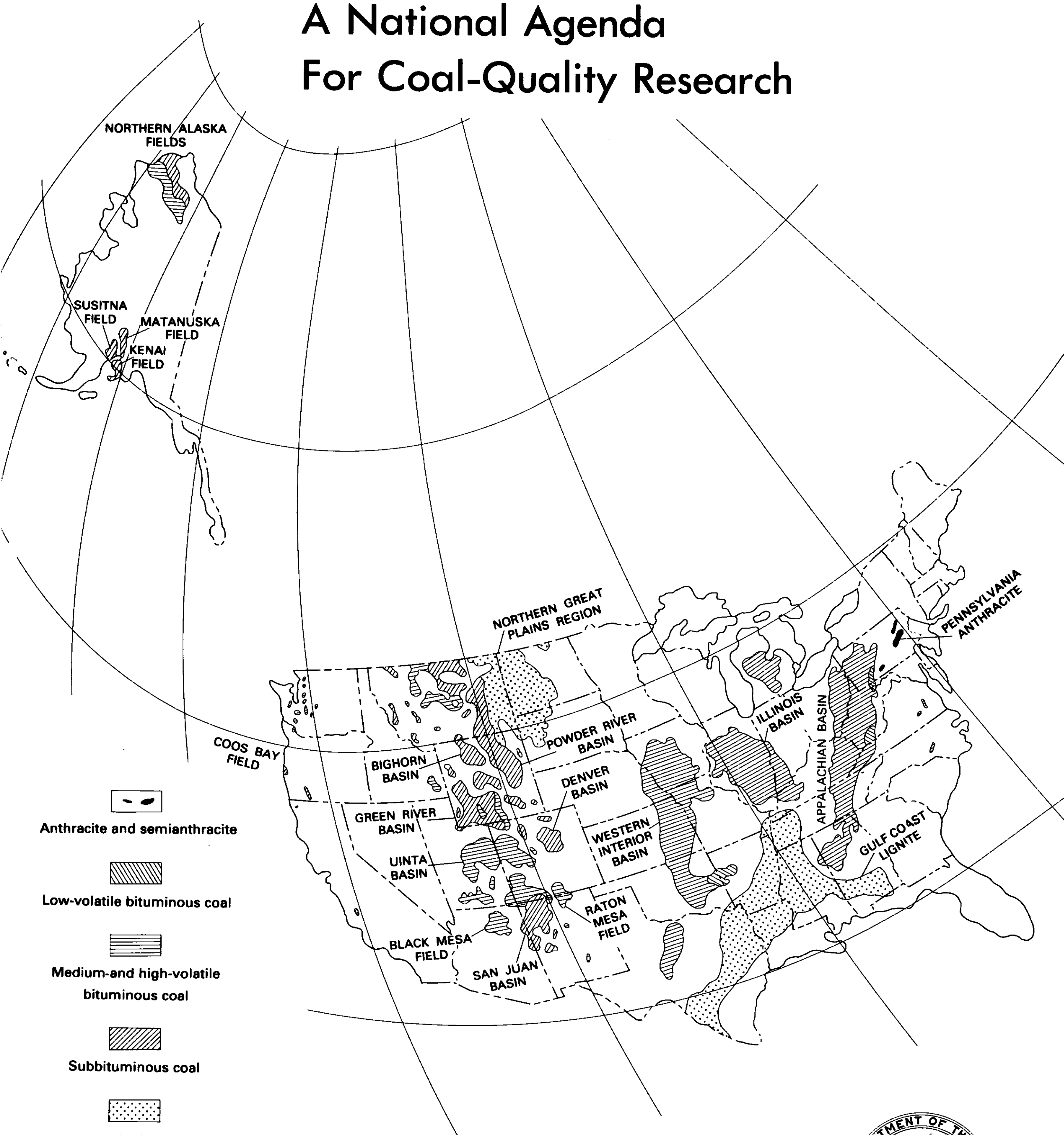
SYMPOSIUM PROCEEDINGS:

A National Agenda For Coal-Quality Research



Symposium convened by the United States Geological Survey

U.S. DEPARTMENT OF THE INTERIOR
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SYMPOSIUM PROCEEDINGS:
A National Agenda For Coal-Quality Research April 9–11, 1985

Edited by Susan Garbini *and* Stanley P. Schweinfurth

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PREFACE

On April 9 to 11, 1985, the U.S. Geological Survey, along with cosponsors, the Association of American State Geologists, the U.S. Department of Energy, the Electric Power Research Institute, and the U.S. Environmental Protection Agency, convened a symposium on coal quality at the headquarters of the U.S. Geological Survey in Reston, Virginia.

The purpose of this symposium was to provide a forum for the exchange of information pertaining to coal-quality research and related activities. The goals for the meeting were to consider data analysis and research priorities and to recommend an agenda for research on coal quality to enable the Nation to take the fullest possible advantage of its vast inventory of coal resources. The approach at the symposium was to discuss all aspects of coal-quality research from the characterization of coal in the ground to the coal-research needs of the struggling synfuels industry. The framework for these discussions consisted of a day of overview talks, a day of workshops, and a half day of workshop reports.

The cosponsors of the symposium were enlisted to provide the widest possible coverage and the best possible balance to the meeting. We wish to express our gratitude to them for their generous and enthusiastic support and most particularly to the members of the coordinating committee of the symposium for their help in planning the meeting and organizing the panels for the workshops. These are: Donald L. Koch, Association of American State Geologists (AASG), Paul C. Scott, U.S. Department of Energy (DOE), Jeremy Platt, Electric Power Research Institute (EPRI), George Rey, U.S. Environmental Protection Agency (EPA), and Jack A. Medlin, U.S. Geological Survey (USGS). In addition to these, many other individuals from the cosponsoring organizations participated directly in the symposium as speakers and panelists and an even larger number participated actively in the proceedings from the floor. We also wish to thank the many individuals from private operating and consulting firms who participated as speakers and panelists and as active audience.

Susan Garbini Stanley P. Schweinfurth

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INTRODUCTION

The U.S. Geological Survey (USGS) has been doing research on coal quality for almost a century (Averitt and Lopez, 1972). Most of the work of the USGS regarding coal went into efforts to assess the quantity of coal in the United States, not the quality. Proximate and ultimate analyses were published with the resource numbers, but only a limited amount of research went into understanding the origin of coal, the chemistry of coal, or whether it might be possible to predict coal quality downdip and away from existing information. Because of the complexities of modern industrial society, the USGS and cosponsors have become increasingly aware of a growing need to understand coal from the standpoint of quality as well as quantity. Consequently, we have been expanding our research in coal quality over the past 10 years and are planning further increases. The perception that greater attention needs to be given to coal quality led to the convening of a symposium on this topic in April 1985.

The opportunity to discuss coal-quality research in a holistic sense apparently struck a responsive chord in the coal community. The workshop panels were quickly oversubscribed, and the participants--approximately 250--came from all corners of the coal community and even included staff members of congressional committees. Judging from the extent to which the objectives and goals of the symposium were achieved, we may consider it a success.

SYMPOSIUM FORMAT

The first day of the meeting consisted of a keynote speech and overview talks on the needs and applications of coal-quality research from the perspectives of the cosponsors and coal-mining and coal-utilization industries.

On the second day of the symposium, five workshops met concurrently. Each of the five workshops was given a separate topic area to discuss with the understanding that there would probably be some overlap among the five topics. Each workshop was led by a panel of experts on the topic consisting of two coleaders and five or six working members. The structure of the workshop included active audience participation. Each workshop was to address its topic from the point of view of current research on coal quality within the topic area and recommendations for research and related activities that need to be done. Workshop topics were as follows:

I - Characterization of the quality of coal resources and reserves.

II - Coal utilization and procurement

III - Coal mining and coal cleaning

IV - Environmental issues

V - Advanced technologies for coal utilization

On the final half-day, reports were presented on individual workshop proceedings and their recommendations for coal-quality research agendas and related activities.

The following Proceedings present the written versions of the keynote and overview speakers, together with summaries and lists of workshop discussions and recommendations. Appendices include additional information relevant to the meeting.

REFERENCE

Averitt, Paul, and Lopez, Lorreda, 1972, Bibliography and index of U.S. Geological Survey publications relating to coal, 1882-1970: U.S. Geological Survey Bulletin 1377, 73 p.

PART I. OVERVIEW

PERSPECTIVES ON U.S. COAL INDUSTRY DEVELOPMENT

by

Richard L. Gordon
The Pennsylvania State University

Discussion of coal is habitually marred by rhetorical excesses. The usual inability to maintain a proper perspective on complex issues is at least as prevalent in coal discussions as in other policy debates. Attitudes about coal have fluctuated widely in the past decade. We started with suggestions that explosive growth would occur. When growth proved merely steady and regionally disparate, disappointment set in. Today, it appears that the proper view of coal has become better recognized.

Typically, viewers have deplored the present but envision a glowing future. Concerns rarely arise about how, other than by a miracle, the situation will change so abruptly. The realistic view rejects both these attitudes. The present is much better than industry grumblings and press stories would suggest. In particular, the prevailing situation includes the basis for sustaining industry growth. The result will be a future less bright than enthusiasts hoped for. However, this will occur because the dreams were based on defective logic. No golden opportunities will have been missed.

This discussion begins with a survey of coal-market conditions. I next turn to questions of the critical regulatory influences on the situation. Then, I treat the role of scientific and technical developments, such as are being considered at this conference, in affecting the coal industry.

Coal Resources Versus Coal Economics

In dealing with coal, a critical problem is avoiding being overly impressed by the ample amounts of known coal resources. Writers on coal insist on proclaiming that it is the most abundant fuel. Such statements are irrelevancies. For many reasons, the comparative known or estimated physical endowments of fuels are not useful indicators of prospects. The basic problem is the ultimate translation of minerals in the ground into reserves and this is an economic, not a technical, process. Neglect of this point has led many, including even some distinguished economists, into serious error.

The practical concern is the economic availability of different fuels over our planning horizon. One particularly obvious objection to considering only physical endowments is that it will take many decades before we can consume all the oil, gas, coal, and uranium that is known to exist. It would be infeasible and unwise to devote significant efforts now to meet problems that might arise several generations from now. We need the time to learn more about what will really happen.

The relevant consideration is the optimum pattern of fuel use in the next decade or two. Experience has shown that perceived relative physical endowment is, for good reason, a poor criterion for choice. At the very least, the perceptions could be very wrong. More critically, the radical differences in the economics of using different fuels must be considered when appraising immediate prospects. The economically sensible route is the one we have been and will be taking of stressing oil and gas use first. The costs of forcing increased saving of oil and gas for future use prove to far exceed the benefits.

Electricity-Based Growth

Because of these economic forces, the health of the coal industry in the United States and elsewhere has increasingly centered on the economic attractiveness of coal as an electric-utility fuel. Electric utilities have been the only growing market for coal (fig. 1). In most major countries belonging to the Organization for Economic Cooperation and Development (OECD), most coal consumption has been by electric utilities (figs. 2 and 3). The U.S. coal industry demonstrates a particularly high level of dependence on the electric-utility market--85 percent of domestic tonnage coal use in 1983 (fig. 4 for the United States and figs. 5-10 for other countries). On a Btu basis, the share was 83 percent; preliminary 1984 Btu figures set the share at 82 percent.

This U.S. growth has actually outpaced expectations of the middle 1970's for U.S. electric-utility coal use. In 1985, we should use about 700 million short tons or 15 quadrillion Btu of coal for electricity generation. In contrast, seven of the eight 1974 Project Independence scenarios called for much lower 1985 consumption in that market. The eight projections range from 417 to 769 million short tons. Four cases were between 417 and 492 million; two at 620 and 630 million; another at 664 million. In Btu, the range was 9 to 16 quadrillion.

