, a high volatile bituminous coal might be predicted.

Due to lack of recognizable coal beds, exposed coal-bearing strata, and general geologic information, lateral continuity and reserve estimates for the Shungnak coals cannot be projected. More geologic study in the Shungnak Quadrangle might be useful if good target areas can be more definitely identified. However, because the rocks are sheared and metamorphosed in the Kogoluktuk River area, thick, laterally continuous coal beds are less likely to be found here than at other localities in neighboring quadrangles. At best, the location of the Kogoluktuk coals near native settlements such as Ambler, Shungnak, and Kobuk means that any coal beds discovered might find use as a local fuel source.

Summary: Hughes Quadrangle (12 of 18)

Coal-bearing strata in the Hughes Quadrangle are known in the Lockwood Hills east of the Pah River and northeast of the village of Hughes on the Koyukuk River. No formation name for these rocks has yet been designated. The coal-bearing rocks in the Lockwood Hills occur on land that is tentatively approved for the State of Alaska, while those near Hughes are on federal land managed by the Bureau of Land Management.

The Hughes Quadrangle coals, both in the Lockwood Hills and near Hughes, are found interbedded with Upper Cretaceous near-shore and nonmarine sandstone and mudstone (Patton and Miller, 1966) formerly considered part of the Bergman Group (Smith, 1913). The latter group of rocks also includes similar nonmarine coal-bearing strata seen farther north and west in the Shungnak and other neighboring quadrangles. The term 'Bergman Group' has been abandoned by Patton and Miller for the Hughes Quadrangle because it blurs distinctions between rock types these authors consider definite and important. This change in terminology leads to differences between geologic maps of the Hughes and adjoining Shungnak Quadrangles in the way rocks are described and grouped, especially in the Lockwood Hills and north of the Kobuk River. Since these areas straddle the map boundary, they have been given the same coal-potential ratings for the sake of consistency, even though the level of information differs somewhat between quadrangles.

The coal-bearing strata in the Hughes Quadrangle directly overlie a volcanic graywacke and mudstone unit and seem to be part of a regressive sequence. These coal-bearing beds, with an aggregate thickness of at least 10,000 feet, underlie about half of the northern Yukon-Koyukok province (Patton, 1973). They were deposited in two deep marginal troughs that have since been broadly folded into anticlinal and synclinal structures, and dissected by numerous high-angle faults. These troughs now connect to form the Kobuk/Koyukuk basin (Patton, 1973).

Upper Cretaceous rocks, which include the coal-bearing strata, were first recognized in the Hughes Quadrangle by F.C. Schrader in 1899. In 1901, W.C. Mendenhall and Schrader, both from the U.S. Geological Survey (USGS),

described the rocks for the first time, naming them the Bergman Group after an important trading post on the Koyukuk River. Coal was first observed in the Lockwood Hills east of the Pah River by Smith and Eakin (1911), also of the USGS, during a traverse of the mountains between the Koyukuk and the Kobuk Rivers. The first regional geologic map of the Hughes quadrangle was completed by Patton and Miller (1966), who were also the first to report coal northwest of the village of Hughes. No drilling has yet been attempted in this quadrangle.

Coal is known in two places in the Hughes Quadrangle. Smith (1913) reported 'fragments of what appears to be wood and lignite beds....here and there in the sandstone member' in the Lockwood Hills southwest of where the Pah River joins the Kobuk River. Unfortunately, no further details on this occurrence are available. Patton and Miller (1966) report coal float near the mouth of Huntington Creek, 3 miles northeast of Hughes. They also mention that carbonized plant debris is locally abundant in the widespread nonmarine unit but report no actual coal beds.

Smith (1913) describes the Lockwood Hills coals as lignite, but their occurrence in Cretaceous nonmarine sedimentary rocks similar to those in neighboring quadrangles makes this judgement questionable. Analysis of these coals, along with those near Hughes, may prove them to be high volatile bituminous.

Due to lack of recognizable coal beds within the exposed nonmarine, potentially coal-bearing strata and the general lack of detailed geologic information, lateral continuity and reserve estimates for the coals in the Hughes Quadrangle cannot be projected. However, any coal that might be found near major river systems like the Kobuk and Koyukuk, or near the native settlements of Shungnak, Kobuk, and Hughes, could be used locally for fuel.

Summary: Teller Quadrangle (13 of 18)

No coal has been reported in the Teller Quadrangle. However, Dames and Moore (1980) suggest an area called the Imuruk basin, which extends from Pilgrim Hot Springs to near Teller, to be a Tertiary basin that might deserve further investigation for coal potential. This basin is defined by a gravity low centered over a shallow lake and the surrounding alluvial lowlands (Barnes and Hudson, 1977). These authors further suggest that the negative gravity anomaly may be due to low-density sedimentary fill deposited relatively recently by erosion of the nearby Kigluaik Mountains during uplift along an active fault. The Pilgrim River valley, an eastward extension of the Imuruk basin, is similarly filled with a thick Tertiary or younger sedimentary sequence, and drilling near Pilgrim Hot Springs indicates the bottom of the sequence there to be about 1,200 feet deep (Dames and Moore, 1980). These few pieces of circumstantial evidence are the only reported indications for coal potential in the Teller Quadrangle. Lands in the immediate vicinity of the Imuruk basin are either native selected or under interim conveyance. These native lands are bordered on the north and south by federal land under the Bureau of Land Management.

Summary: Bendeleben Quadrangle (14 of 18)

The coal deposit of primary interest in the Bendeleben Quadrangle is located 70 miles south of Kotzebue in unnamed Tertiary-age rocks on Chicago Creek, a tributary of the Kugruk River. The deposit is on land under interim conveyance to the Village of Deering under the Alaska Native Claims Settlement Act (ANILCA) of 1971. NANA Regional Corporation holds subsurface mineral rights.

The coal-bearing rocks of the Chicago Creek deposit occur in a north-south trending linear trough that may be as much as 2 miles wide; the strike is about N-S, with dips from 70° to 50° W. The coal occurs in one bed up to 100 feet thick with intermittent partings of sandy or silty clay. Examination of fossil pollen samples has dated these rocks as late Tertiary or younger (Haga, 1984). Coal has been traced along strike for 8,000 feet, both north and south of the original mine site, and is believed to continue for some distance (Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, Inc., 1983; 1985). The main bed is truncated by a fault 50 feet south of the old mine adit on the south side of Chicago Creek, but continues with an offset beyond the fault. Another fault, 300 feet north of the adit, is the inferred cause of an abrupt thinning of the main coal bed within a very short interval. Besides being disturbed by faults, the coal's irregular thickness suggests plastic deformation, which causes pinching out and thickening of the unit at irregular intervals north and south of Chicago Creek.

The Chicago Creek coal deposit was discovered by gold prospectors in 1902 (Moffit, 1906), staked in 1905, and mined between 1907 and 1911. During the same period, the Wallin and Superior coal mines six miles to the south worked what is probably a continuation of the same bed. Total coal production of the three mines, approximately 110,000, tons was used by local placer mining operations (Toenges and Jolley, 1947).

The coal bed mined at the Wallin site is up to 66 feet thick, with several partings of sandy clay and shale; the strike is N. 15° E., with an average dip of 62° W. (Reed, 1933). Coal at the Superior mine has a similar strike and dip, and is reported to be at least 53 feet thick (Reed, 1933). The Superior mining venture was discontinued because the coal bed is truncated by a fault offset on the south side (Reed, 1933; Dames and Moore, 1980).

Tertiary coal-bearing rocks and coal float have been mapped in the vicinity of French Creek, Goose Creek, Independence Creek, and Mina Creek, all tributaries of the Kugruk River. Although little is known of these coal-bearing rocks, they may be part of the same sequence as those at Chicago Creek (Moffit, 1905; Roehm, 1941; Sainsbury, 1975).

Another coal occurrence, unrelated to Chicago Creek and the Kugruk River, is located on Perry Creek about 15 miles west of Chicago Creek. Here the coal-bearing rocks, with a 2- to 4-foot thick bed of lignite (J.T. Kline, personal commun., 1980), are found beneath Tertiary to Holocene basalt flows. Tertiary coal-bearing rocks may also underlie the Quaternary flats in the upper Pinnell River and Burnt River area (Dames and Moore, 1980).

In the southeastern portion of the quadrangle, Tertiary rocks have been mapped in a large basin known as Death Valley, where outcrop exposures are rare; Tertiary to Holocene basalt flows cover much of the southern part of the basin. Coal has been reported as float along the Tubutulik River, as coal fragments in the sands underlying the basalt flows, and in Tertiary outcrops along the northern margin of the basin (Resource Associates of Alaska, 1978). According to drill logs, the Grouse Creek coal deposit, exposed at the southern limit of the Death Valley basin, consists of one very large coal lense up to 190 feet thick, that contains minor partings (Dames and Moore, 1980).

West of Death Valley, a large Tertiary basin known as McCarthy's Marsh is both a present- day topographic depression and a deep geologic basin, with gravity measurements indicating sedimentary fill between 3,000 and 10,000 feet thick (Barnes and Hudson, 1977). This basin is fault-bounded to the north and east by the Bendeleben and Darby Mountains, and to the southwest by a less distinct upland. Coal float with a woody, lignitic appearance, and sedimentary rocks typical of the Tertiary coal-bearing units seen elsewhere, have been found on Omilak, Windy, and Telephone Creeks. Given the great depth of this basin, it might contain a considerable quantity of coal (Resource Associates of Alaska, 1978).

