are needed. Production history, which is limited, will probably prove to be the best method of estimating recoverable reserves.

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Trace-Element Content of Bituminous Coal from Appalachian and Eastern Interior Regions and Rocky Mountain Coal Province—Data as of 1979

We have studied 2,035 samples from the Appalachian bituminous coal beds, 370 samples from the eastern interior coal beds, and 362 samples from the Rocky Mountain coal beds.

The coals analyzed range in rank from high-volatile bituminous to low-volatile bituminous; the Appalachian coals have the lowest mean volatile-matter and moisture contents and the highest fixed-carbon content and Btu value. The Rocky Mountain coals have the highest mean ash content and lowest fixed-carbon content and Btu value. The average Appalachian coal has a much higher rank than does coal from either of the other regions.

Of the 19 elements reported, seven (Cu, F, Mn, Pb, Sb, U, and V) have mean values that vary less than twofold among the three areas. Of these, U is the most uniformly distributed. Other elements (Co, Ni, Zn, and S) have about a fourfold variation, whereas As is 6.5 times as abundant in Appalachian coal as in Rocky Mountain coal. In average, the other elements are 2 to 6.5 times as abundant in some coals from the three areas as in others.

Table 1.--Statistical summary of data on Appalacian, Interior, and Rocky Mountain bituminous coals.

(Mean contents of all elements except sulfur are in parts per million, sulfur and ash contents are in weight percent, calorific values are in Btu's per pound, Gm = Geometric mean, Gd = Geometric deviation.)

	Rocky Mountain		Eastern Interior		Appalachian	
	Gm	Gd	Gm	Gd	Gm	Gd
As	1.4	2.6	6.9	2.9	9.1	3.6
Be	.87	2.3	2.4	1.8	1.9	1.9
Cd	.12	2	.19	4.2	.08	2.5
Co	1.5	2.1	4.3	2.1	5.5	2
Cr	5	2.3	12	1.7	14	2
Cu	7.7	1.8	10	1.8	14	2
F	73	2.2	55	1.7	68	2.1
Hg	.05	2.5	.09	2	.13	2.8
Li	9.3	2.3	7.3	2.2	15	2.5
Mn	15	2.9	23	2.5	15	2.7
Mo	1.1	2	2.7	2.5	1.8	2.3
Ni	3.2	2.2	14	2.3	11	2
Pb	5.2	2	9.1	3.1	6.7	2.2
Sb	.40	2.2	.73	2.8	.68	2.4
Se	1.2	1.9	2.2	1.7	2.9	2
U	1.4	2.2	1.3	2.3	1.2	2
V	12	2.1	15	3.3	17	2.5
Zn	8.6	2.4	32	3.3	13	2.5
Ash (550°C)	11	1.8	9.4	1.6	10	1.9
Calorific value	10,690	1.2	11,630	1.1	12,620	1.1
Sulfur	.67	1.7	2.8	1.8	1.6	2.2

The Rocky Mountain coals have the lowest mean contents of 15 of the elements listed in the table; only U and F mean contents are slightly higher in this area. The eastern interior coals have the highest mean contents of nine of the elements, and the Appalachian coals have the highest mean contents of eight of the elements.

As the average rank of the coals increases, the average contents of As, Co, Cr, Cu, Hg, Se, and V also increase; however, the distribution of most other elements is not related to rank. In general, the trace-element content of coal is influenced largely by the depositional environment and does not depend on rank.

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Overview of Geothermal Energy Developments

Exploration for geothermal resources includes evaluation of the volcanic history, regional geology and hydrology, geochemistry of hot springs, and use of selected geophysical methods to determine temperature, heat flow, and structure of prospective areas.

Geothermal energy is primarily used for electric power generation. At the Geysers field in northern California, geothermal energy has proved to be a viable, mechanically reliable, and environmentally acceptable resource. The field competes economically with alternative forms of power generation such as oil, gas, nuclear, and hydroelectric. The Geysers field is an example of a vapor-dominated geothermal reservoir. The field produces 630 Mw, with a total capacity estimated to be about 2,000 Mw. It is the only geothermal field used to generate significant quantities of electricity in the United States.

Other areas experiencing active development are the Imperial Valley of California, Baca area of New Mexico, and Roosevelt area of Utah. Overall, plans have been announced for nine power plants at seven sites, with a total generating capacity of 300 Mw. The new areas are all liquid-dominated systems.

The Department of Energy estimates that 15,000 to 20,000 Mw of geothermal power can be developed in the western United States in the next 2 decades. With improved exploration, drilling, and utilization technology, it has been estimated that several times this amount of power can be developed, provided that delays due to environmental and legal/institutional issues can be resolved.

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San Juan Basin of New Mexico and Colorado, Classic Area of Stratigraphic Exploration

The San Juan basin of northwestern New Mexico and southwestern Colorado is a Laramide structural basin with a maximum thickness of 15,000 ft (4,572 m) of Paleozoic to Eocene sedimentary rocks. The basin is elongate north-south, approximately 125 × 100 mi (201 × 161 km); it is structurally asymmetrical, with the deepest part in the north near the New Mexico-Colorado line. Monoclinal basin rims are especially prominent.