Overestimates of electricity output growth were more than compensated for by failure of nuclear power to develop as strongly as expected. The 1985 Energy Information Administration (EIA) forecasts for electric power in 1985 project 4 quadrillion Btu of nuclear power out of total electric-utility fuel use of 27

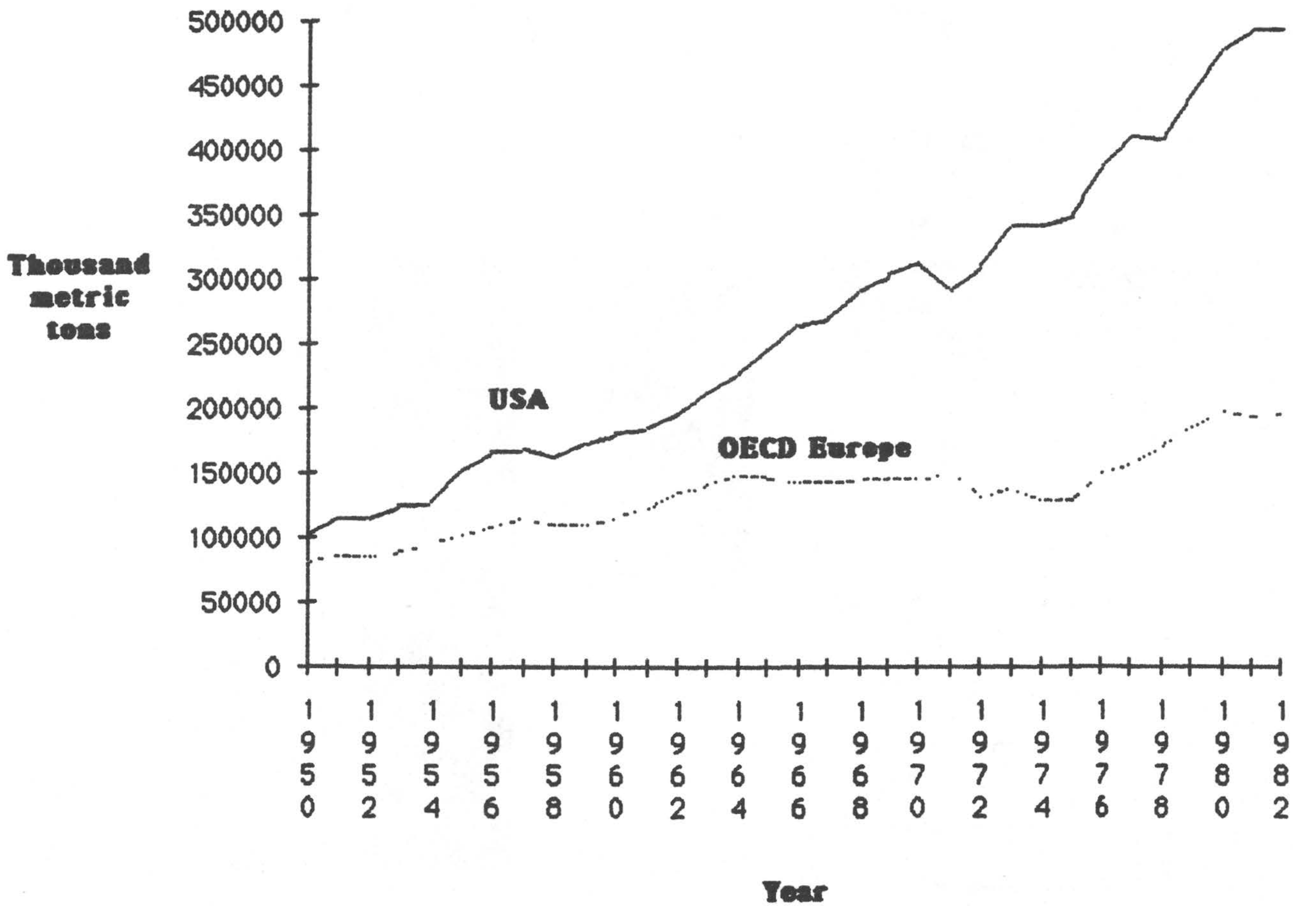

Figure 1. Electric-Utility Coal Consumption.

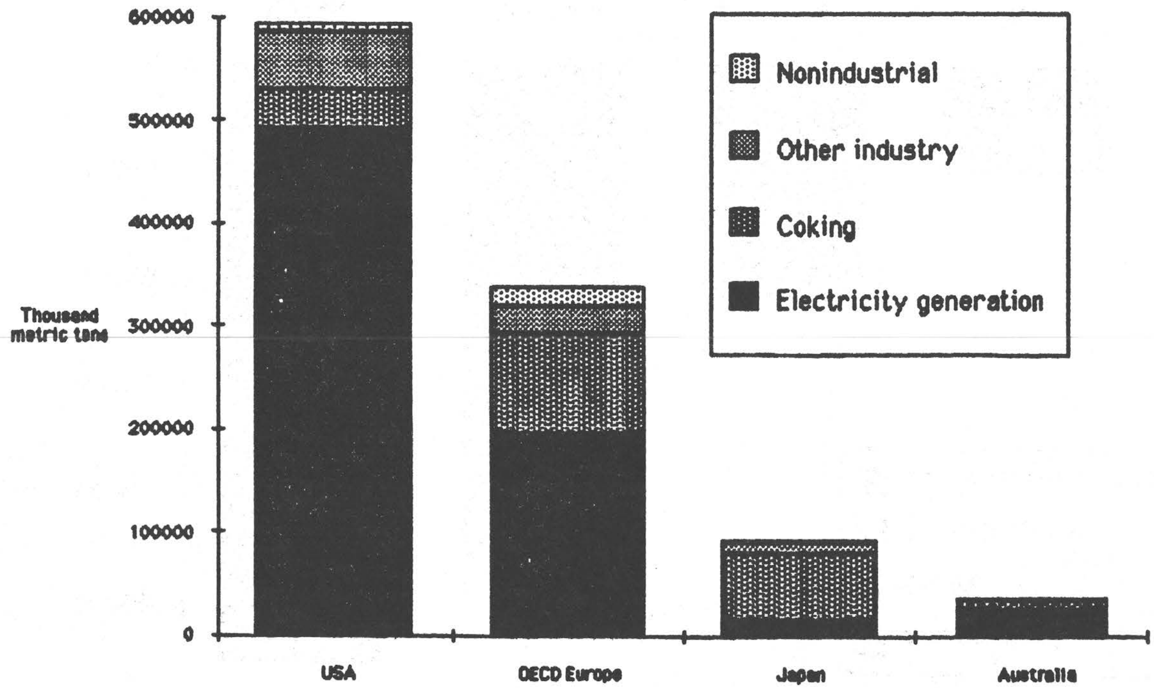

Figure 2. Coal Use by Sector, 1982.

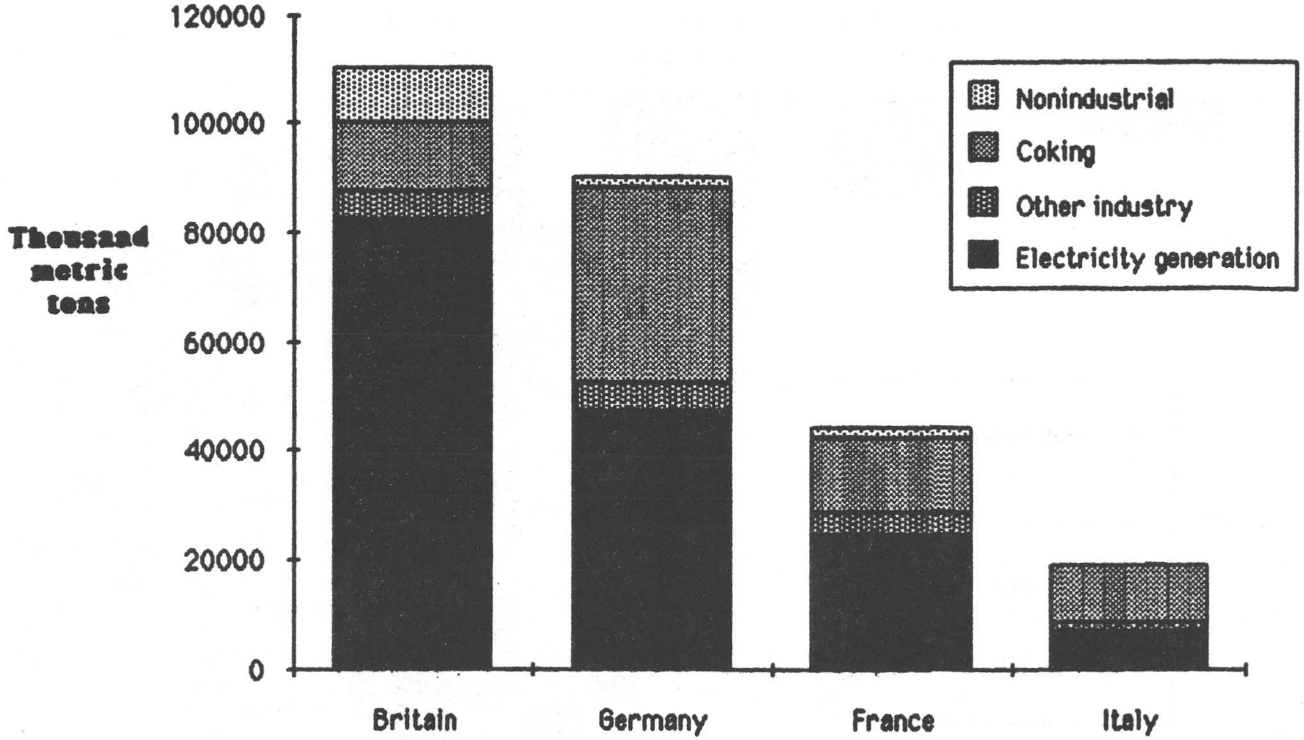

Figure 3. Coal Use in OECD Europe, 1982.

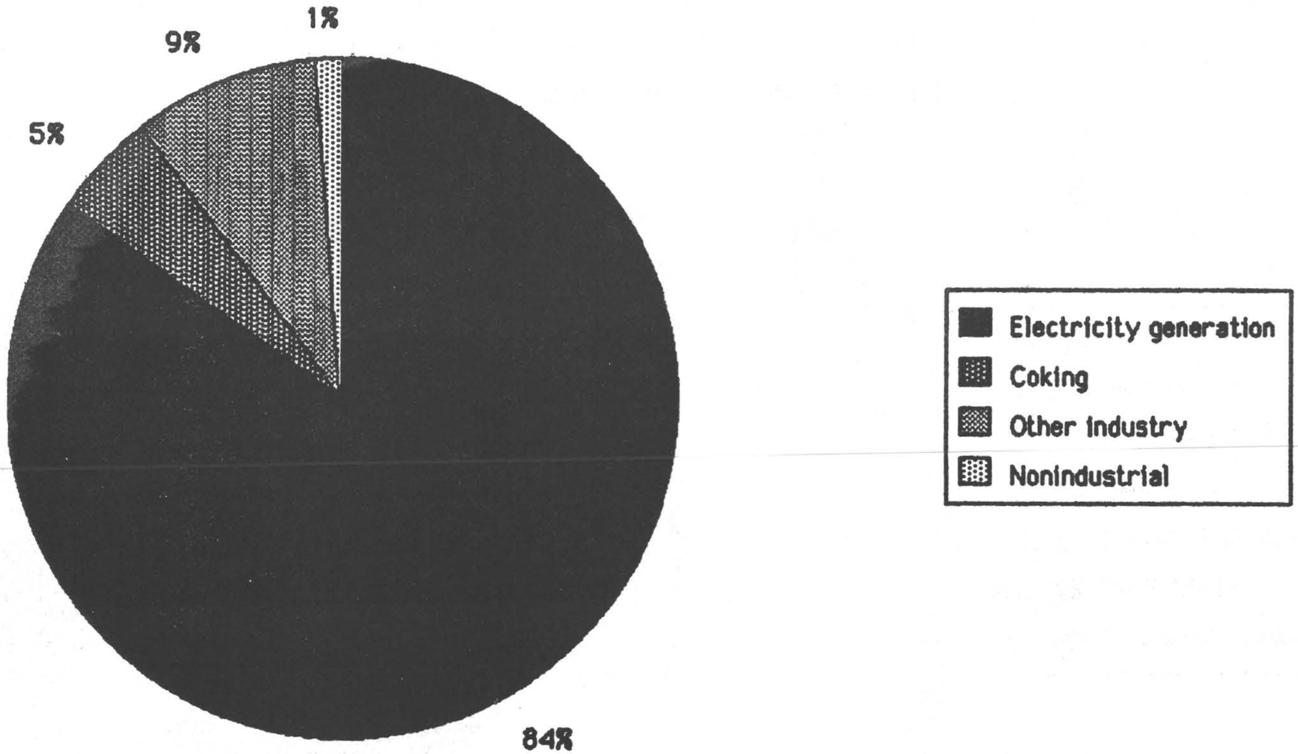

Figure 4. U.S. Coal Consumption, 1983.