Northwest of McCarthy's Marsh, along the upper Kuzitrin River drainage, the 250 square mile Kuzitrin basin contains Tertiary-aged coal-bearing rocks of the Noxapaga Formation which include claystone, sandstone, minor conglomerate, and coal (Dames and Moore, 1980). Outcrops of this formation are found on the northeast bank of Turner Creek and in a pingo west of the Noxapaga River, a major tributary of the Kuzitrin River (Sainsbury, 1975; Dames and Moore, 1980). During the early 1900's, lignite was mined from a 1- to 12-foot thick bed in the pingo. In 1982, geologists from the Alaska Division of Geological and Geophysical Surveys (ADGGS) and the U.S. Geological Survey excavated this bed and sampled it for analysis (ADGGS, 1982, unpublished). A gravity anomaly associated with the Kuzitrin basin suggests that the coal-bearing sedimentary rocks may continue under Tertiary basalt flows for some distance northeast (Barnes and Hudson, 1977; Dames and Moore, 1980).

From the summer of 1982 through the summer of 1985, contractors for ADGGS conducted extensive investigations of the Chicago Creek deposit. This included field mapping, core and auger drilling, and both down-hole and surface geophysics. Over 60 holes were drilled to a maximum depth of 300 feet, from which hundreds of samples have been analyzed.

Analysis of coal samples from Chicago Creek, Grouse Creek, the Noxapaga River in the Kuzitrin basin, and from a small lake ¼ mile from the pingo give values of from 6,191 to 7,680 Btu/lb. Chicago Creek and Grouse Creek are the highest in heating value, but all of the coals within the Bendeleben Quadrangle are low-sulfur lignites. Ash content is variable, tending to be lowest in the thicker beds (ADGGS, 1982, unpublished; Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, Inc., 1983; 1985).

Known geological indicators point to the possibility of large subsurface coal potential within the Bendeleben Quadrangle. If the Chicago Creek coal

bed continues north and south of the 8,000-foot drilling program baseline, as expected, the 4.5 million tons of demonstrated coal reserves could double (R. Retherford, personal commun., 1985). Further, 'the district probably contains still more coal in extensions of the Chicago Creek basin to the north and south, and additional undiscovered parallel coal basins may also exist' (C.C. Hawley and Associates, Inc., 1985). In the long term, further study of possible coal deposits at the Upper Kugruk River, Death Valley, McCarthy's Marsh, the Kuzitrin basin, and elsewhere in the Bendeleben Quadrangle may be warranted.

## Summary: Candle Quadrangle (15 of 18)

The three main areas of interest in the Candle Quadrangle are the Kiwalik basin, located near the northwestern margin of the quadrangle; the Buckland basin, located approximately 20 miles due east of the Kiwalik basin; and the Koyuk basin, a poorly defined feature extending northwesterly along the course of the Koyuk River from somewhere near Dime Creek. About one half of the Kiwalik basin is state patented ground, the remainder is state tentatively approved, state selected, or native selected. The Buckland Basin is on state tentatively approved land, with two native allotments on the eastern edge. The Koyuk basin area is a patchwork of federal and native lands.

There has been very little detailed geologic study of the unnamed coal-bearing sedimentary rocks in this region, and no firm correlation has been attempted. Strata in all three basins are typical of Tertiary rocks found in other areas of the state. Because the coal-bearing units in the Candle Quadrangle closely resemble Miocene rocks in the adjacent Bendeleben Quadrangle, they are tentatively assumed to be of the same age or younger (Harrington, 1919; Dames and Moore, 1980).

Although most of the known coal occurrences in the Candle Quadrangle were discovered and noted by prospectors around the turn of the century, more recent investigations have revealed a few additional locations and furthered understanding of the geologic conditions associated with the coal deposits. Mapping and geophysical programs conducted by the U.S. Geological Survey (USGS), U.S. Bureau of Mines (USBM), the State of Alaska Division of Geological and Geophysical Surveys (ADGGS), and private industry have contributed to the coal data base.

Harrington (1919) reported many of the known coal occurrences in USGS Bulletin 692. Aeromagnetic data produced by the ADGGS in 1972-73, and Bouguer gravity measurements published by the USGS in 1976-77 have helped to define the Kiwalik and Buckland basins. In 1980, contractors for the Alaska Power Authority compiled a comprehensive report on the coal resources of northwest Alaska. This report includes previously unpublished locations of Tertiary outcrops and coal float discovered in 1978-1979 during uranium and precious metals exploration of the area (Dames and Moore, 1980). In 1982, ADGGS geologists did a brief field check of occurrences reported in the Candle Quadrangle, including a coal location at Wilson Creek in the southern end of the Kiwalik basin, but snow cover severely hampered this investigation (ADGGS, 1982).

Large portions of all three Tertiary basins are covered by basalt flows that mask the suspected coal-bearing rocks below. A few outcrops of Tertiary rocks are exposed near the edges of the flow, and in local stream cuts. Coal float and rubble found within the drainage system give further evidence for coal within the basins. Thickness of the Tertiary rocks within these basins is not known, but all three are believed to be relatively shallow. The coal-bearing strata appear to be flat-lying or slightly dipping, and are typically composed of sandstone, conglomerate, claystone (often containing coalified wood and plant detritus), and coal beds. The linear shape of the Kiwalik and Buckland basins suggests that they are fault controlled, while the structure of the Koyuk basin is not known.

In the Kiwalik basin, the coal-bearing sedimentary rocks are thought to be thickest near the Kiwalik River, which probably marks the axis of the basin. The basalts covering much of this basin are thought to be thickest in the northern and southern portions, and thin to absent near the center (Barnes, 1977; Dames and Moore, 1980). The eastern and western boundaries of the Kiwalik basin are defined by contacts with older metamorphic and igneous rocks.

The thickest coal bed known in the Candle Quadrangle is described by Harrington (1919). Tertiary sediments overlain by a basalt flow are exposed on Wilson Creek, a headwater tributary of the Kiwalik River, where a coal bed occurs beneath a clay unit. The coal and clay are badly slumped but partly exposed for 20 to 30 feet along the creek bank. When examined by Resource Associates of Alaska geologists in 1978, only 3 feet of the coal bed was visible, but it is believed that the total thickness could be as much as 10 feet. Coal rubble along the creek indicates that the coal may extend under the surface for an additional 600 feet or more downstream from the outcrop. This coal occurrence is located at the supposed southeast extremity of the Kiwalik basin. Additional coal float and outcrops of Tertiary sedimentary rocks are found on Coal Creek, Connolly Creek, Hunter Creek, and Lava Creek, all tributaries of the Kiwalik River on the eastern perimeter of the basin (Dames and Moore, 1980).

The Buckland basin is an elongated depression that extends southward along the west fork of the Buckland River. Basin boundaries are only approximately located due to an extensive cover of Tertiary basalt flows, but are probably defined east and west by contacts with older igneous intrusive rocks (Dames and Moore, 1980). Limited gravity data (Barns, 1977) and aeromagnetic data (ADGGS, 1973) suggest that the Tertiary sedimentary rocks are probably thin, while the basalt cap is quite thick. The coal-bearing rocks include micaceous claystone and sandstone. Although no coal beds have been found, coal fragments are present in several creeks. Tertiary rocks and coal fragments suggestive of subsurface coal beds have been found on the west side of the basin near Bear Creek, Cape Horn Creek, Fairhaven Creek, and along the West Fork River.

The Koyuk basin is also poorly defined. Its areal extent is probably from somewhere near Dime Creek, between Dime Landing and Haycock, along the Koyuk River to an indefinite point where the Koyuk basin may join the Kiwalik basin. Approximate, tentative boundaries are based on the presence of coal

float found in several creeks, and radiometric and aeromagnetic surveys. Very little information is available on the extent of Tertiary sedimentary units in this basin, since much of it is covered by Tertiary to Holocene basalt flows and modern muskeg. Outcrops of Tertiary sedimentary rock are scarce, and no coal beds have been found. The only indications of coal in this basin are four occurrences of coal float on Dime Creek, near Salmon Creek, near First Chance Creek, and at one location on the Koyuk River.

No analysis has been done on any of the coals from the Candle Quadrangle, but the appearance of the coal is reported to be that of typical woody lignite. No more accurate assessment of the coal resources of the Candle Quadrangle can be made without additional geological field work. Considerable amounts of coal could exist in the subsurface, but this is speculative and coal extraction might be costly.

Summary: Nome Quadrangle (16 of 18)

Coal-bearing strata in the Nome Quadrangle occur on Coal Creek, a small tributary to the Sinuk River, about 32 miles west of Nome. Coal Creek flows easterly down a gentle gradient to the Sinuk River, exposing coal-bearing bedrock in only a few places (Collier, 1906). The land along most of Coal Creek is under interim conveyance to the Bering Native Corporation.

The Nome Quadrangle coals are interbedded with well-indurated conglomerate composed of schist, vein quartz, and a few large, well-rounded, slightly sheared greenstone boulders (Dames and Moore, 1980). In addition to the conglomerates, the coal-bearing rocks contain finer sediments made up largely of decomposed schist pebbles and thin seams of fire clay and coal (Collier, 1906). These clastic units appear to unconformably overlie Paleozoic crystalline limestones and schists (Dames and Moore, 1980), but the beds are slightly crushed and sheared, which often makes it difficult to distinguish the clastic material from underlying schist bedrock (Collier, 1908). Exposures along Coal Creek are limited by vegetation and deep surficial cover, so that coal-bearing strata are difficult to trace. Collier (1908) and Smith (1908) estimate that the coal-bearing strata only extend for about one half mile along the creek and underlie less than a square mile. These coal-bearing units are inferred to be Late Cretaceous or Tertiary by Collier (1908), but Sainsbury (1973) postulates a strictly Cretaceous age because of their highly deformed character and because the conglomerate lacks granitic clasts from the middle to later Cretaceous intrusives in the area. Herreid (1970) considers the sediments to be Tertiary, however, and related in origin to the present drainage. Further geologic studies will undoubtedly resolve this discrepancy.