Petroleum occurs in Pennsylvanian carbonate rocks, Jurassic eolian sandstones, but predominantly in Cretaceous sandstones and fractured shales. The San Juan basin is gas-prone, although significant oil fields are common. The Cretaceous Blanco basin gas field is one of the largest in the United States. The key to exploration in this mature area lies in understanding the complex stratigraphy that controls most of the traps.

The San Juan basin area was a part of larger depositional basins prior to the Laramide orogeny. Major sedimentation in the area began during the Pennsylvanian with deposition of shelf-carbonates and flanking arkosic clastics from Ancestral Rocky Mountain uplifts. Regression during the Permian resulted largely in nonmarine clastic deposition. Triassic fluvial red beds were deposited across the area after an erosional interval. After another erosional interval, Jurassic nonmarine clastics and restricted limestones and evaporites were deposited. During the Cretaceous, the sea returned and repeatedly transgressed and regressed across the basin, producing well-developed depositional cycles. Laramide uplift around the San Juan basin during latest Cretaceous and earliest Cenozoic time produced the structural basin which became partly filled with Paleocene and Eocene nonmarine clastics.

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Rock-Eval Pyrolysis as Source Rock Screening Technique

Rock-Eval pyrolysis (by the IFP-FINA Method) provides a rapid (20 min) screening evaluation of the source potential, type, and maturity or organic matter (OM) in rocks. Whole rock samples are used, thereby eliminating time-consuming sample preparation.

The pyrolysis instrument is a dual-detector gas chromatograph to which a pyrolysis heating chamber and gas-handling circuits have been added. A small sample (0.1 g) is heated from 250 to 550°C at a uniformly increasing temperature in a furnace flushed with helium. The volatilized gases are swept either directly into the flame ionization detector or into a CO_2 trap and then into the thermal conductivity detector. The signal is fed through an integrator to a strip-chart recorder, resulting in three peaks: Peak 1, the amount of OM (mg hydrocarbons/g rock) present in the rock as oil-like components and broadly analogous to the solvent-extractable (bitumen) part of the OM; Peak 2, the amount of OM (mg hydrocarbons released/g rock) cracked from the insoluble (kerogen) part of the OM pyrolysis. The temperature of maximum evolution of Peak 2 provides an estimate of maturity; Peak 3, the amount of CO_2 (mg CO_2/g rock) derived from the oxygen in the kerogen.

Comparison of pyrolysis data with conventional geochemical data suggests the following interpretation. Peak 2—hydrocarbon potential: poor, 0 to 2.5; fair, 2.5 to 5.0; good, 5.0 to 10.0 mg hydrocarbons/g rock. Peak 2/Peak 3—expected hydrocarbon type: gas, 0 to 2.5; gas + oil, 2.5 to 5.0; oil, 5.0 to 10.0 mg hydrocarbons/g rock. Peak 1/(Peak 1 + Peak 2)—migrated hydrocarbons: present, greater than 0.2. Temperature of maximum evolution: immature, 435°C; oil-generating, 435 to 450°C; gas generating, 450 to 470°C; cooked out, 470°C or greater.

Because of problems, such as the presence of solid bitumen and mixed kerogen type, Rock-Eval does not replace conventional geochemical evaluation. Instead, pyrolysis data outline general trends facilitating the selection of samples for further analysis.

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Future Trends in Coal Resource and Reserve Evaluations in United States

Most currently available estimates of coal resources and reserves in the United States were prepared to determine only general areas of coal occurrence and thicknesses of beds. Such estimates were usually accompanied by coal analyses to indicate the coal rank and to a much lesser degree, other quality parameters of the coal deposits. Estimation of coal tonnage was accomplished by simple but time-consuming arithmetic and/or geometrical procedures, which usually involved the use of hand-drawn maps and the polar planimeter. For many regions of the United States, data and/or manpower available were so limited that only broad estimates of coal resources could be made. As a result, our national coal resource data base is quite limited in both scope and detail.

In the future, computers will be used extensively to process such data as depth, thickness, quality, environmental factors, and other parameters associated with coal resources. Computers can be programmed to generate many kinds of maps and numerical tabulations. By the use of point data (e.g., drill holes, outcrops) resources can be classified according to any desirable classification system, such as thickness categories.

Most procedures currently used to evaluate coal resource and reserve data rely upon point-of-observation spacing only for geologic assurance of coal occurrence. Several major studies are underway to develop geostatistical methods such as kriging and the use of variograms, which facilitate evaluation of other uncertainties inherent in both quantity and quality data on coal resources. Thus, by use of computer processing and geostatistical methods, a more comprehensive understanding of the amount of characteristics of United States coal resources will be developed during the coming decade.

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MonDak Mississippian Oil Field, Williston Basin

The MonDak Mississippian limestone oil field contains 13.7 million to 68.6 million MT (100 million to 500 million bbl) of recoverable oil. It produces from irregular intervals, both vertically and horizontally, in a 168 m section of fractured Mississippian limestone. Dip in the field is eastward into the Williston basin at 3 to 11 m/km, with some structural flattenings and irregularities. The trap is not structural. The reservoir is limestone with a depositional texture range from mudstone to grainstone, but most of the reservoir rock is wackestone. Normal matrix porosity is 2 to 4% and matrix permeability is less than 0.01 md. Some lentils of fossil