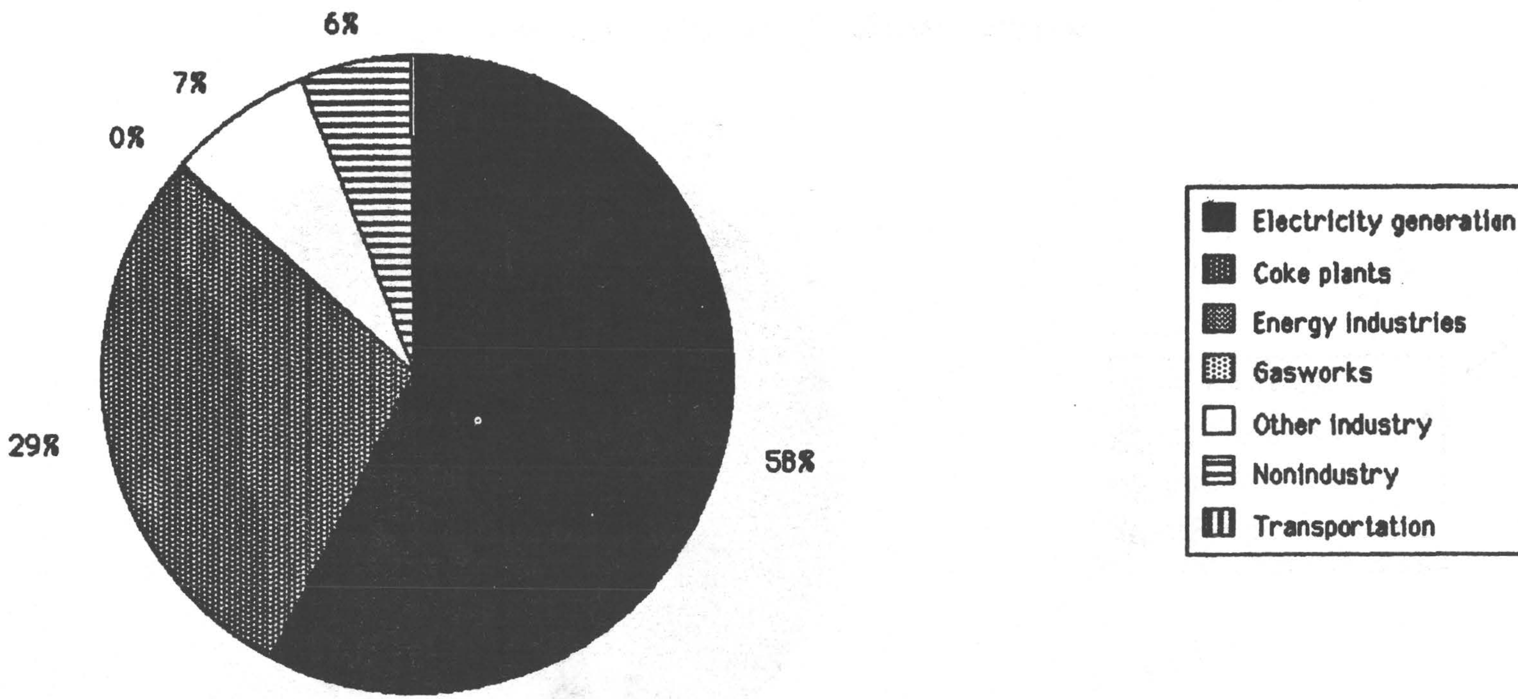

Figure 5. OECD Europe Coal Consumption,1982.

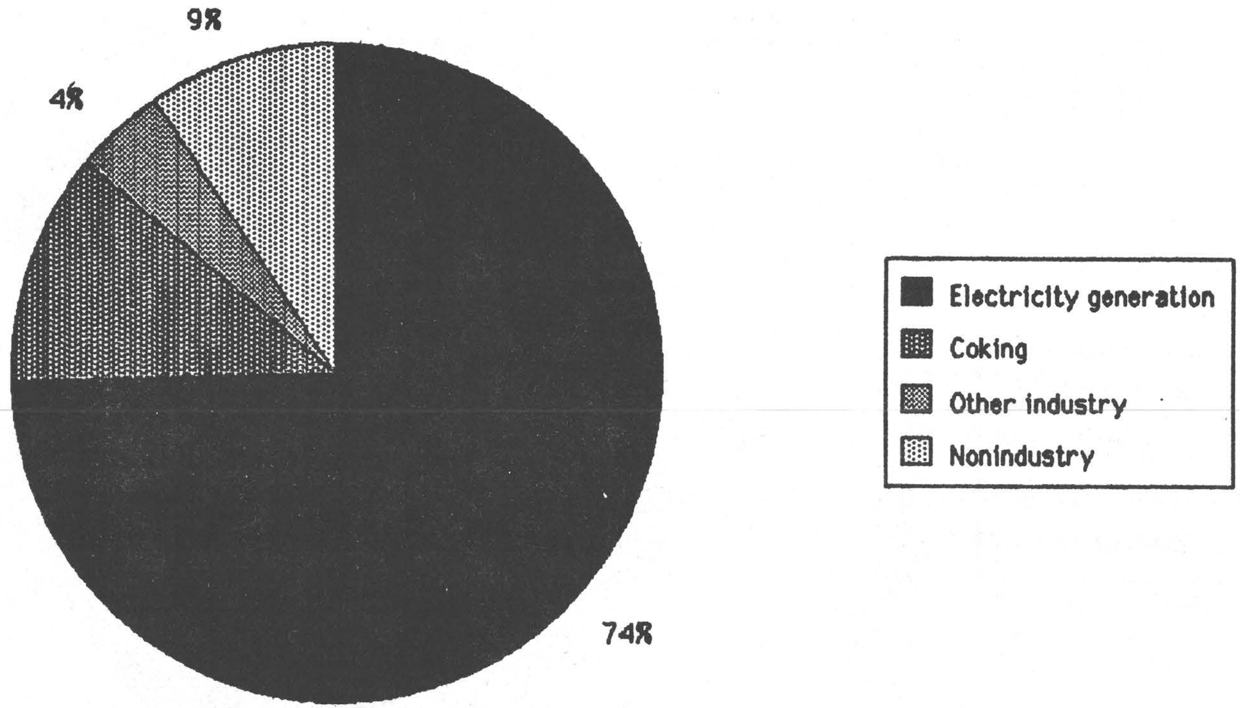

Figure 6. UK Coal Consumption,1982.

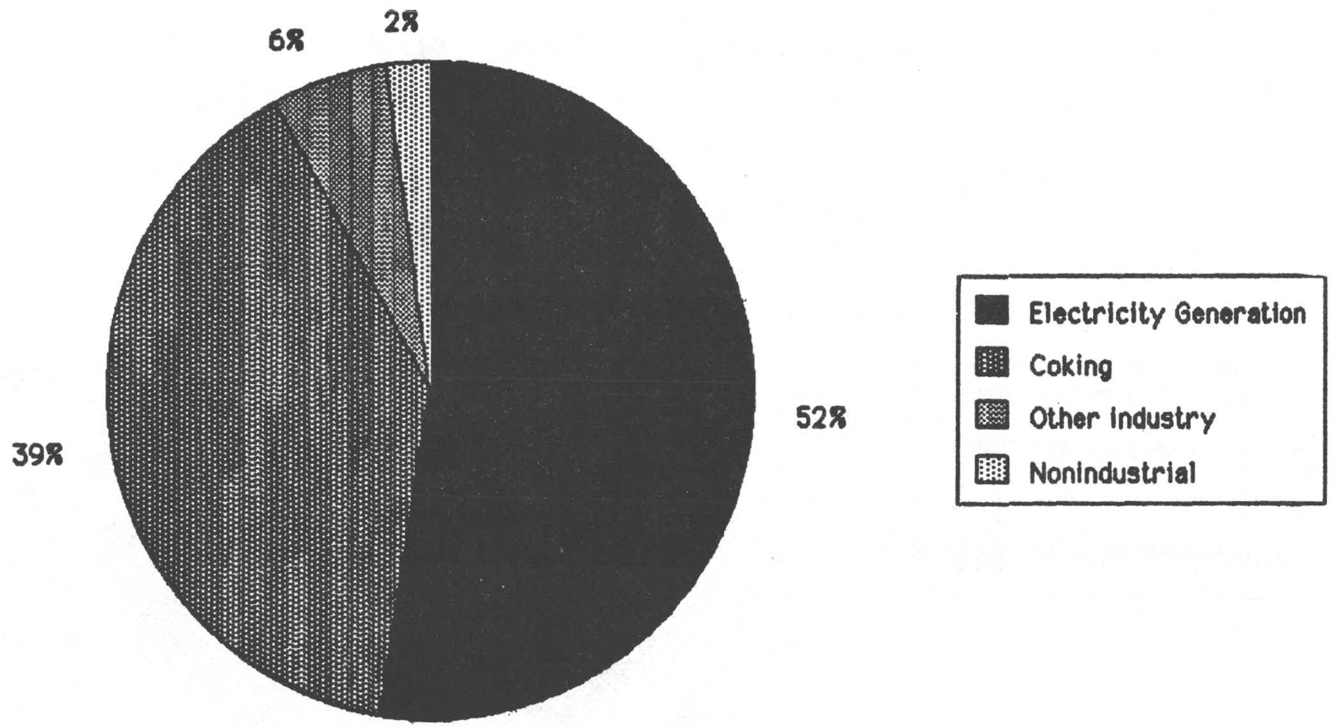

Figure 7. German Coal Consumption, 1982.

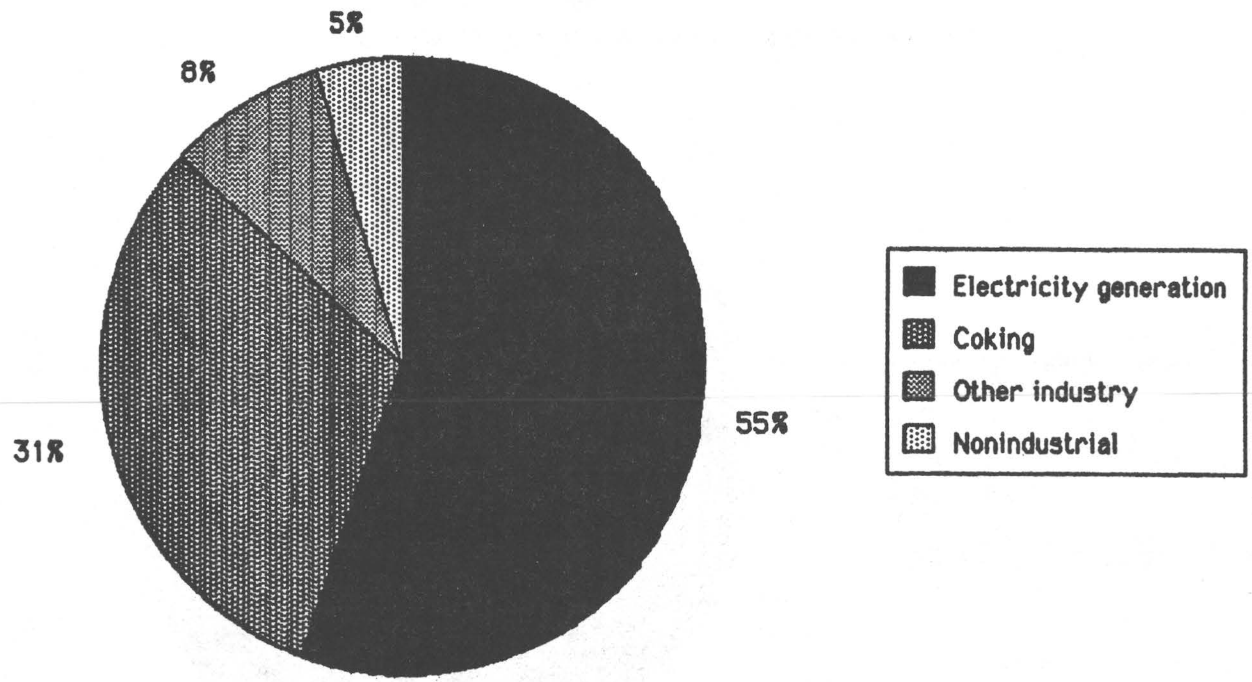

Figure 8. French Coal Consumption, 1982.

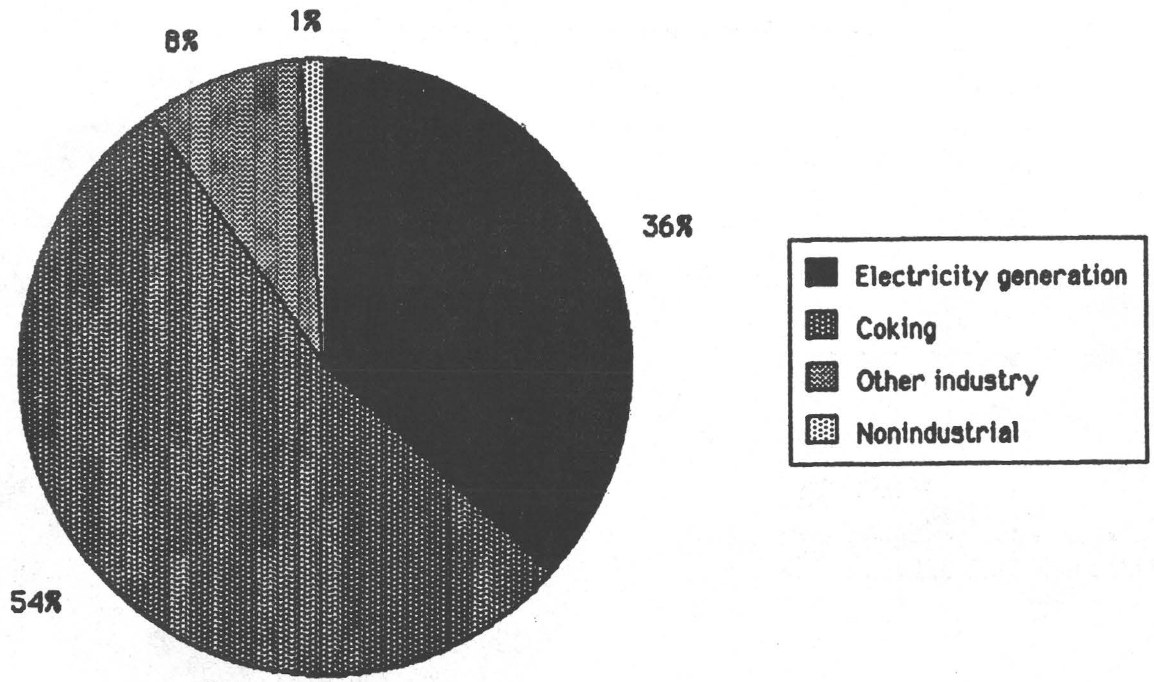

Figure 9. Italian Coal Consumption,1982.