Natives from the village at the mouth of the Sinuk River first brought the coal to the attention of prospectors in 1902; systematic development of this deposit was first attempted in the same year (Collier, 1908), but no production records remain. A tunnel driven into the west bank of Coal Creek across the strike of the coal-bearing strata exposed seventeen seams of coal 3 to 16 inches thick separated by laminae of white fire clay (Collier, 1908). Bedding of these coal-bearing strata strikes northwest and dips 18° - 30° SW (Eakins and Clough, 1982). The Sinuk River area continued to be investigated

by various people who were mainly interested in the numerous mineralized gossan zones in the area rather than in coal. The first detailed geologic map in the Sinuk River area was compiled by Herreid (1970) to determine the extent of mineralized zones for the State of Alaska. However, this author notes the coal beds along Coal Creek and a caved-in shaft and adit. He also reports that the same conglomerate hosting the coal on Coal Creek is found on nearby Washington Creek and above the ore zone on Aurora Creek.

In 1982, the Alaska Division of Geological and Geophysical Surveys (ADGGS) performed a limited drilling program at the old Coal Creek mine site to determine if there was enough subsurface coal to warrant a larger-scale investigation. Of sixteen holes completed, only seven encountered thin stringers of carbonaceous shale and coal, and schist bedrock was found to be only about 77 feet deep. No samples large enough for laboratory analysis were recovered by drilling, but a weathered sample was collected from a pile found near some old mining carts. Analysis of this coal gave an ash content of 17 percent, and a heating value of 11,300 Btu/lb. These values correspond to an apparent rank of subbituminous A or B, though analysis of weathered samples is not very reliable.

No other analyses have been done of the coals on Coal Creek, but Collier (1908) reports the coal to be bituminous in appearance and of fair quality. Collier also reports that 'a blacksmith at Nome found it very satisfactory for welding purposes, but considered the deposit to have little value because of the small size of the beds.'

In short, little is definitely known about the coal resource potential of the Nome Quadrangle. Detailed geologic study of the coal-bearing strata, and perhaps more exploration drilling, would be required to make an accurate estimate, but results of the 1982 ADGGS drilling program are not encouraging. If thick enough coal beds were located near the Sinuk River, however, development for local fuel use might be possible.

Summary: Solomon Quadrangle (17 of 18)

Coal occurrences in the Solomon Quadrangle are limited to the southern part of the large Tertiary basin called McCarthy's Marsh. This feature is both a present-day topographic depression, and a deep, fault-bounded geological basin. Although most of the basin is located in the Bendeleben Quadrangle to the north, its southern end is the part of the Solomon Quadrangle most likely to have coal potential; this is federal land managed by the Bureau of Land Management.

Tertiary sedimentary rocks have been found in several widely scattered locations in McCarthy's Marsh. Smith and Eakin (1910) noted Tertiary strata exposed on Omilak Creek (then called the Rathlatulik River), and reported finding coal float with a woody, lignitic appearance, in pieces up to 24 inches thick, in the creek bed. Occurrences of coal float extend up both forks of Omilak Creek to the front of the Darby Mountains. Tertiary sedimentary rocks are also reported to crop out near Dry Canyon Creek, about 4 miles south of Omilak Creek, and coal float similar to that on Omilak Creek has reportedly been found in the bed of Dry Canyon Creek (Fankhauser and others, 1978; Dames and Moore, 1980).

There is no detailed stratigraphic or lithologic description available of the Tertiary sedimentary rocks of McCarthy's Marsh. Outcrops are sparce, but exposures are described as similar to other Tertiary coal-bearing rocks on the Seward Peninsula. Although the coal-bearing strata in the Solomon Quadrangle have not been dated, their similarity to rocks in other Seward Peninsula locations, and the appearance of the coal float, suggest a late Tertiary to Quaternary age (Dames and Moore, 1980).

A coal potential rating area in the extreme northeastern corner of the Solomon Quadrangle contains sedimentary rock units that continue into adjoining quadrangles. Due to differences in the way rock units are described, and because of different mapping emphasis, geologic maps of these quadrangles can only be correlated in a general way. Rocks in the indicated area are described as poorly sorted conglomerate with minor layers of graywacke and thin coal seams (C.C. Hawley and Associates, 1977a,b,c). Although the unit has not been reported specifically to host coal beds within the Solomon Quadrangle itself, the area in the northeast corner of the map has been rated consistently with corresponding parts of adjacent quadrangles because the rocks are otherwise similar.

There has been no exploration concentrated on locating and mapping coal in the Solomon Quadrangle. U.S. Geological Survey geologists who visited the area in 1909 to compile information on the mineral resources of the region reported the Omilak Creek locations (Smith and Eakin, 1910). Between 1975 and 1978, Resource Associates of Alaska noted additional coal float and Tertiary outcrops in the area during reconnaissance mineral exploration (Fankhauser and others, 1978). A composite map of gravity data acquired over many years shows McCarthy's Marsh to be the largest Bouger gravity anomaly on the Seward Peninsula (Barnes, 1977), with strongly negative gravity readings suggesting a sedimentary fill between 3,000 and 10,000 feet deep (Barnes, 1977; Dames and Moore, 1980). This, if correct, indicates that a large volume of potentially coal-bearing rocks probably underlies McCarthy's Marsh. Except for this indirect evidence, the subsurface geology of the Solomon Quadrangle is unknown.

Although coal float has been noted through the years, no analyses have been done on samples from the McCarthy's Marsh basin. However, the coal has been described as woody and lignitic in appearance, and it is common for near-surface coal beds of Tertiary or younger age to be either subbituminous C or lignite in rank. It is reasonable to speculate that thicker, better quality coals might be found at depth in a basin like McCarthy's Marsh. Judging from the geologic setting, further coal exploration might be warranted in this part of the Solomon Quadrangle.

Summary: Norton Bay Quadrangle (18 of 18)

The major coal occurrence in the Norton Bay Quadrangle is located in an unnamed sedimentary sequence approximately one mile east of the village of Koyuk, near the mouth of the Koyuk River. This land has been selected by the village of Koyuk, and is in the process of being conveyed. Another large area, in the southeast part of the quadrangle, is underlain by sedimentary rocks of the Kaltag and Nulato formations, which are known to be coal-bearing

along the Yukon River to the east in the Nulato Quadrangle (Patton, 1973). This area includes both state and Doyon Ltd. land.

The unnamed coal-bearing sequence in the lower Koyuk River area may be Late Cretaceous in age, possibly related to the Shaktolik Group (including the Kaltag and Nulato formations) or to the Ungalik Conglomerate (Cass, 1958; Patton, 1973), or may be of Tertiary age, contemporary with the Koyuk basin coal-bearing group to the north in the Candle Quadrangle (Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, Inc., 1983).

For rating purposes, a boundary has been drawn on the map in the area near Koyuk to include locations where coal float has been found, and the places drilled and mapped in 1982-83. Northwest from the Koyuk River mouth, an isolated wedge of coal-bearing rocks has been mapped as Cretaceous Shaktolik group (Cass, 1959). To the east, these rocks are believed to be more continuous, though thickly blanketed by alluvium and may continue northward along the Koyuk River for as much as 30 miles (Harrington, 1919; Hudson, 1977; Dames and Moore, 1980). Coal-bearing strata are bounded on the west by older metamorphic rocks, and on the north by rolling hills composed mostly of volcanic rocks.

The units of the coal-bearing sequence near Koyuk dip 10° to 20° S., with a strike of N. 70-85° E. Typical coal-bearing strata are thin, low-angle cross-bedded, unconsolidated silts and sands, containing clay laminae and scattered coaly material. The coal occurs in irregularly shaped lenses rather than in continuous beds (Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, 1983).

For years, residents of the Koyuk area have picked up coal chunks on the beach of Norton Bay for fuel, and barges have hauled up coal from the bottom of the bay when weighing anchor (Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, 1983). Coal was first prospected in the Koyuk area sometime before 1909. Coal claims were located on a creek locally called 'Coal Creek,' a tributary of the Koyuk, and Harrington (1919) reports that a coal mining permit was issued in 1919 for an unspecified location on the Koyuk River.

The vicinity was visited by U.S. Geological Survey (USGS) geologists Smith and Eakin in 1909. Their examination of the abandoned prospect sites failed to reveal any coal beds. The sedimentary rocks exposed in old prospect shafts were reportedly much less indurated than those of the Kaltag and Nulato formations to the east (Smith and Eakin, 1910). This may mean that the coal-bearing rocks are Tertiary rather than Cretaceous in age. Harrington (1919) recorded secondhand reports of a 2- to 4-foot coal bed and some thin seams said to be exposed at about sea level near the mouth of the Koyuk, but he never saw these would-be occurrences. Later mapping on a regional scale by USGS geologists J.T. Cass (1959), W.W. Patton (1973), and Travis Hudson (1977), has not precisely defined the units with coal-bearing potential.