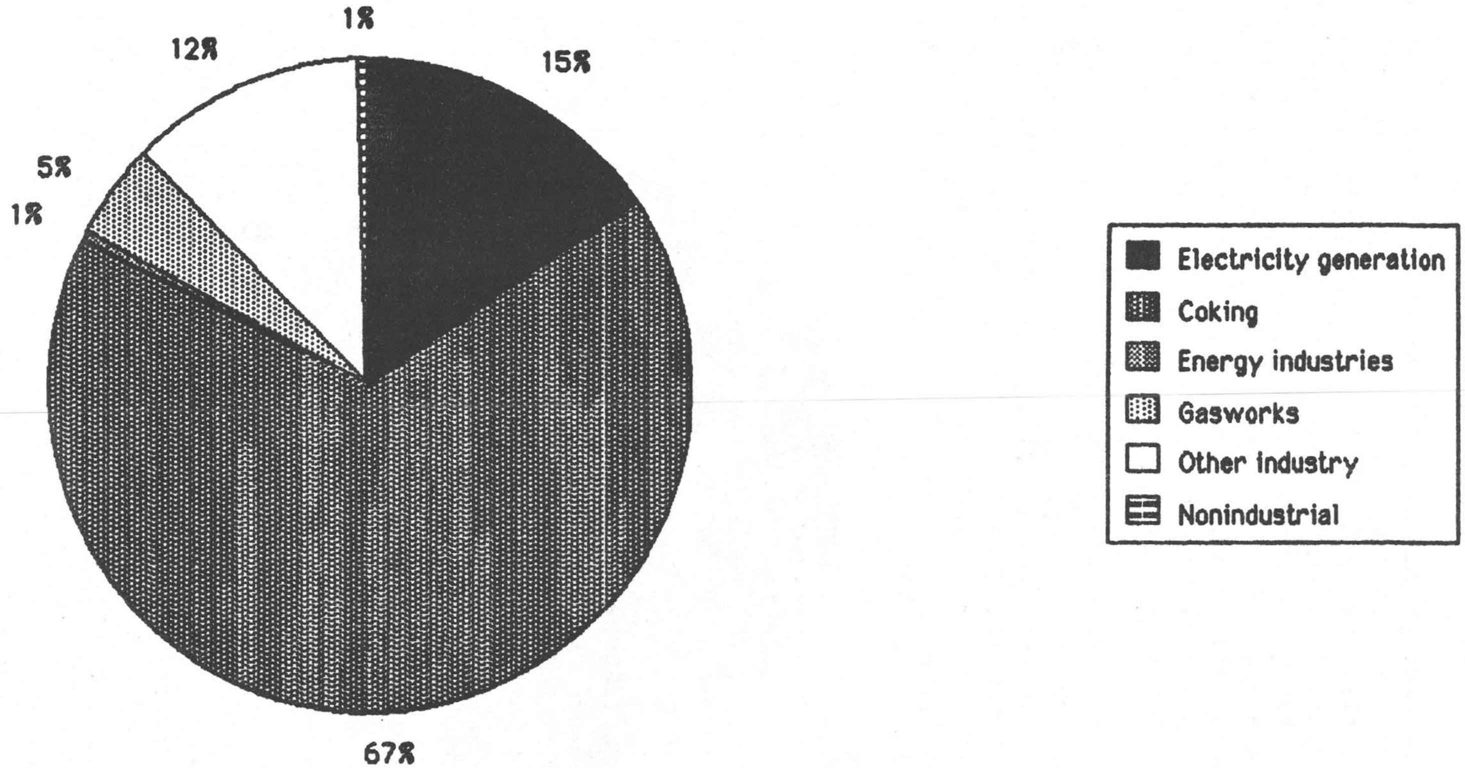

Figure 10. Japanese Coal Consumption, 1982.

quadrillion. Project Independence projected at least 12.5 quadrillion Btu of nuclear power out of a 36-41 quadrillion total. (Subsequent forecasts, however, were better about 1985 prospects in this market.)

The current prognosis for growth from EIA and Data Resources tends to call for consumption of around 800 million tons in 1990, 900 to a billion by 1995, and 1.1 to 1.2 billion by the year 2000. Energy Ventures' Coalcast service set 1995 levels 100 million tons below Data Resources which, in turn, has a forecast at the low end of the EIA range. This is a scaling back. The Department of Energy (DOE) published its first estimates of 1995 coal use in 1979 (in its annual report covering 1978). It set a range of 1.2 to 1.5 billion tons (Table 1).

Similarly, in western Europe, coal use for electricity generation has been rising for more than three decades, and growth was greater in the 1970's than in the 1960's. This growth should continue. However, because of strong commitments to nuclear power, a severe limit exists to further growth of coal consumption in western Europe and Japan. Tables 2 and 3 summarize various coal forecasts for 1990 and 2000.

As several different regional groupings are used for western Europe, data comparison is more complex than in the case of Japan. Japanese forecasts have been scaled back markedly. Reduced expectations about steel industry needs have been a major influence. Projections for 1990 coal use in electricity generation have been fairly stable, but this is not the case for the year 2000.

The main distinction in western Europe is between the full region and the group of leading countries belonging to the European Communities. (The definition of the full region used by the United Nations includes Yugoslavia, which is not a member of the OECD, a major source of energy studies. The OECD operates an International Energy Agency [IEA] which France, Iceland, and Finland refused to join.) Again, in forecasts of Europe, scaled-back expectations are evident. Coking use is expected to decline. In the European Economic Community (EEC), electric power coal use might easily have little or no increase by the year 2000. Non-EEC countries, such as Spain, Portugal, Turkey, and Sweden, might increase coal use more.

The expansion in electric-utility coal use has sufficed to permit an increase in total U.S. consumption of coal. In contrast, total coal use in western Europe was declining through the late 1970's. By 1982, consumption was still well below post-World War II peaks. Japanese consumption, in which coking coal dominates, had a more complex pattern growth in the fifties and sixties, something of a downturn in the seventies, and a recovery in the early eighties.

Table I

Selected Forecasts of 1995 U.S. Coal Tonnages *

Million short tons

Source	Production	Exports	Electricity	Coking	Other	Synthetics	Total Use
DOE 1979A-HS/HD	2,113.9	134.0	1,509.5	98.9	292.0	77.4	1,960.3
DOE 1979B-LS/HD	2,119.5	134.0	1,301.1	97.8	331.8	250.3	1,943.7
DOE 1979C-MS/MD$23.50OIL	1,999.0	89.0	1,375.7	95.6	306.7	128.2	1,876.8
DOE 1979D-HS-LD	1,699.2	89.0	1,226.9	93.5	241.0	45.2	1,595.2
DOE 1979E--LS/LD	1,871.1	89.0	1,231.2	92.7	304.5	149.5	1,741.8
DOE 1979CLow-MS/MD$16.50OIL	1,771.0	89.0	1,271.8	96.3	258.1	52.0	1,649.6
1979CHigh MS/MD$31.50OIL	2,055.9	89.0	1,370.1	94.7	304.8	193.5	1,935.8
DOE 1979C*MS/MD$23.50OIL	1,986.0	89.0	1,377.8	95.6	291.4	128.3	1,863.5
DOE 1979C*NukeMoratortium	2,122.8	89.0	1,502.4	95.6	297.9	136.9	2,006.1
DOE 1979C High Capital Cost	1,822.8	89.0	1,206.3	95.6	304.6	123.4	1,706.3
DOE 1980 Low	1,592.0	143.0	1,055.0	80.0	268.0	50.0	1,452.0
DOE 1980 Medium	1,715.0	143.0	1,115.0	79.0	280.0	101.0	1,575.0
DOE 1980 High	1,718.0	143.0	1,136.0	79.0	258.0	105.0	1,577.0
DOE 1981 Low	1,847.0	143.0	1,160.0	77.0	257.0	208.0	1,702.0
DOE 1981 Medium	1,878.0	143.0	1,167.0	75.0	249.0	266.0	1,757.0
DOE 1981 High	1,895.0	143.0	1,160.0	74.0	235.0	298.0	1,767.0
DOE 1982 $49 Oil	1,485.9	171.0	1,037.3	85.0	168.6	24.0	1,314.5
DOE 1982 $67 Oil	1,568.5	171.0	1,034.5	82.7	192.3	88.0	1,397.5
DOE 1982 $88 Oil	1,615.5	171.0	1,019.1	79.6	205.3	140.5	1,444.5
DOE 1984 Medium Oil Price	1,191.0	116.0	916.0	52.0	93.0	7.0	1,061.0
DOE 1984 Low Oil Price	1,205.0	116.0	924.0	54.0	97.0	6.0	1,076.0
DOE 1984 High Oil Price	1,174.0	116.0	905.0	50.0	89.0	6.0	1,044.0
DOE 1985A Medium Oil	1,221.0	106.0	951.0	49.0	105.0	6.0	1,110.0
DOE 1985B Low GNP Growth	1,172.0	106.0	909.0	47.0	98.0	6.0	1,060.0
DOE 1985C High GNP Growth	1,259.0	106.0	982.0	51.0	109.0	6.0	1,148.0
DOE 1985D Low World Oil	1,234.0	106.0	961.0	49.0	107.0	6.0	1,122.0
DOE 1985E High World Oil	1,202.0	106.0	936.0	49.0	101.0	6.0	1,091.0
DRI May 1979	1,558.5	88.6	1,146.9	109.0	191.5	22.5	1,469.9
DRI June 1980	1,575.0	121.7	1,065.1	96.1	177.7	121.0	1,453.3
DRI Winter 82/83	1,389.9	192.8	959.7	64.3	136.5	28.0	1,188.4
DRI Summer 1984	1,284.2	133.4	969.8	53.6	110.9	0.4	1,134.7
DRI Winter 1984/85	1,164.4	85.4	908.2	52.6	111.1	0.3	1,071.8
Coalcast 1985	1,030.0	65.0	819.0	56.0	90.0		965.0

Notes: DOE from reports issued in years listed--from 1979 to 1982, the Annual Report to Congress; subsequently the Annual Energy Outlook
Data Resources from listed issues of its Coal Review
Coalcast: oral communication

* See Sources and Notes on the Tables

Table 2

Selected Forecasts of Coal Consumption and Output in Different Regions in 1990 *

Country	Total Output	Net Import	Total Use	Steam Output	Coking Output	Steam Imports	Coking Imports	Electric	Nuclear	Coking	Other Steam
	Million Coal Equivalent Tons										
Forecasts of EEC											
IEA Steam Coal 78	274.0	114.1	388.1	195.2	78.8	93.8	20.3	232.8	192.6	99.1	56.2
UN ECE 1983	285.9	133.7	419.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA Coal Information	248.7	101.6	350.7	183.8	65.0	73.5	28.1	212.6	185.5	93.1	45.0
EEC 1984	254.8	81.7	336.8	N/A	N/A	N/A	N/A	206.6	196.4	N/A	N/A
EEC 1985	250.0	95.7	345.7	N/A	N/A	N/A	N/A	228.6	207.1	N/A	N/A
Saarberg 1985	190.0	91.0	281.0	N/A	N/A	N/A	N/A	171.0	214.0	62.0	48.0
Forecasts of OECD Europe											
IEA Steam Coal 78	332.2	152.9	485.1	246.5	85.7	111.9	41.0	270.6	241.5	126.7	87.8
IEA 1982 World Energy	360.0	189.0	549.0	N/A	N/A	N/A	N/A	297.0	294.3	119.0	133.0
UN ECE 1983	399.3	193.2	592.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA Coal Information	334.7	135.6	470.4	264.2	70.4	94.1	41.5	261.0	230.8	111.9	97.5
Calarco 1985	499.6	133.6	633.2	453.9	45.7	95.5	38.1	468.8	0.0	83.9	80.2
Forecasts of Japan											
IEA Steam Coal 78	19.0	123.0	142.0	8.9	10.1	33.1	89.9	32.1	65.1	100.0	9.9
World Coal Case A	18.0	101.0	119.0	11.0	7.0	24.0	77.0	30.0	92.0	84.0	5.0
World Coal Case B	18.0	112.0	137.0	11.0	7.0	33.0	79.0	37.0	98.0	86.0	14.0
IEA 81 Coal Policy	18.9	140.9	159.7	12.3	6.6	56.6	84.3	50.6	128.6	90.9	68.9
IEA 1982 World Energy	18.0	139.0	157.0	N/A	N/A	N/A	N/A	37.0	0.0	101.0	19.0
IEA Policy 83	15.7	88.6	102.9	10.0	5.7	N/A	N/A	38.6	N/A	77.1	-11.4
IEA Coal Information	15.0	88.0	103.0	10.0	5.0	22.0	66.0	38.7	66.6	71.0	-6.7
Cararco 1985	18.4	89.9	108.3	15.5	2.9	25.9	64.0	27.8	N/A	66.9	13.6
Forecasts of North America											
IEA Steam Coal 78	1,063.3	-88.0	975.3	883.7	179.6	-10.0	-78.0	776.7	326.7	101.6	97.0
World Coal Case A	850.0	-82.0	768.0	692.0	158.0	-25.0	-57.0	570.0	307.0	101.0	97.0
World Coal Case B	1,152.0	-125.0	1,027.0	986.0	166.0	-60.0	-65.0	788.0	373.0	101.0	138.0
IEA 81 Coal Policy	987.0	-127.7	859.3	814.3	149.9	-54.7	-73.0	597.6	281.6	76.9	766.7
UN ECE 1983	986.9	-127.7	859.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA 1982 World Energy	987.0	-127.0	860.0	N/A	N/A	N/A	N/A	597.0	251.4	77.0	186.0
IEA 83 Coal Policy	992.9	-132.9	861.4	845.7	147.1	N/A	N/A	618.6	N/A	67.1	174.3
IEA Coal Information	993.3	-132.4	860.9	846.7	146.6	-53.4	-79.0	618.6	270.0	67.6	174.7
Calarco 1985	967.4	-89.8	877.6	856.4	111.0	-21.4	-68.4	747.8	0.0	42.6	83.7
Forecasts of Australia											
IEA Steam Coal 78	150.9	-90.0	60.9	83.2	67.7	-36.0	-54.0	44.0	5.0	1[illegible].7	3.2
World Coal Case A	195.0	-105.0	90.2	115.0	80.0	-37.0	-68.0	64.2	0.0	12.2	13.8
World Coal Case B	195.0	-105.0	90.2	115.0	80.0	-37.0	-68.0	64.2	0.0	12.2	13.8
IEA 81 Coal Policy	188.0	-111.6	76.3	112.3	72.1	-55.3	-56.3	52.4	0.0	15.9	56.9
UN ECE 1983	205.0	110.0	95.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA 1982 World Energy	188.0	-112.0	76.0	N/A	N/A	N/A	N/A	53.0	0.0	16.0	7.0
IEA 83 Coal Policy	148.6	-85.7	62.9	92.9	57.1	N/A	N/A	44.3	N/A	14.3	7.1
IEA Coal Information	149.1	-86.0	63.1	92.0	57.1	-42.8	-43.2	43.7	0.0	13.9	5.5
Calarco 1985	190.3	-88.1	102.2	132.6	57.7	-38.2	-49.9	82.3	0.0	7.8	12.1

* See Sources and Notes on the Tables   N/A = Not Available

Table 3

Selected Forecasts of Coal Consumption and Output in Different Regions in 2000 *

Country	Total Output	Net Import	Use Total	Steam Output	Coking Output	Steam Imports	Coking Imports	Electric	Nuclear	Coking	Other Steam
			Million Coal Equivalent Tons								
Forecasts of EEC											
IEA Steam Coal 78	292.4	248.9	541.3	211.7	80.7	219.3	29.6	355.8	413.0	110.3	75.2
UN ECE 83	302.1	207.3	509.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA Coal Information	248.3	162.3	410.7	184.0	64.3	136.7	25.6	252.2	278.3	89.9	68.6
EEC 1985	245.7	131.4	377.1	N/A	N/A	N/A	N/A	254.3	307.1	N/A	N/A
Saarberg 1985	175.0	137.0	312.0	N/A	N/A	N/A	N/A	198.0	314.0	53.0	61.0
Forecasts of OECD Europe											
IEA Steam Coal 78	364.0	310.7	674.7	276.3	87.7	254.2	56.5	419.0	529.5	144.2	111.5
World Coal Case A	375.0	179.3	555.5	296.0	79.0	143.8	36.7	313.2	N/A	115.7	125.7
World Coal Case B	426.6	386.3	812.9	343.0	83.6	332.5	53.8	431.4	N/A	136.8	243.8
IEA 82 World Energy	379.0	410.0	789.0	0.0	0.0	0.0	0.0	450.0	422.9	147.0	192.0
UN ECE 83	409.6	281.9	691.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA Coal Information	354.0	222.2	574.8	284.0	70.0	178.1	44.0	333.9	337.1	114.0	126.9
Calarco 1985	506.7	166.1	672.8	469.8	36.9	128.8	37.3	509.6	N/A	74.2	88.6
Forecasts of Japan											
IEA Steam Coal 78	19.0	180.9	199.9	9.3	9.7	76.5	104.4	75.7	147.1	114.1	10.1
World Coal Case A	18.0	158.0	224.0	11.0	7.0	73.0	85.0	72.0	199.0	92.0	60.0
World Coal Case B	18.0	132.0	150.0	11.0	7.0	53.0	79.0	57.0	188.0	86.0	7.0
IEA Coal Policy 83	15.7	140.0	155.7	10.0	5.7	N/A	N/A	67.1	N/A	84.3	4.3
IEA Coal Information	15.9	140.0	155.9	10.6	5.3	70.0	70.0	67.6	129.6	75.3	13.0
Cararco 1985	17.6	111.3	128.8	16.0	1.6	49.7	61.6	51.0	N/A	63.1	14.7
Forecasts of North America											
IEA Steam Coal 78	1,252.0	-143.0	1,109.0	1,056.8	195.2	-50.0	-93.0	845.0	632.8	102.2	161.8
World Coal Case A	1,281.0	-124.0	1,157.0	1,098.0	183.0	-56.0	-68.0	850.0	345.0	115.0	192.0
World Coal Case B	2,042.0	-221.0	1,821.0	1,839.0	203.0	-143.0	-78.0	1,235.0	688.0	125.0	461.0
UN ECE 83	1,465.7	-211.4	1,254.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
IEA 82 World Energy	1,693.0	-296.0	1,397.0	N/A	N/A	N/A	N/A	1,036.0	335.7	96.0	265.0
IEA 83 Coal Policy	1,371.4	-225.7	1,145.7	1,198.6	172.9	N/A	N/A	838.6	N/A	75.7	231.4
IEA Coal Information	1,372.0	-225.7	1,146.3	1,198.7	173.3	-128.2	-97.6	837.9	377.0	75.7	232.7
Calarco 1985	1,223.7	-110.1	1,113.7	1,115.6	108.1	-37.9	-72.2	977.1	N/A	36.0	97.0
Forecasts of Australia											
IEA Steam Coal 78	285.1	-195.0	90.1	192.8	92.3	-120.0	-75.0	69.7	10.0	17.3	3.1
World Coal Case A	18.0	132.0	150.0	11.0	7.0	53.0	79.0	57.0	188.0	86.0	7.0
World Coal Case B	326.0	-160.0	165.4	224.0	102.0	-75.0	-85.0	107.3	0.0	16.8	41.3
UN ECE 83	300.0	-160.0	140.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IEA 83 Coal Policy	242.9	-154.3	88.6	171.4	71.4	N/A	N/A	67.1	N/A	21.4	2.9
IEA Coal Information	242.9	-154.5	88.4	171.4	71.4	-104.5	-50.0	66.5	0.0	21.4	0.5
Calarco 1985	239.3	-101.4	137.9	178.9	60.4	-49.0	-52.4	114.5	N/A	8.0	15.3

* See Sources and Notes on the Tables   N/A = Not available

Malaise about coal, then, is discontent with this situation. The coal industry naturally would like more markets and a better situation in the markets it serves. Here in the United States, the primary concerns about extant markets relate to the slower growth of electricity generation and the resistance of regulators to allow creation of new capacity. Regions producing high-sulfur coal (particularly the Illinois basin and Ohio) are worried about present and proposed regulations limiting sulfur emissions. Those parts of the coal industry, such as Pennsylvania and parts of West Virginia, that were major suppliers to the steel industry are upset by the collapse of the U.S. market for coking coal. Coking, the only market in which coal has a technological advantage, has proven one in which demand has shifted from stagnation to decline.

Because of what I consider unfortunate developments, the threat of nuclear power to coal in the U.S. market is limited to the impacts of such plans from the early 1970's that will ultimately be realized in the next few years. However, much of the rest of the world has chosen to continue nuclear development. Nuclear power expansion deprives the coal industry of a sales rise.

Weaknesses in Other Markets

Beyond these difficulties is the failure of other industrial markets or synthetic fuels markets to develop as forecast. The synfuels situation is less surprising. The case for synfuels was based on dubious projections about oil prices. It was feared that such prices would rise continually and that it would become economic to develop oil shale and various synthetics from coal to compete with high-priced oil. The primary failing of such analyses was an excessive pessimism about oil. In addition, synthetic fuel production started to appear far more expensive than its advocates initially claimed.

The experience with other industrial markets is trickier. A standard forecast for over a decade has been for coal to absorb much of the growth in industrial fuel use. The 1974 Project Independence scenarios call for total industrial coal use (including coking) to hit 215-230 million tons by 1985. Numerous armchair calculations were published purporting to prove that coal was the cheapest fuel source for new boilers. (The maturity of fluidized bed reactor technology is creating some optimism that the problem is close to solution. This remains to be seen.)

Actual consumption through 1983 was stagnant in the "other industry" portion of the market. Sales never returned to 1973 levels (fig. 11). With sales of more than 70 million tons in 1984, we saw the first signs of a comeback. Current 9 month figures are at an annual rate of 72 million tons. The Energy Information Administration's forecasts, issued in early 1985, set

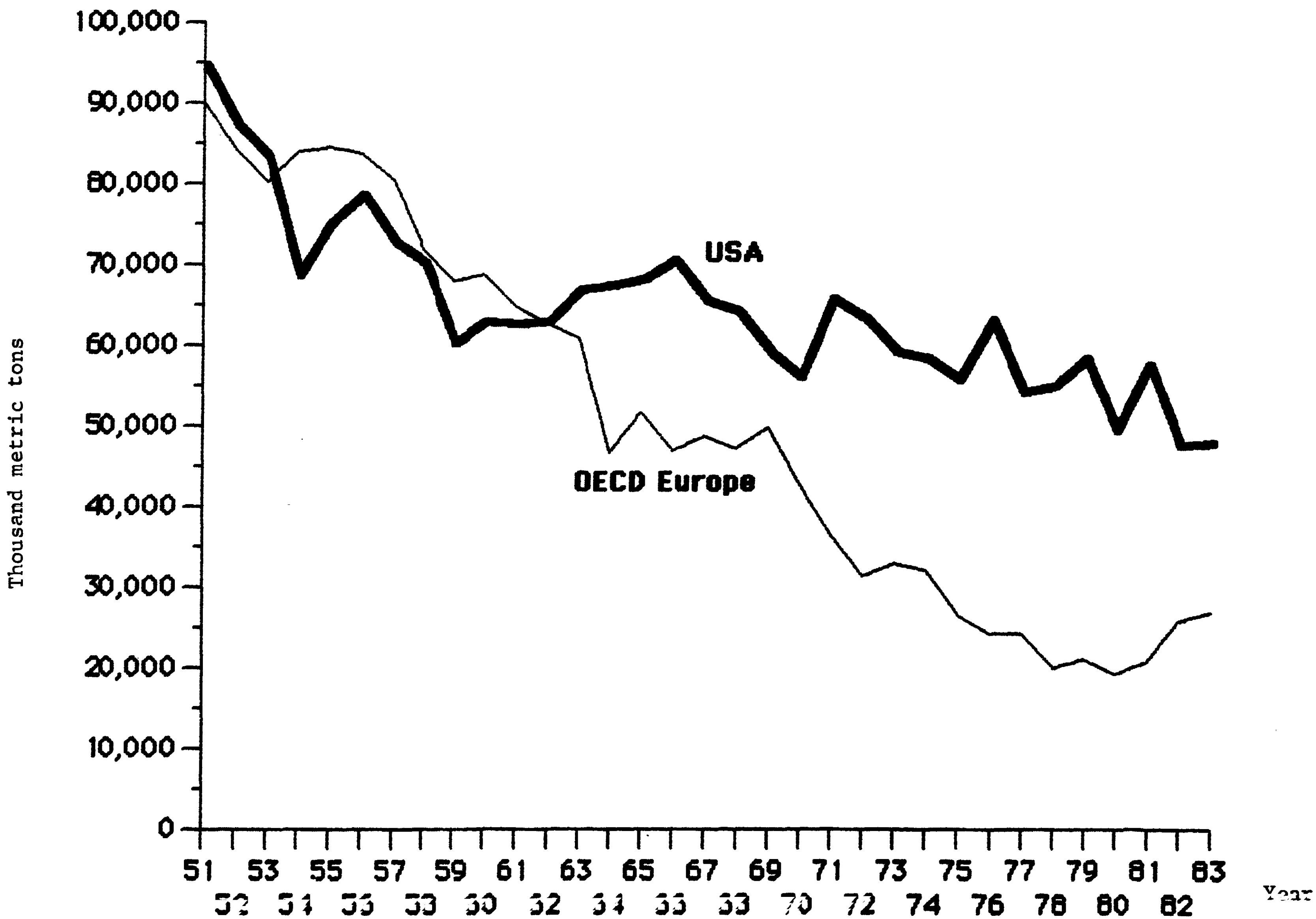

Figure 11. Industrial Coal Consumption in the USA and OECD Europe.

the 1985 levels for total industry coal use at 130 million (58 coking and 72 other).