During the summer of 1982, the State of Alaska Division of Geological and Geophysical Surveys (ADGGS) explored for coal by rotary drilling in the

Chicago Creek and Norton Sound area. A contractor drilled twenty-two holes along the Koyuk River to an average depth of 20 feet, ten of which penetrated coal up to 3.5 feet thick. In 1983 another contractor undertook a program of surface mapping, drilling, and geophysics on approximately 230 acres near the mouth of the Koyuk River. Thirteen holes, all drilled within 400 feet of the 1982 drill sites, logged a cumulative total of 1,442 feet, intercepting coal that proved to be thin and discontinuous. Of 10 coal intercepts, all at different horizons, the thickest was 3.5 feet, and most were less than 1.5 feet thick. The discontinuous nature of the coal, as encountered during 1982 and 1983, makes quantitative coal resource calculation unrealistic (Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, (1983).

Analyses of the 16 samples taken during the 1982 Koyuk exploration program were performed by the Mineral Industry Research Laboratory (MIRL), University of Alaska, Fairbanks. Average values (equilibrium moisture basis) are: 8,247 Btu/lb., 20.66 percent moisture, 9.29 percent ash, and 0.42 percent total sulfur. The coals rank as subbituminous C to subbituminous B, and are typical of Tertiary coals found in Alaska (Stevens Exploration Management Corp., 1982).

The coals encountered by the 1982-1983 investigations near Koyuk are interpreted as being the product of an ancient river delta distributary system. Such an environment of deposition does not promote thick, continuous coal bed formation. Judged solely on drilling results, the coal resource potential in the Koyuk area is not high. However, abundant, widespread coal float and other indirect indications of coal in the Koyuk region suggest the possible presence of undiscovered coal deposits (Stevens Exploration Management Corp., 1982; C.C. Hawley and Associates, 1983).

Still more speculative is the coal potential of the marginal-marine to non-marine Kaltag and Nulato formations within the large area rate '2' in the southeast corner of the Norton Bay Quadrangle. The Cretaceous sedimentary units, with a total thickness of over 10,000 feet, are known to host numerous coal beds up to 4 feet thick further east along the Yukon River (Chapman, 1963; Patton, 1973; Goff, 1984). However, these rocks are thought to have originated in a delta distributary system, with a low chance of thick, continuous coal beds. In the Norton Bay Quadrangle, these rocks are highly folded and faulted, and so far not reported to host coal. If and when the need arises, it might be useful to explore this region further for coal.

## APPENDIX B - THE U.S. GEOLOGICAL SURVEY COAL RESOURCE CLASSIFICATION SYSTEM[1]

### Introduction

The classification system presented herein is an expansion of the system adopted in 1976. It employs a concept by which coal is classified into resource/reserve base/reserve categories on the basis of the geologic assurance of the existence of those categories and on the economic feasibility of their recovery. Categories are also provided for resources/reserve base/reserves that are restricted because of legal, environmental, or technologic con-

[1]From U.S. Geological Survey Circular 891.

straints. Geologic assurance is related to the distance from points where coal is measured or sampled; thicknesses of coal and overburden; knowledge of the rank, quality, depositional history, areal extent, and correlations of coal beds and enclosing strata; and knowledge of the geologic structure. Economic feasibility of recovery is affected not only by such physical and chemical factors as thicknesses of coal and overburden, quality of coal, and rank of coal, but also by economic variables---such as price of coal, cost of equipment, mining, labor, processing, transportation, taxes, and interest rates, demand for and supply of coal, and weather extremes---and by environmental laws, restrictions, and judicial rulings. For example, the Clean Air Act of 1970 issued standards that severely limited the emission of sulfur by new coal-burning powerplants and, as a result, made the low-sulfur, low-rank coal deposits of the Northern Great Plains economically competitive. Similarly, environmental restrictions on the surface mining of coal and the need for adequate reclamation of mined areas has adversely affected the economic and technologic feasibility of extracting coal from some near-surface deposits.

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

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

The reserve base is identified coal defined only by physical and chemical criteria such as thicknesses of coal and overburden, quality, heat value, rank, and distance from points of measurement. The criteria for thickness of coal and for overburden have been selected so that the reserve base includes some currently subeconomic coal. The concept of the reserve base is to define a quantity of in-place coal, any part of which is or may become economic

depending upon the method of mining and the economic assumptions that are or will be used. An additional purpose is to aid in long-range public and commercial planning by identifying coal suitable for economic recovery.

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

Figures 2 and 3 are conceptual diagrams modified from Circular 831 (U.S. Geological Survey, 1980) that show the relationship of the various classes of coal resources, the reserve base, and reserves. The classes are categorized in both figures according to their degree of geologic assurance (geologic assurance or proximity to points of control increases to the left), and according to their degree of economic feasibility of recovery (economic feasibility of recovery (economic feasibility of mining increases upward). The resource/reserve base/reserve categories (classes) that can be used are not limited to those shown in figures 2 and 3 nor to the categories described in succeeding pages. For example, a particular bed of coal may be identified as being low-sulfur (0-1 percent), low-ash (0-8 percent), high-volatile A bituminous, and premium coking coal; other beds of coal may be identified as medium-sulfur (1.1-3.0 percent), high-ash (>15 percent), high-volatile bituminous, surface-minable canned coal, and so forth. The ability of the classification system to precisely describe the characteristics of a body of coal allows the coal resources of the United States to be divided into many hundred resource classes or categories.

The hierarchy of coal resources shown in figure 4 illustrates the conceptual relationships between the classes of resources as distinguished by their definitions and criteria. Examination of figures 2, 3, and 4 makes clear that each succeeding class in the hierarchy from original and remaining resources to reserves is included in the overlying classes. Original resources include remaining resources and cumulative depletion. Remaining resources include identified and undiscovered resources (divisible into hypothetical and speculative resources). Identified resources include measured, indicated, inferred, and demonstrated resources. Measured and indicated resources contain coal classed as reserve base, and inferred resources contain coal classed as inferred reserve base. Some measured, indicated, and inferred resources are subeconomic because they are too thin to mine or are buried too deeply to be mined by current extraction techniques; furthermore, parts of the reserve base and inferred reserve base are potentially subeconomic because they will be lost-in-mining. Reserves and inferred reserves are economically minable as of the time of classification. The reserve base and inferred reserve base also contain some coal that is believed to be potentially economic and which is classed as marginal and inferred marginal reserves.

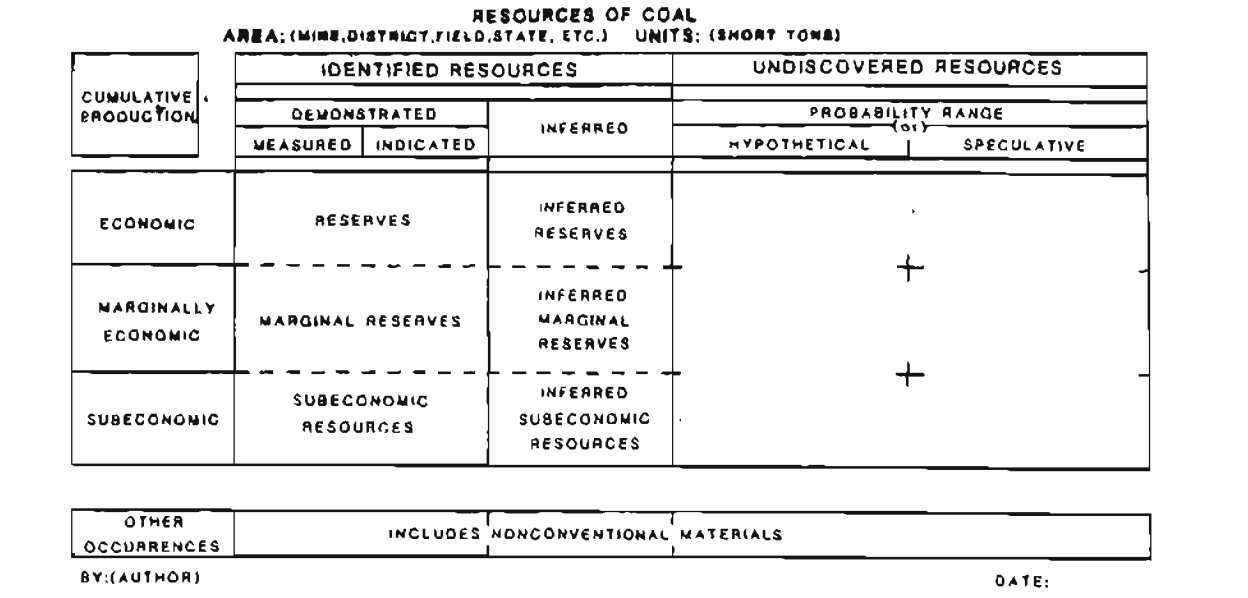



Figure 2. Format and classification of coal resources by reserves and subeconomic resources categories.