Similarly, in neither western Europe nor Japan has there been a major shift to coal in other industrial uses. Japan has raised coal use for this purpose from only slightly more than a million metric tons in 1973 to about 11 million in 1982. The long decline in European industrial coal consumption did not end until 1979. By 1982, consumption was still below the levels of 1974. Coking-coal demand has tended to collapse (fig. 12).

The Underlying Forces

The central consideration in all appraisals of coal is the amount of coal that can be produced at costs significantly below the prevailing prices of oil and gas. No one would use coal unless the delivered price were below the delivered price of oil. Every coal user endures extra nonfuel costs in receiving, storing, and burning coal. These costs involve both a higher investment and greater nonfuel operating costs.

The extent of coal markets depends upon the interaction of user size and location. Location is critical for the usual reason that it greatly affects transportation costs. Transportation, in turn, is a major influence on costs. Thus, those with access to coal that is cheaper to mine and transport and farther from sources of oil and gas are more likely to use coal.

User size is critical in that the disadvantage of using coal can be materially reduced with large-scale burning. The most obvious advantages are the ability to receive coal in trainload (or, internationally, in large shipload) lots and the lower unit costs of large-scale pollution control equipment and its operation. The advantage of large-scale use is lower unit nonfuel costs at almost every stage of the coal-consumption process.

As far as the relative importance of size and location, experience has been that coal sales have gained far more from selling to electric utilities more distant from coal mines than from selling to other types of users nearer the mines. The available evidence suggests that the scale effect has been both increasing in importance and of greater impact than location in affecting coal use. On the first score, the two considerations already stressed seem the critical forces for increasing the advantage of large scale employment of coal. Bulk shipping has become an increasingly important influence. The sixties saw the rise of unit train rates in the United States; the seventies saw the rise of ports in South Africa and Australia to handle larger colliers.

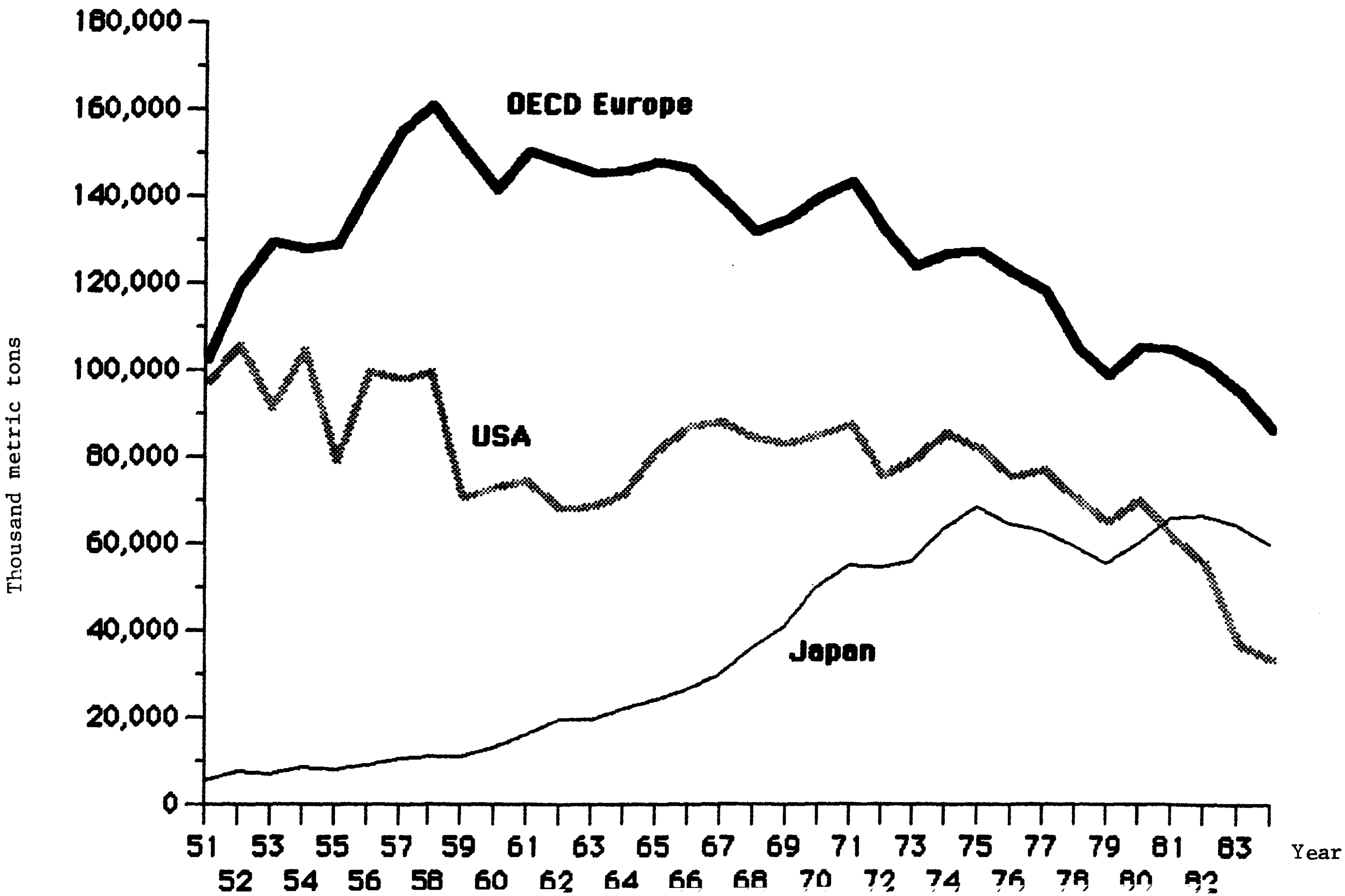

Figure 12. Coking-Coal Consumption in OECD Europe, the USA, and Japan.

Air-pollution regulation since the 1977 move to a best available control technology (BACT) approach has also significantly increased the advantage of large-scale use. Not only are the unit costs of constructing pollution-control devices lower for large-scale users, but important economies of scale arise in operation. The close controls and frequent cleanings required to keep stack gas scrubbers operational are less burdensome for large operations.

I suspect that inadequate appreciation of these points is the source of the many expressions of surprise over the lack of coal conversion by nonutility boilers. The forecasts alluded to before seem to underestimate the magnitude of the nonfuel costs of fuel use at levels well below those of large power plants, as well as overestimating the price of oil. The converse of this argument is that in a large part of the world, coal, at least from the low-cost suppliers, is a cheaper fuel than oil and gas for new electric power plants. As noted, a critical further question is the comparative economics of coal and nuclear power.

The regulatory uncertainties in the United States have guaranteed that no more nuclear plants will be ordered in the foreseeable future. Nuclear regulation has the dubious reputation of being universally damned as both inordinately slow and expensive and incapable after all that of ensuring nuclear safety. The situation is aggravated by the reluctance of public utility commissions to allow new investments in facilities. The only open question is whether the death would have occurred even with different regulation.

The experience abroad strongly indicates that the intrinsic economics do make nuclear power an attractive option. The French, Germans, and Japanese, using U.S.-developed technologies, have proceeded with extensive nuclear developments. The one major country that has faltered is Britain, which insisted on developing its own technology. To be sure, there are alternative explanations. Most of these countries have less access to low cost coal than does the United States. However, Ontario is as well placed to receive U.S. coal as many parts of the United States, and Ontario Hydro is going heavily nuclear (using a successful Canadian technology).

Similarly, it is not clear that foreign nuclear and electric-utility industries are better organized and better coordinated. The much cited example of the coordinated French effort appears to be an exception rather than a typical case. A more plausible, but still dubious, defense of the U.S. outcome is that regulation in those countries is too lax. If my views that nuclear power was killed predominantly by unwise public policy are correct, coal analysts must recognize that in the very long run with which this conference is concerned nuclear power may revive.

With all this in mind, we can return to the question of the prospects for coal. Expectations for the United States are that by 1995 use will reach 1.1 billion tons. This contrasts with a 1979 DOE forecast range of 1.6 to 2.0 billion short tons. By 2000, we might reach 1.4 or 1.5 billion. The reductions reflect both the cuts already noted in estimates for electric utilities and slashing of all the other estimates. Both coking coal and nonutility steam coal forecasts were more than halved; forecasts for synthetic fuels went from substantial to negligible. The range of views on European and Japanese prospects as noted is even wider and rapidly changing.

Production Impacts

Coal-production trends follow the fundamental economic principle of reflecting the interaction of demand and supply. Thus, consumption trends have interacted with world-supply conditions to produce diverse production developments. The United States shares with China, South Africa, India, Australia, and Canada the maintenance of growth and nontrivial production levels (figs. 13-16). (Soviet coal production, in contrast, has tended to stagnate in recent years.) At the other extreme, the controlled contraction of western European coal production continues to stumble onward. Here the more interesting cases are Britain and Germany. They have the largest coal industries in western Europe. Both have shut down larger amounts of capacity than elsewhere, but this was mainly because there was more capacity to begin with. The percent declines were much greater in other western European countries (fig. 17).

More than slightly perversely, it is the Germans who have preserved the largest fraction of prior coal-producing capacity. In 1957, at the start of the European recognition of its coal problems, Britain was producing about 225 million metric tonnes; West Germany, 155 million. The respective 1983 levels were 116 and 90 million. Such differences conflict with the vision of Britain as a more protectionist, lower coal-cost country. Presumably, the availability of North Sea oil and gas put more pressure on British coal protectionism than was experienced in Germany.

The biggest influence on coal production in the United States has been the interaction among rapid growth in the West, rising natural gas prices, and the availability of low-cost coal in the West. Within the United States, the production rises have been predominantly in the West. The great bulk of the growth of western coal output has been to serve new markets, especially in the West South Central States. A second major force has been air-pollution regulations that encourage the use of low-sulfur coal. This has brought significant amounts of western coal into Minnesota, Wisconsin, Illinois, Indiana, Michigan, and Ohio.

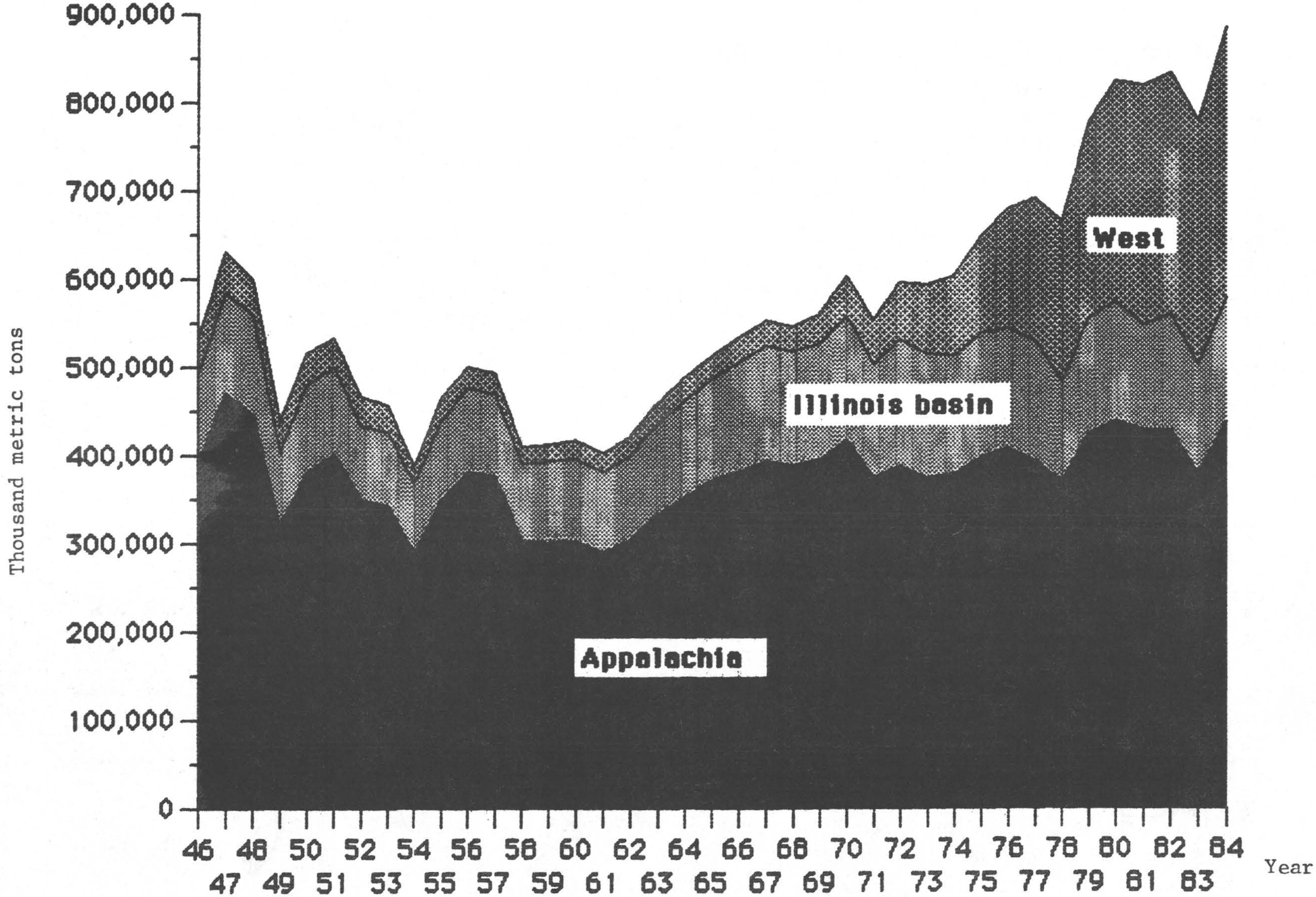

Figure 13. U.S. Coal Production by Region.

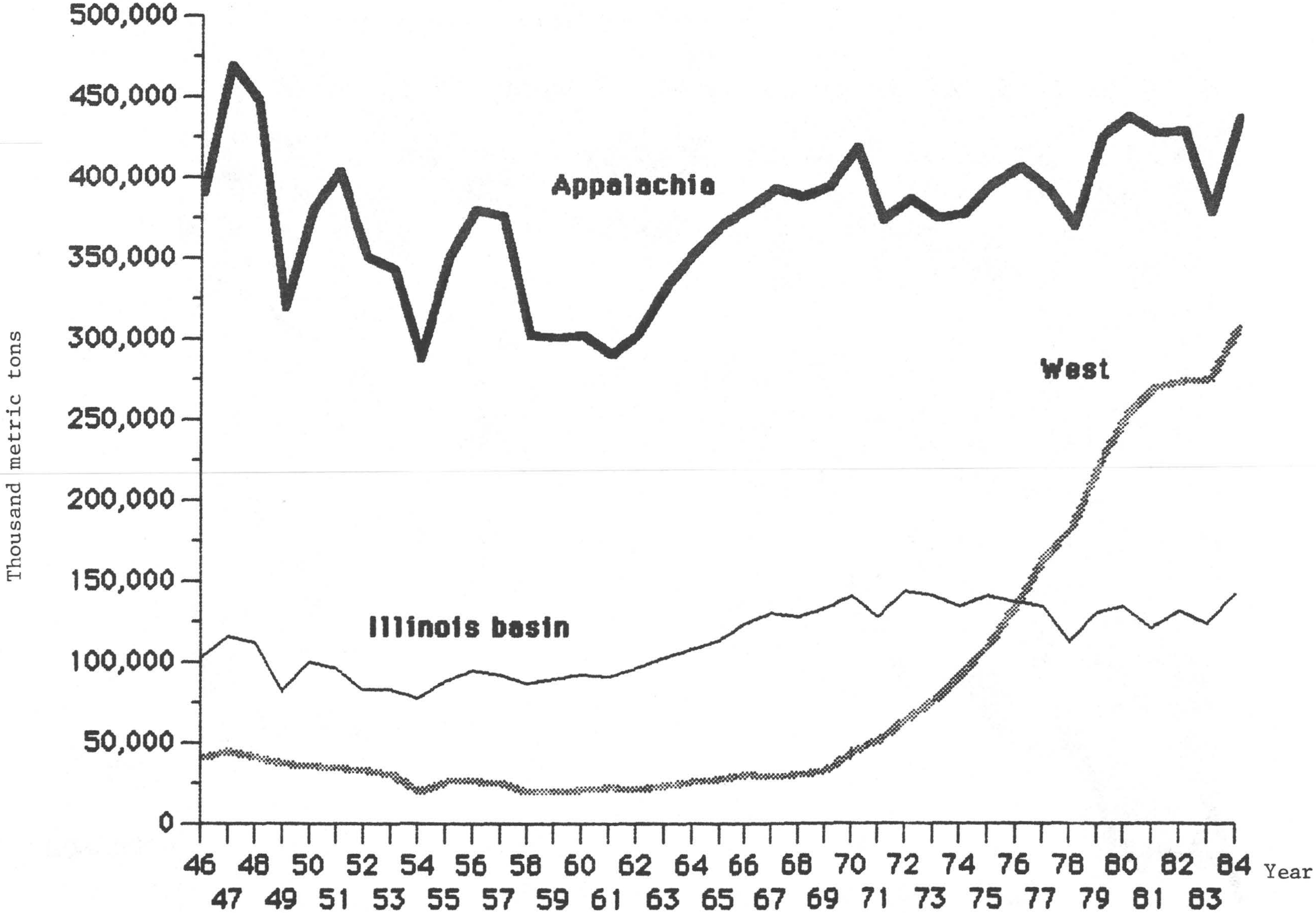

Figure 14. U.S. Coal Production by Region.

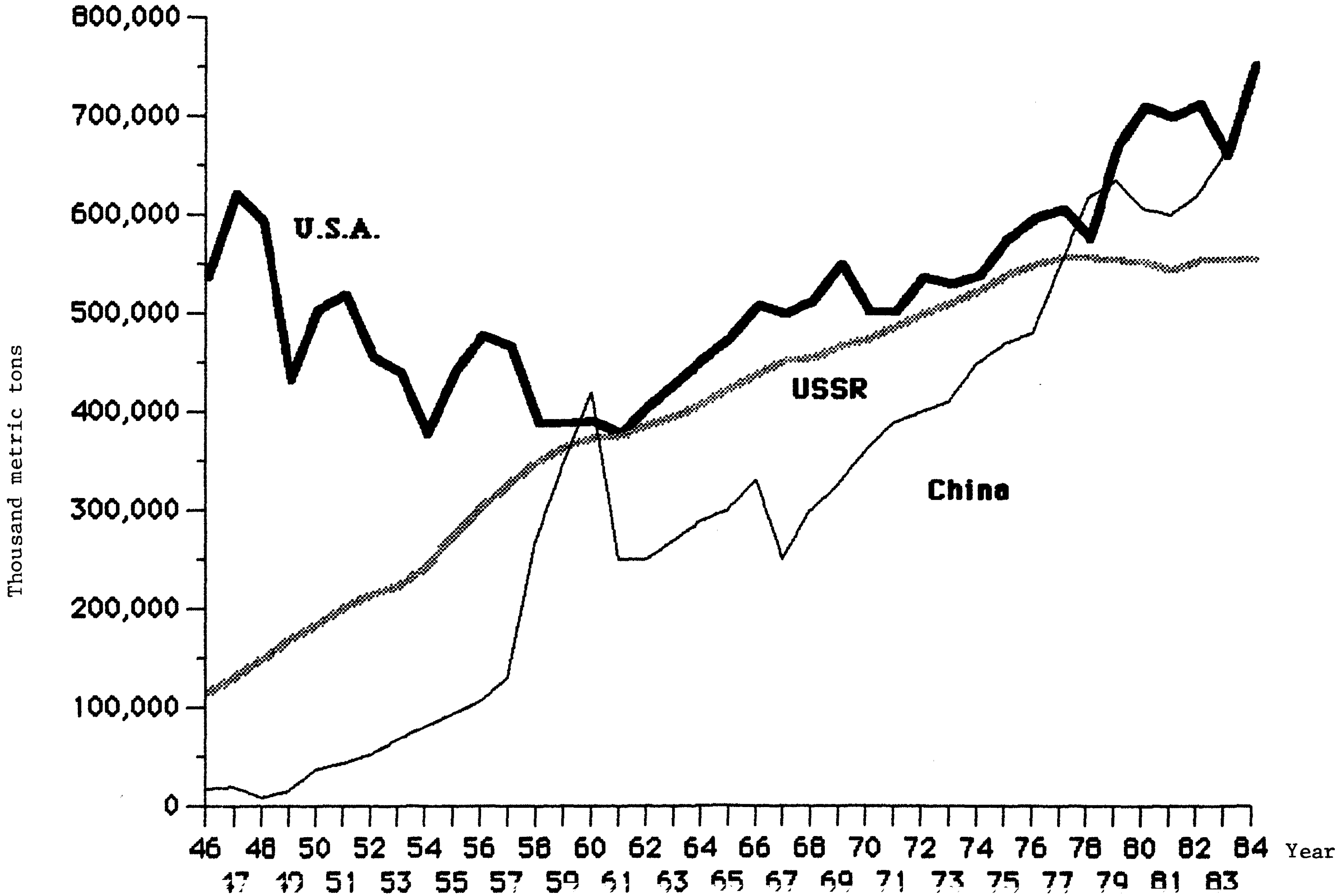

Figure 15. Coal Production USA, USSR, China.

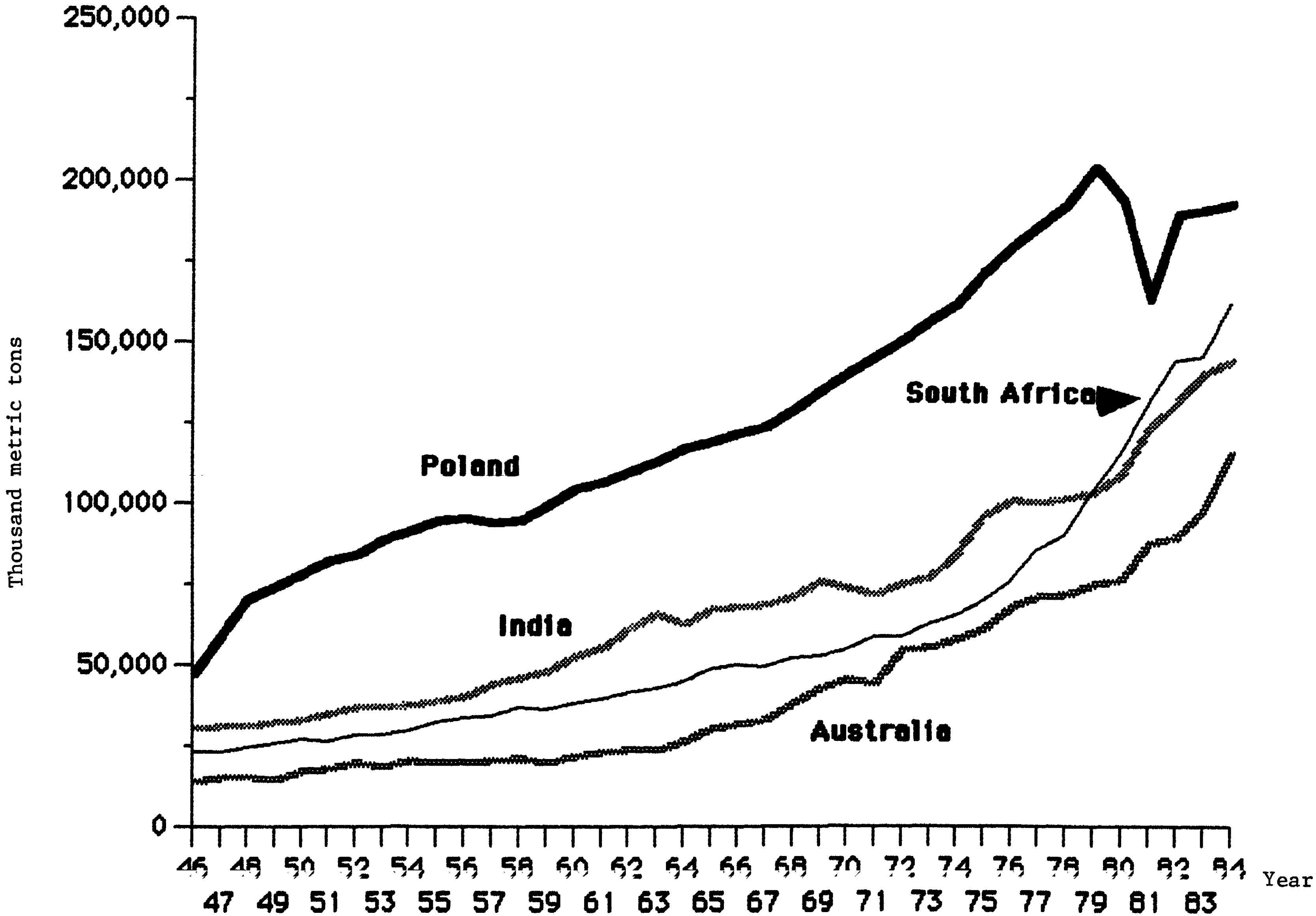

Figure 16. Coal Production in India, Poland, South Africa, and Australia.