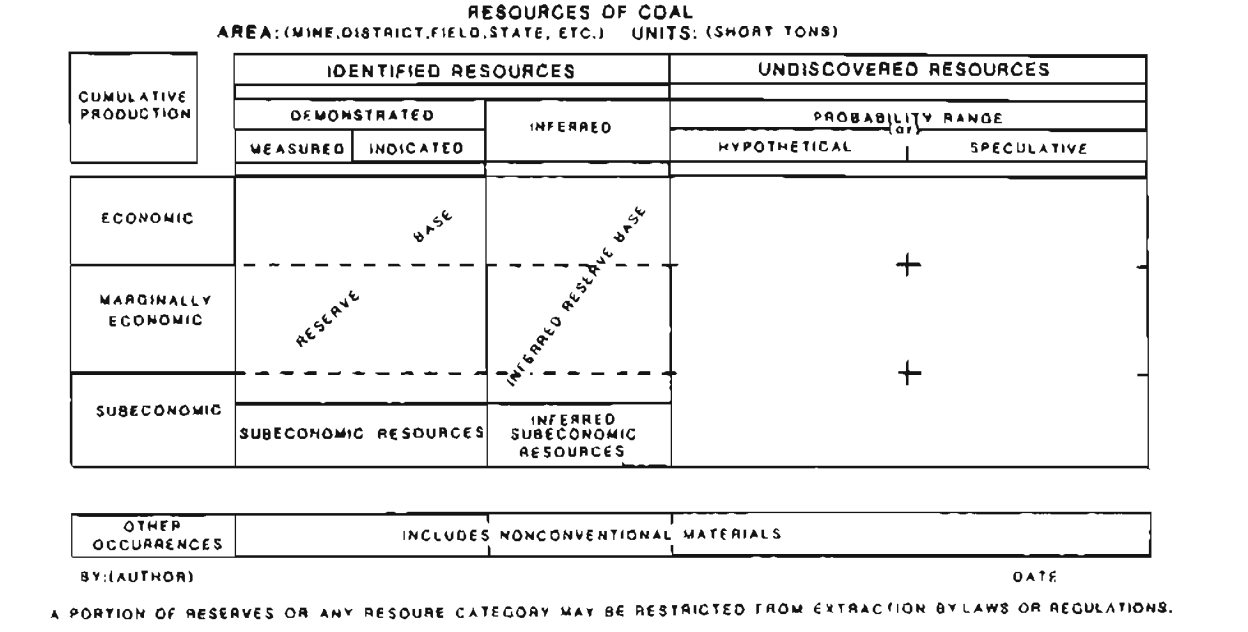



Figure 3. Format and classification of coal resources by reserve and inferred reserve bases and subeconomic and inferred subeconomic resources categories.

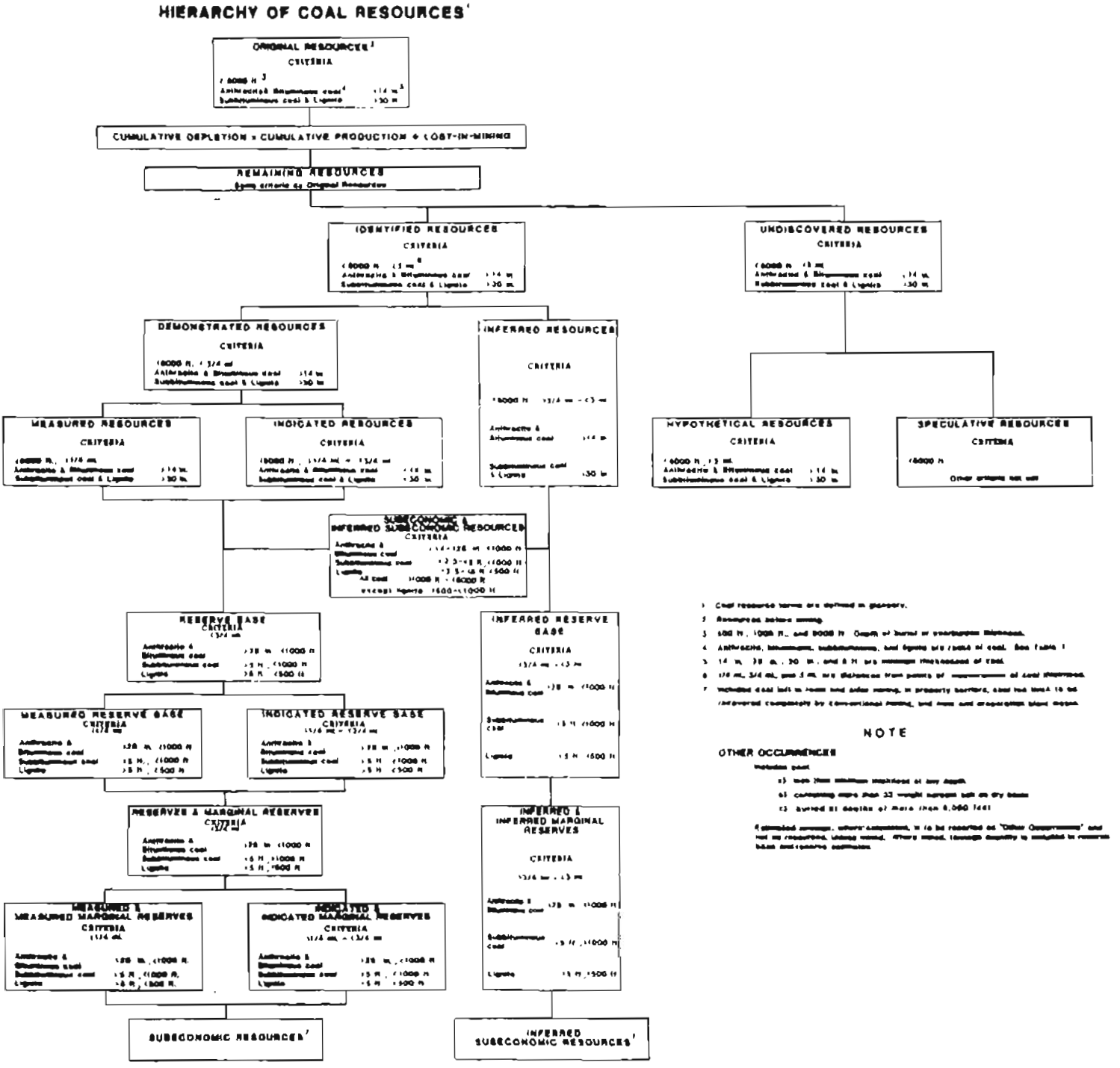



Figure 4. Hierarchy of coal resources- criteria for distinguishing coal resource categories.

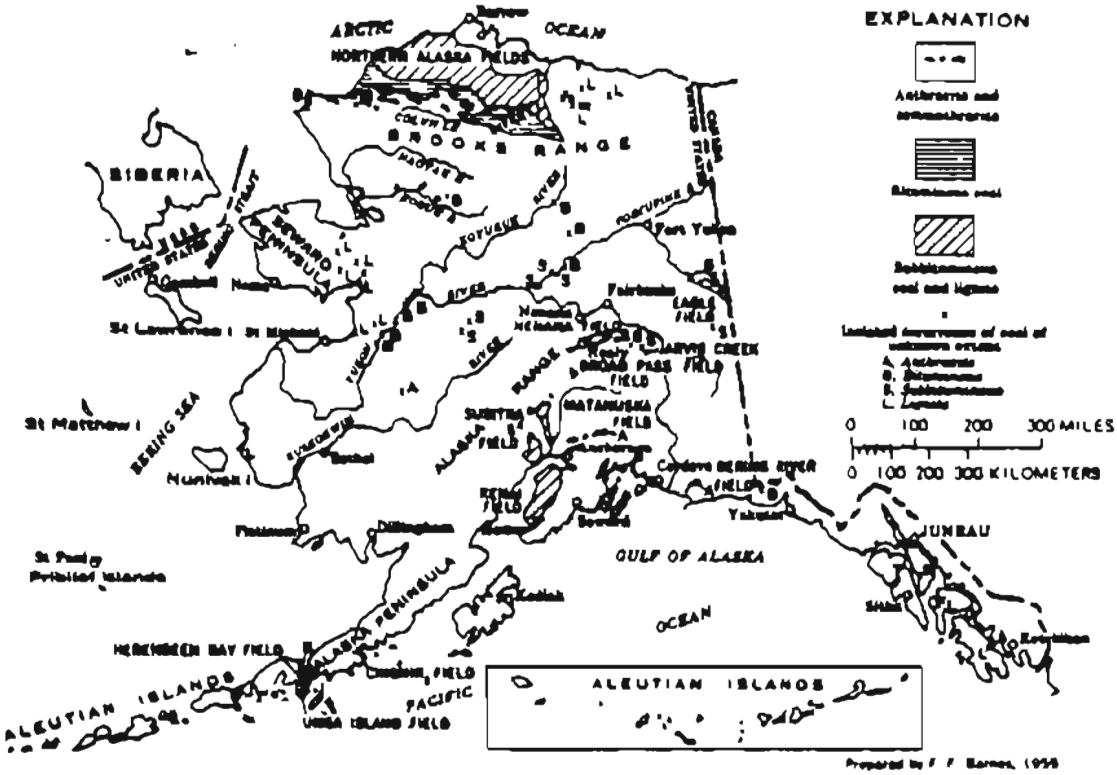



Figure 5. Coal fields of Alaska (from Averitt, 1975).

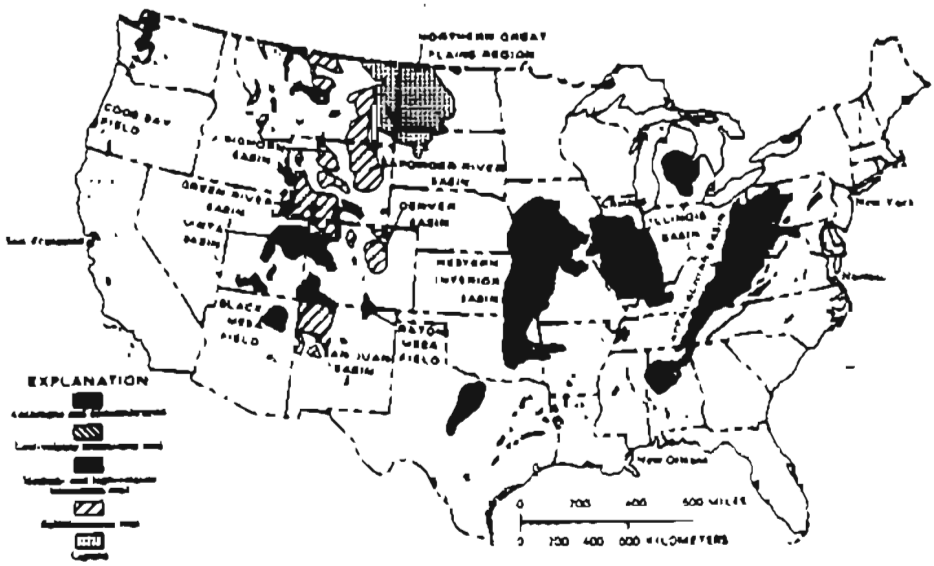



Figure 6. Coal fields of the conterminous United States (from Averitt, 1975).

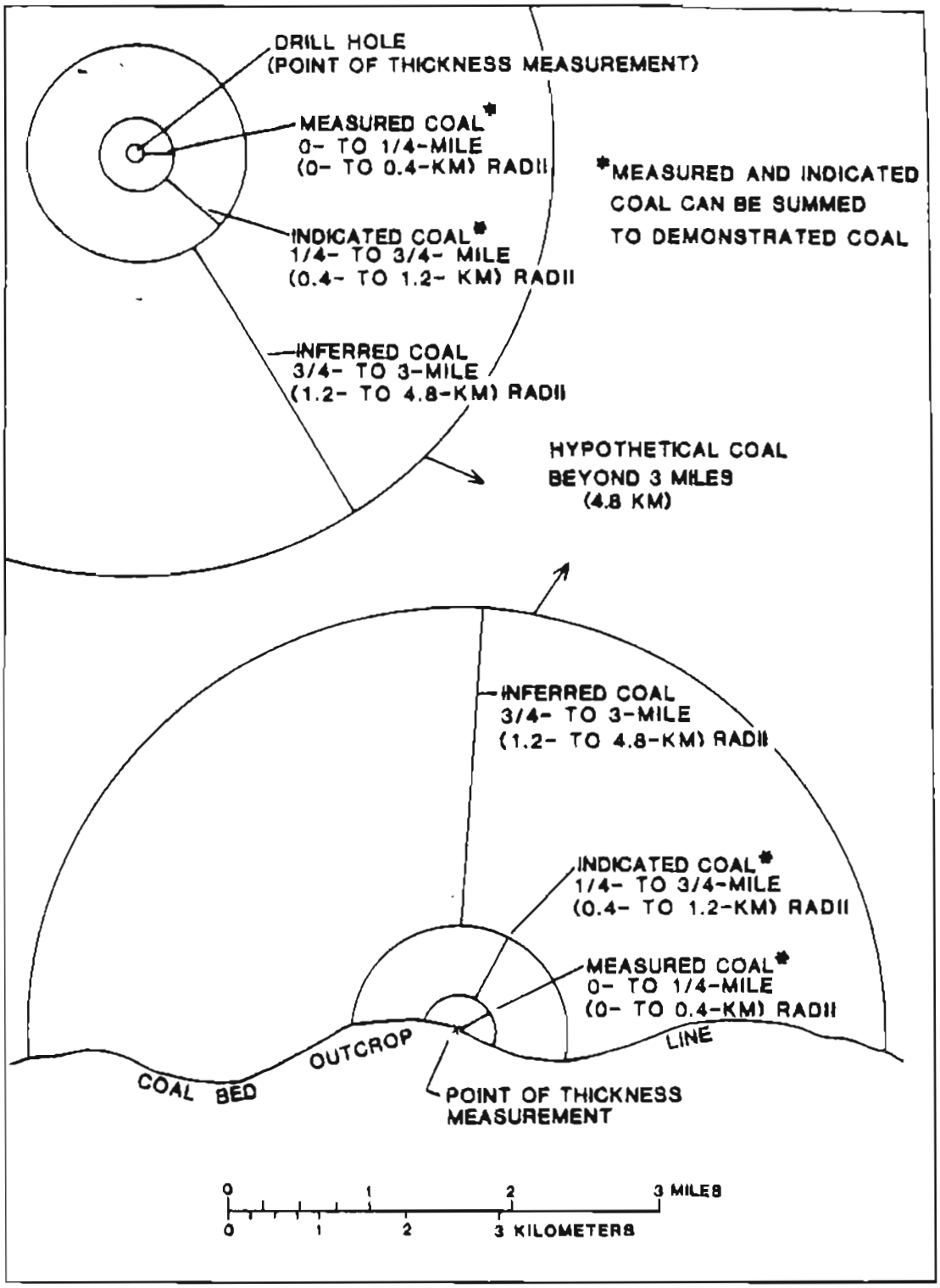



Figure 7. Diagram showing reliability categories based solely on distance from points of measurement.

## Glossary of Coal Classification and Supplementary Terms

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

All definitions herein refer only to usage in this coal resources classification system and are not intended as definitions of the terms relative to any other usage. Comparative values for units in the metric and English (U.S. Customary) systems of measurement are based on the Handbook of Chemistry and Physics by R.C. Weast (1971, p. F-242-F-263).

Note---Glossary terms and specific criteria are cross-referenced within this report. To aid the reader, specific criteria are underlined.

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

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

acreage.---The number of acres at the ground surface.

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

acre-inch (acre-in.).---The volume of coal that covers 1 acre at a thickness of 1 inch (3,630 cubic feet; 134.44 cubic yards; 102,7903 cubic meters). The weight of coal in this volume varies according to rank.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

coal bed.---See bed.

coal field.---A discrete area underlain by strata containing one or more coal beds.

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

coal province.---An area containing two or more coal regions.

coal region.---An area containing one or more coal fields.

coal reserves.---See reserves.

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

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

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

consolidated coal.---See lignite.

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

control point.---A point of measurement, a point of observation, or a sampling point.

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

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

Where data indicate that correlation of a coal bed is possible or probable among data points within an area, an estimate of the resources of that coal bed can be made for the entire area. However, where a coal bed at single data point cannot be correlated

with beds at other data points, or where there is only one data point, resources can be calculated for that coal bed using the single data point as the center of circles defining measured, indicated, and inferred.

cumulative depletion.---The sum in tons of coal extracted and lost-in-mining to a state date for a specified area or a specified coal bed.

cumulative production.---The sum in tons of coal extracted to a stated date for a specified area or a specified coal bed.

demonstrated.---A term commonly used for the sum of coal classified as measured and indicated resources. Used when not feasible or desirable to subdivide into measured and indicated.

demonstrated reserves.---Same as reserves.

demonstrated reserve base.---Same as reserve base.

demonstrated resources.---See resources.

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

depleted resources.---Resources that have been mined; includes coal recovered, coal lost-in-mining, and coal reclassified as subeconomic because of mining. See cumulative depletion.

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

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

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

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

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

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

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

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

feasibility.---The possibility of extracting coal.

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

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

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

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

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

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

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

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

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

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

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

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

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

hypothetical.---A low degree of geologic assurance. Estimates of rank, thickness, and extent are based on assuming continuity beyond inferred. Estimates are made, not exceeding a specified depth beyond coal classed as inferred, by projection of thickness, sample, and geologic data from

distant outcrops, trenches, workings, and drill holes. There are no measurement sites in areas of hypothetical coal. Used as a modifier to resource terms. See resources and undiscovered.

hypothetical resources.---See Undiscovered Resources.

identified resources.--- See Identified Resources.

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

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

indicated reserves and indicated marginal reserves.---See reserves and indicated.

indicated reserves base and indicated marginal reserve base.---See reserve base.

indicated resources.---See Indicated Resources.

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

inferred reserves and inferred marginal reserves.---See subdivisions of reserves.

inferred reserve base.---See reserve base.

inferred resources.---See Inferred Resources.

inferred subeconomic resources.---See Inferred Subeconomic Resources.

in situ.---Refers to coal 'in place' in the ground.

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

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

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

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

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

known coal.---Coal whose existence has been perceived from measurements and observations at the outcrop, in mines, from dill holes, and from exploratory trenches. Data confirming existence may be projected for several miles (kilometers) if based upon reasonable geologic assumptions. See identified resources.

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

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

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

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

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

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

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

marginal reserves.---Borders on being economic.

measured.---The highest-degree of geologic assurance. Estimates of quantity are computed partly from dimensions revealed in outcrops, trenches, workings, and drill holes and partly by projection of thickness, sample, and geologic data not exceeding a specified distance and depth. Rank is calculated from the results of detailed sampling that may be located at some distance from this type of resource and may be on the same or other coal beds. The sites for thickness measurement are so closely spaced and the geologic character so well defined that the average thickness,

areal extent, size, shape, and depth of coal beds are well established. However, a single measurement can be used to classify nearby coal as measured. Used as a modifier to resource terms.

measured reserves and measured marginal reserves.---See subdivisions of reserves.

measured reserve base.---See reserve base.

measured resources.---See Measured Resources.

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

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

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

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

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

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

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

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

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

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

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

moisture content.---The percentage of moisture (water) in coal. Two types of moisture are found in coal, namely, free or surface moisture removed by exposure to air, and inherent moisture entrapped in the coal and removed by heating to 220°F.

noneconomic.---Not capable of profitable production or extraction. Coal classified as noneconomic may be reported in other occurrences.

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

original resources.---See Original Resources.

other occurrences.---Coal in the ground that is excluded from classification as coal resources. Includes anthracite and bituminous coal less than 14 inches thick, subbituminous coal and lignite less than 30 inches thick,

and any coal more than 6,000 feet deep unless it is currently being mined. May include coal that contains more than 33 percent ash.

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

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

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

parting.---A layer or stratum of non-coal material in a coal bed which does not exceed the thickness of coal in either the directly underlying or overlying benches.

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

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

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

production.---The coal that has been extracted from a mine for a specified period. Production may be reported for a mine or larger area such as a

coal field, region, province, basin, township, quadrangle, state, nation, and (or) the world. Production in the United States is usually reported in short tons; most other nations report production in metric tons.

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

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

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

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

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

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

rank calculation.---The determination on the rank of a coal. Such determination must use the instructions given under rank calculation.

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

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

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

reliability categories.---Categories based on distance from points of measurement and (or) sampling. The measured, indicated, inferred, and hypothetical resource categories, as defined, indicate the relative reliability of tonnage estimates as related to distance from points of thickness control of particular parts of a coal deposit. The reliability categories are not indicative of the reliability of the

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

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

[A]This classification does not include a few coals, principally occluded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous rivals. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 13 500 moist, mineral-matter-free British thermal units per pound.

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

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

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

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

[1]ASTM, 1981, p. 213.

[A]Modified from ASTM, 1981.

basic data (that is, the accuracy of coal measurements, or the accuracy of location of the coal outcrop). It is assumed that all basic data used in resource estimation have been judged reliable by the estimator and that unreliable data have been discarded.

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

Discussion: Reserves can be categorized as measured and indicated, as underground or surface minable, by thickness of overburden, by thickness of coal in the bed, and by various quality factors. The term 'economic reserves' is not to be used because reserves by definition are economic. Reserves, which are derived from reserve base coal, exclude coal thinner or deeper than that classified as reserve base unless such coal is currently mined.

MANDATORY SUBDIVISIONS:

A. Indicated Reserves and Indicated Marginal Reserves.---Categories of virgin reserves having a moderate degree of geologic assurance. See indicated and marginal reserves.

B. Inferred Reserves and Inferred Marginal Reserves.---Categories of virgin reserves having a low degree of geologic assurance. See inferred reserves and marginal reserves.

C. Measured Reserves and Measured Marginal Reserves.---Categories of accessed and virgin coal reserves having the highest degree of geologic assurance. See measured reserves and marginal reserves.

OPTIONAL SUBDIVISIONS:

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

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

Discussion: For example, coal in a national park may meet all the physical, chemical and economic requirements of a reserve but is prohibited from extraction. The assign-

ment to a restricted category may be either temporary or permanent; however, because laws and regulations can be repealed or changed, such coal should be separately distinguished, and tonnage estimates recorded as a restricted reserve. Locally, a specific regulation or law might prohibit one method of mining and allow or not specify other methods. In such a circumstance, the coal would be restricted from mining by the prohibited method and tonnage estimates would be so recorded. In other circumstances, other methods would be unrestricted, and tonnage estimates would be reported accordingly.

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

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

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

resources.---Naturally occurring concentrations or deposits of coal in the Earth's crust, in such forms and amounts that economic extraction is currently or potentially feasible.

MANDATORY SUBDIVISIONS:

A. Hypothetical Resources.---See Undiscovered Resources

B. Identified Resources.---Resources whose location, rank, quality, and quantity are known or estimated from specific geologic evidence. Identified coal resources include economic, marginally economic, and subeconomic components. To reflect varying distances from points of control or reliability, these subdivisions can be

divided into demonstrated and inferred, or preferably into measured, indicated, and inferred.

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

C. Indicated Resources.---Identified bodies of virgin coal having a moderate degree of geologic assurance. See indicated.

D. Inferred Resources.---Identified bodies of virgin coal having a low degree of geologic assurance. See inferred resources.

E. Measured Resources.---Accessed and virgin demonstrated resources having a high degree of geologic assurance.

F. Original Resources.---The amount of coal in-place before production. Where mining has occurred, the total of original resources is the sum of the identified resources, undiscovered resources, coal produced, and coal lost-in-mining.

G. Remaining Resources.---The resources in the ground in a mine, area, field, basin, region, province, county, state, and (or) nation after some mining. The term does not include coal lost-in-mining unless such coal ban be considered potentially recoverable. Remaining resources may be divided into categories such as remaining economic, marginally economic, subeconomic, measured, indicated, inferred, identified, and undiscovered (hypothetical and speculative) resources or other types of resources.

The total remaining resources are the sum of the remaining identified and undiscovered resources as of the date of the estimate.

H. Subeconomic Resources.---That part of identified (demonstrated) resources that does not meet the economic criteria of reserves and marginal reserves. See resources and economic.

I. Inferred Subeconomic Resources.---That part of identified (inferred) resources that does not meet the economic criteria of inferred reserves or inferred marginal reserves. See resources and economic.

J. Speculative Resources.---See Undiscovered Resources.

K. Undiscovered Resources.---Undiscovered resources, the existence of which is only postulated, comprise deposits that are either separate from or are extensions of identified resources. Undiscovered resources may be postulated in deposits of such quality,

rank, quantity, and physical location as to render them economic, marginally economic, or subeconomic. To reflect varying degrees of geologic certainty, undiscovered resources may be subdivided into two parts as follows.

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

OPTIONAL SUBDIVISIONS:

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

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

The division of coal resources into the many different categories described heretofore and into other categories not differentiated in the text is desirable and encouraged. Many requests for information about resources are received by coal resource specialists

and are unanswerable because the scopes of the systems of classification used in the past were too limited. Persons and institutions classifying resources are, therefore, encouraged to use initiative in defining and developing additional classes of coal resources.

restricted reserves.---See optional subdivisions of reserves.

restricted resources.---See optional subdivisions of resources.

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

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

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

TYPES OF SAMPLES:

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

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

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

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

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

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

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

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

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

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

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

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

J. grab sample.---A sample, commonly a single piece, selected from a coal bed, tipple, preparation plant, blend pile, conveyor belt, or coal car.
Discussion: Grab samples are not recommended because many comparisons with properly collected samples indicate they are rarely representative.

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

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

M. tipple sample.---A sample of coal collected at a mine tipple.

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

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

specific gravity of coal.---The ratio of the mass of a unit colume of coal to the mass of an equal volume of water at 4°C.
Discussion: The specific gravity of coal varies considerably with rank and with differences in ash content. The values shown in table 2 are close to the average specific gravities of unbroken or unmined coal in the ground (in situ) for the four major rank categories and are to be used in preparing U.S. Geological Survey estimates of coal resources and reserves.

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

speculative.---Lowest degree of geologic assurance. Estimates of rank, thickness, and extent are base on assuming the existence of known types of coal deposits in favorable geologic settings or on assuming the existence of unknown types of deposits as yet unrecognized for their economic potentials. Tonnages are estimated by assuming thickness of coal, overburden, extent, and rank to a specified depth. There are geologic evidence sites but no measurement sites in areas of speculative coal. Used as a modifier to resource terms. See Hypothetical Resources, Speculative Resources, and Undiscovered Resources.

speculative resources.---See Speculative Resources.

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

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

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

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

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

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

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

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

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

subeconomic resources.---See resources and economic.

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

thickness categories.---The categories of thickness of coal beds employed in calculating, estimating, and reporting coal resources and reserves.

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

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

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

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

undiscovered resources.---See mandatory subdivisions of resources.

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

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

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

## Criteria for Coal Resource Classification

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

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

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

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

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

## Applications of Criteria

The criteria are to be applied only to those deposits of coal that are currently or potentially feasible for economic extraction by underground mining, surface mining, and (or) in situ gasification methods. Coal beds that are thinner than 14 inches (35 cm; anthracite and bituminous) and 30 inches (75 cm; lignite and subbituminous) generally are excluded from resource consideration unless currently being mined. All coal beds deeper than 6,000 feet (1,800 m) are excluded. These limits are imposed as the result of consultations with geologists and mining engineers throughout the international coal community. In the United States, beds that contain more than 33 percent ash also are excluded; because of a shortage of energy in some countries, however, coal containing more than 33 percent ash is being mined and is classified as reserves.

Coal beds thinner or more deeply buried than the imposed limits have been mined locally at several places in the United States and are mined in other parts of the world; however, their extraction in the United States has generally not proven economic. Where such mining is taking place, the coal should be classed as a reserve and recorded at the time of assessment in the coal resource figures. With the few exceptions owing to current mining and similar future exceptions, the imposed limits should be adhered to.

## Specific Criteria

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Note.---Specific criteria and glossary terms are cross referenced within this report. To aid the reader, specific criteria, beginning below, are underlined.

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ANTHRACITE AND BITUMINOUS COAL RESERVES.---Tonnage estimates for these classes of coal are determined by summing the recoverable quantities of coal in the reserve base and are assigned to the following categories: (a) thickness of coal---28 to 42 inches (70 to 105 cm), 42 to 84 inches (105 to 215 cm), 84 to 168 inches (215 to 430 cm), more than 168 inches (>430 cm); and (b) thickness of overburden---0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 to 300 m). Tonnage estimates for the bituminous coal class may be divided into low-volatile, medium-volatile, high-volatile A, high-volatile B, and high-volatile C groups. Similarly, tonnage estimates for the anthracite class may be divided into meta-anthracite, anthracite, and semianthracite groups. Reserves assigned to these coal classes must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative.

<u>anthracite and bituminous coal inferred reserves</u>.---Tonnage estimates for these classes of coal are determined by summing the recoverable quantities of coal in the inferred reserve base and are assigned to the same coal thickness

and overburden thickness categories as anthracite and bituminous coal reserves. Inferred reserves must be considered as economically producible at the time of classification. Facilities for extraction need not be in place and operative.

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

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

anthracite and bituminous coal resources.---Tonnage estimates for these classes of coals are determined by summing the estimates for anthracite and bituminous coal identified and undiscovered resources (fig. 3). They are assignable to the same thickness categories as for anthracite and bituminous coal reserves with the addition of a 14-28 inch (35-70 cm) category, and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). Tonnage estimates for the bituminous coal class may be divided into the low-volatile, medium-volatile, high-volatile, high-volatile A, high-volatile B, and high-volatile C groups, and tonnage estimates for the anthracite class may be divided into the meta anthracite, anthracite, and semi anthracite groups.

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

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

demonstrated reserves and demonstrated marginal reserves.---Tonnage estimates for these categories of coal are the sum of the estimates for measured and indicated reserves and marginal reserves, respectively, which are the preferred usages. See Reserves and Marginal Reserves.

demonstrated reserve base.---Tonnage estimates for this category of coal are determined by summing the estimates for the measured and indicated reserve bases. The demonstrated reserve base is the same as the 'reserve base,' which is the preferred usage. See reserve base.

demonstrated resources.---Tonnage estimates for this category ar the sum of the estimates for the reserve base and subeconomic resources.

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

hypothetical resources.---Tonnage estimates for this category of resources are for (1) extensions of inferred resources (coal beyond a radius of 3 miles or 4.8 km from a point of measurement), and (2) regions where tonnage estimates are based on a knowledge of the geologic character of coal. Hypothetical resources include coal that is 14 inches (35 cm) or more thick (anthracite and bituminous coal) and 30 inches (70 cm) or more thick (subbituminous coal and lignite) to a depth of 6,000 feet (1,800 m).

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

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

indicated marginal reserves.---Tonnage estimates for this category of reserves include those parts of an indicated reserve base that at the time of determination border on being economically producible assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic profitability should be documented.

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

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

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

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

inferred marginal reserves.---Tonnage estimates for this category of reserves include those parts of an inferred reserve base that at the time of determination border on being economically producible assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic profitability should be documented.

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

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

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

lignite reserves.---Tonnage estimates for this class of coal reserves are determined by summing the recoverable quantities of coal in the reserve base

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

Discussion: Currently, there are few underground ground lignite mines in the United States. In addition, there are few, if any, lignite strip mines that are removing as much as 300 feet (100 m) of overburden. In order to provide for future technologic and surface mining advances, the maximum thickness of overburden for surface-minable lignite reserves and reserve base is set at 500 ft (150 m). It is deemed inexpedient to estimate underground-minable lignite reserves and reserve base at depths greater than 500 feet (150 m).

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

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

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

lignite resources.---Tonnage estimates for this class of coal are determined by summing the estimates for lignite identified and undiscovered resources. The same thickness categories as for lignite reserves are to be used with the addition of 30-60 inches (75-150 cm) category and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m); and 3,000 to 6,000 feet (900 to 1,800 m). The tonnage estimates for this class of coal may be divided into lignite A and B groups.

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

measured marginal reserves.---Accesses and virgin coal that lies within a radius of 1/4 mile (0.4 km) of a point of thickness of coal measurement. Tonnage estimates for this category of reserves includes those parts of a measured reserve base that at the time of determination border on economic

producibility assuming certain projected economic or technologic changes. The assumed changes and the specific criteria suggesting potential economic producibility should be documented.

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

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

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

original resources.---Tonnage estimates determined for coal in the ground prior to production. Where coal has been mined, estimates are made by summing remaining resources, cumulative production, and coal lost-in-mining. An estimate of total original resources is the sum of the original resources determined for many mines, fields, basins, regions, provinces, states, and the nation.

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

rank assignments.---The assignment of rank is a necessary part of classifying a coal; however, data for determining rank are commonly sparse or ar far-removed from the localities where the data required for rank assignments is needed. In general, rank gradually changes laterally over many miles or stratigraphically over hundreds to thousands of feet. Because of the lack of data in some areas, conclusions concerning rank assignments commonly must be

derived from analytic or petrographic determinations made on coal that lies some distance from where the rank assignment is desired. Conclusions concerning rank where analytic or petrographic data are sparse must be viewed as tentative. However, if a geologists' understanding of the setting of the area sampled is adequate, the rank assignment probably will be correct even though the rank data are sparse.

## Rank Calculations

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

### Calculation to Mineral-matter-free Basis

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

Calculation to Mm-free basis:

Parr Formulas:

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

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

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

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

Approximation Formulas:

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

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

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

where

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

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

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

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

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

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

where

RF = Recovery factor or percent coal estimated extractable during mining,

X = The total tonnage of coal estimated in the ground,

Y = The tonnage of coal estimated to be recoverable during mining.

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

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

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

mean recovery factor in percent for many mines, ascertaining the quantity of reserve base coal in the area of study, and ascertaining the total quantity of coal that is restricted from mining for any legal, environmental or technologic reason. These formulas are:

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

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

where

X = tonnage of coal restricted from extraction for any legal, environmental, or technologic reason,
Y = tonnage of coal included in the reserve base category of a large area,
Z = restricted coal (percent),
W = recovery factor percent obtained from local mines, and
NRF = National, state, or large area recovery factor in percent applied to all coal including restricted.

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

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

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

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

feet (1.5 m) or more thick that occurs at depths to 1,000 feet (300 m), and lignite 5 feet (1.5 m) or more thick that occurs at depths to 500 feet (150 m).

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

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

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

reserves.---Reserve tonnage estimates are to be determined by summing the recoverable quantities of coal in the reserve base for each rank of coal and are assigned to the following categories: (1) thickness of overburden---0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 to 300 m); and (2) thickness of coal---28 to 42 inches (70 to 105 cm), 42 to 84 inches (105 to 215 cm), 84 to 168 inches (215 to 430 cm), and more than 168 inches (>430 cm) for anthracite and bituminous coal; and 5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3.0 to 6.0 m), 20 to 40 feet (6.0 to 12.0 m), and more than 40 feet (>12.0 m) for subbituminous coal and lignite.

Reserves must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative. In addition, categories based on potential mining methods (surface and underground); chemical constituents such as sulfur, phosphorous and ash content; heat value; and usage such as metallurgical, steam, petrochemical, gasification, and liquefaction are desirable. Reserves and marginal reserves are estimated by determining the amount of coal in each reserve base category that can be extracted at the time of classification (reserves), and the amount that borders on being extractable at a profit (marginal reserves).

These two amounts and the amount that will be lost-in-mining, when summed, are equal to the reserve base. The estimates of each reserve category are to be totaled into quadrangle, township, field, basin, region, province, county, and state estimates, and into a national total, and then the various estimates for all categories are to be totaled similarly to reach an inclusive estimate of all reserves.

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

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

speculative resources.---As of publication, there are no speculative resources of coal estimated for the United States. However, if it is desirable to make such an estimate, the definition of Speculative Resources and the criteria for resources will be followed, and the geologic evidence supporting the estimates and methods of quantification will be made available publicly.

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

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

subbituminous coal reserves.---Tonnage estimates for this class of coal are determined by summing the recoverable quantities of coal in the reserve base and are assigned to the following categories: (a) thickness of coal---5 to 10 feet (1.5 to 3.0 m), 10 to 20 feet (3.0 to 6.0 m), 20 to 40 feet (6.0 to 12.0 m), and more than 40 feet (>12.0 m); and (b) thickness of overburden---0 to 500 feet (0 to 150 m) and 500 to 1,000 feet (150 to 300 m). Such reserve estimates may be divided into subbituminous A, B, and C rank groups.

Reserves assigned to this coal class must be considered as economically producible at the time of classification, but facilities for extraction need not be in place and operative.

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

subbituminous coal resources.---Tonnage estimates for this class of coals are determined by summing the estimates for identified and undiscovered subbituminous coal resources. The same thickness categories as for subbituminous coal reserves are to be used with the addition of a 30 inches-5 feet (75 cm-1.5 m) category, and the following overburden categories are to be recognized: 0 to 500 feet (0 to 150 m); 500 to 1,000 feet (150 to 300 m); 1,000 to 2,000 feet (300 to 600 m); 2,000 to 3,000 feet (600 to 900 m)1 and 3,000 to 6,000 feet (900 to 1,800 m). Such resource estimates may be divided into subbituminous coal A, B, and C rank groups.

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

thickness of coal for resource calculations.---The thickness of coal used for resource calculations is the net thickness of coal in a bed excluding all partings more than 3/8 inch (>1 cm) thick. Beds and parts of beds made up of alternating layers of thin coal and partings are omitted from calculations if the partings comprise more than one-half of the total thickness. Also, benches of anthracite and bituminous coal less than 14 inches (35 cm) thick and benches of subbituminous coal and lignite less than 30 inches (75 cm) thick are omitted from calculations if they lie above or below partings that may deter their mining. Coal and coaly material containing more than 33 percent ash is excluded from resource and reserve estimates unless the ash is largely in associated partings so that the coal is cleanable to less than 33 percent ash.

undiscovered resources.---Tonnage estimates for this category of resources are based (1) on knowledge of the geologic character, habit, and pattern of a coal bed or coal zone in an area or region, or (2) on speculative geologic

data. Estimates are made by summing the tonnage estimates for coal assigned to the hypothetical and speculative resources reliability categories. Included are hypothetical and speculative resources of bituminous coal and anthracite in beds 14 inches (35 cm) or more thick and hypothetical and speculative resources of subbituminous coal and lignite in beds 30 inches (75 cm) or more thick presumed to occur in mapped areas and in unmapped or unexplored areas to depths of 6,000 feet (1,800 m).

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