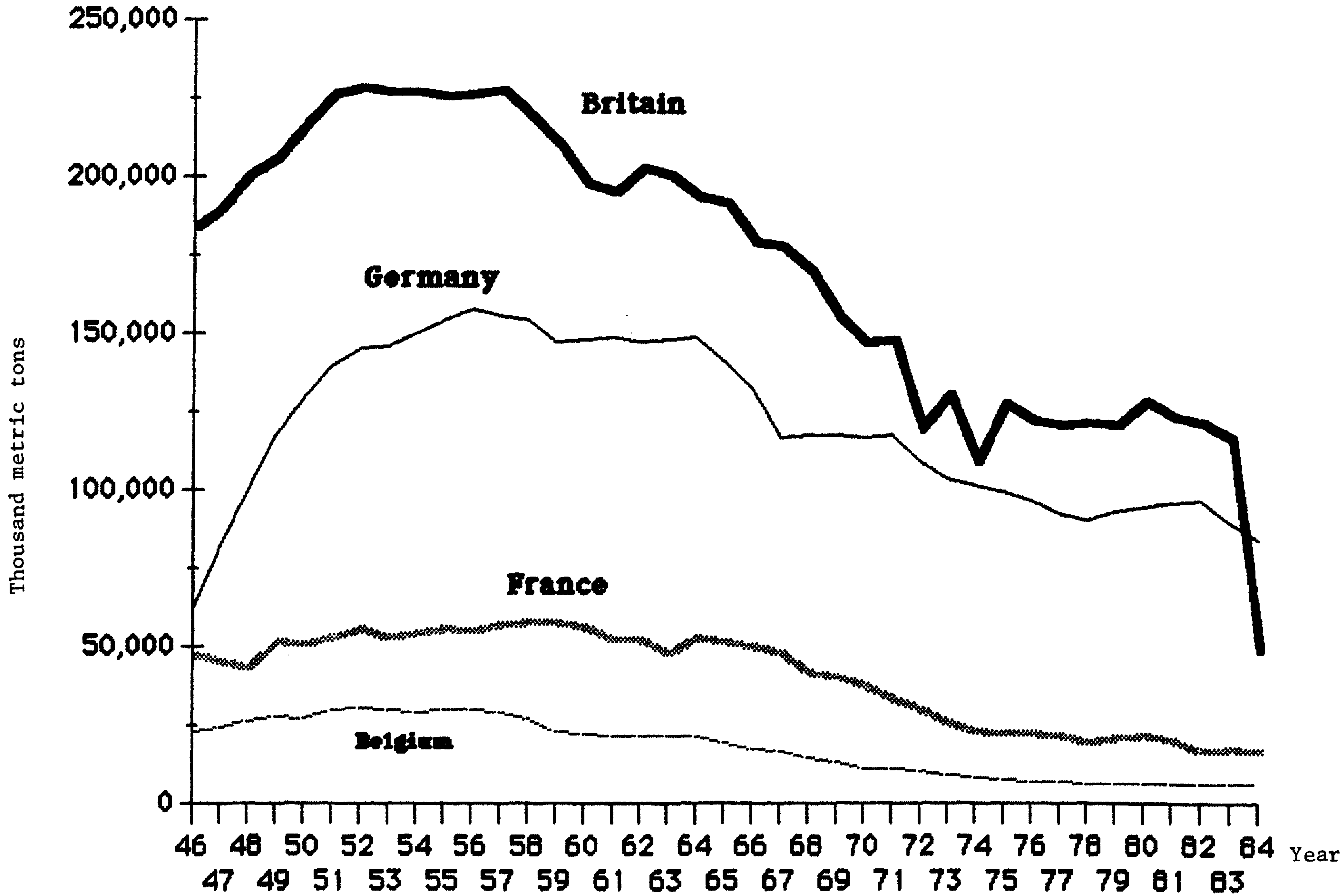

Figure 17. Western European Coal Production.

Within the East, several forces have been at work. Some regions, notably eastern Kentucky, have waxed while others waned. Eastern Kentucky has benefited from many influences. It is a source of low sulfur fuel; it is well located to serve growing markets in the Southeast; it has better labor relations and a more favorable regulatory climate than in some other eastern States.

The international situation is even more complex. As already suggested, government intervention has allowed the gradual reduction of coal output in high-cost areas such as western Europe and Japan. The decline in Japanese production coupled with rising consumption has resulted in sharply higher imports, with the United States, Australia, Canada, and South Africa as key suppliers.

Each of these countries has a different role in the world market. The United States is the long-time but challenged leader. Its advantages are availability of particularly high quality coking coals and experience in export markets. Its drawbacks are higher costs, especially for low sulfur steam coals. Australia has large amounts of cheap surface mineable coking and steam coals in regions fairly close to port. South Africa has low-cost surface mineable coals, predominantly steam coals. Canada's coals are in the West; they compete best as coking coals for Japan. Other competitors may arise. Exxon's large Colombian venture has a minimum export target (15 million) close to current Canadian levels (18 million in 1982). Hopes are for output double the minimum.

How the world market actually is shared is not readily forecast and depends upon the underlying economics and the wisdom of public policies. It is to be hoped that the strong industries will not be hampered by excessive controls or the weak ones overly protected by continued heavy subsidies.

The Policy Climate

All this has occurred and continues to occur despite the existence of a mass of government policies that restrict the production and use of coal. These policies differ radically in the wisdom of their purported intents. However, they suffer uniformly from unsatisfactory implementation. All countries have become concerned with the environmental impacts of coal production and use. Those countries with expanding coal industries are also interested in ensuring an equitable sharing of the bounties of production. Those countries with contracting industries have tried to ease the pains.

In every situation, an argument can be made for some action. Serious environmental damages are a burden on the society that should be alleviated. A long tradition exists in the theory and practice of public finance of taxing the economic rents--the profits in excess of a reasonable return on capital--from mineral exploitation. Modern governments believe that assistance should be provided to the innocent victims of economic change.

The mildest criticism of all these policies is that they are very badly designed. A vast literature has arisen suggesting that environmental regulations seek to attain their goals through inordinately expensive, time-consuming rules. The evidence also suggests that policymakers have set their objectives on the basis of flimsy, exaggerated estimates of damages (particularly to health) and a poor idea of what causes them. The Lave and Seskin (1977) estimates of health damages from air pollution have been severely criticized, particularly by Ramsay (1979), as far too high; nevertheless, they are still widely used in policy debates. The Office of Technology Assessment used them in 1984 to justify action on acid deposition.* The damages to lakes are too small to justify massive control outlays, so a health rationale is needed. We appear to be seeking too much abatement and possibly emphasizing the wrong problems.

Similarly, efforts to tax economic rents are severely flawed. Generally, the drawback again is reliance on undesirable instruments. A standard exercise in elementary economics is to show that sales taxes and percentage royalties cause undesirable decreases in production. Nevertheless, sales taxes and royalties are the favorite way of transferring economic rents to government. In the United States, we behave like an underdeveloped country and are overly obsessed with avoiding inadequacy of payment. For various reasons, we demand a ridiculously high level of proof that sufficient payment is received. Many different motives inspire these attacks; some are sincerely concerned with rent taxation, others, such as environmentalists and those using coal-bearing lands for other purposes, view high charges as a good way to discourage mining. Institutional peculiarities make State governments desire vigorous efforts to get high prices for Federal minerals. Under present law, the States enjoy the benefits of

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*For the fullest statement of the Lave and Seskin views, see Lester B. Lave and Eugene P. Seskin, Air Pollution and Human Health, Baltimore, Md.: Johns Hopkins University Press for Resources for the Future, 1977. See William Ramsay, Unpaid Cost of Electric Energy: Health and Environmental Impacts from Coal and Nuclear Power, Baltimore, Md.: Johns Hopkins University Press for Resources for the Future, 1979. Ramsay sets the deaths from coal pollution at much lower levels than Lave and Seskin. Finally, see U.S. Congress, Office of Technology Assessment, Acid Rain and Transported Air Pollutants: Implications for Public Policy, Washington, D.C.: U.S. Government Printing Office, 1984.

higher payments for Federal minerals without bearing the costs of producing such incomes.

I believe this is extraordinarily shortsighted policy and that everyone, including tax collectors, would be better off if land were put into its socially most valuable use as soon as possible. An action system of disposal is desirable as the administratively most satisfactory way of choosing among claimants. The problem is the insistence on vainly waiting for higher offers that will never emerge.

Finally, however much one wants to ease transitions, the prolongation since 1958 of efforts to assist western European coal seems excessive. The facts reinforce this view. Policy has been and continues to be guided by incorrect visions of the prospects. This experience is the quintessence of the drawbacks of the argument that coal is a plentiful fuel.

The coal industry has done remarkably well given these adversities. Even though the industry has managed to lessen the impacts, the policies should be reformed. I would argue that policy reform may be by far the most critical need in the coal realm.

Implications for Research

Thus, the perspective provided as a preliminary to discussions of research needs is an emphasis on the critical role of intrinsic market forces and regulation in affecting coal developments. Those suggesting increased research should be more realistic about what can be accomplished.

The research community loses credibility when it makes performance claims that cannot be realized. Such a loss has occurred in energy research. To a large extent, the failure was based on excessive reliance on the incorrect views of coal that I criticized. Another influence, however, has been the inability to meet the technological promises. A decade or so ago, the impression was created, by at least some of the more flamboyant and thus more publicly known advocates, that several alternative technologies for coal utilization would soon be economically available. Opportunistic politicians, particularly in the Carter administration, used these ideas to create ill-advised energy research and development programs, particularly the Synthetic Fuels Corporation, as a substitute for policy reform. The refusal to remove a morass of price controls was rationalized by invalid claims that only new technologies would solve the problem. The result has been drastic deterioration of the climate for energy research.

This, of course, denotes neither a failure to effect technological advances nor the undesirability of careful efforts to formulate a better research program. I merely suggest that we should practice the much advocated and inadequately implemented concept of learning from experience. The new research agenda that is proposed here should not suffer from the defects already noted of past efforts. We should not repeat the discredited notion that we must use coal for everything. There are, nevertheless, many opportunities for coal. The problem is not to obscure them in the all too traditional hyperboles of coal advocacy.

Sources and Notes on the Tables

Table 1 - DOE 1979-1982

U.S. Department of Energy, Annual Report to Congress.
Energy Information Administration, Annual Report to Congress.
In some years the forecasting volume was supplemented by another volume tabulating results.
DOE 1983 to date, Energy Information Administration, Annual Energy Outlook.
DRI: Data Resources, Coal Review.

Tables 2 and 3 - World Coal: IEA Steam Coal 1978

International Energy Agency, Steam Coal Prospects to 2000. Paris: Organization for Economic Co-operation and Development, 1978.
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IEA Coal Policy, 1981, International Energy Agency, Coal Prospects and Policies in IEA Countries, 1981 Review. Paris Organization for Economic Co-operations and Development 1982.
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UN ECE 1983: United Nations Economic Commission for Europe, Working Party on Coal Trade, World Coal Trade Up to the Year 2000. Geneva Economic Commission for Europe.
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IEA Coal Information, International Energy Agency, Coal Information 1984. Paris: Organization for Economic Co-operation and Development, 1984.
Saarberg 1985: Saarberg, Market Perspectives in 1985. Saarbruchen: Saarberg, 1985.

Note: Certain figures are inferred. IEA Coal Policy 1981 and 1983 and the two EEC reports report in oil equivalent tons (OET). Conversion to coal equivalent tons (CET) was by multiplication by 10/7, the standard IEA relation between OET and CET. IEA Coal Policy 1981 and 1983 and IEA Coal Information do not report steam use as such. It was calculated as production plus net imports and other steam was computed as total steam consumption less electric power. In some cases, a negative number results. This could occur if production or trade estimates report as coking coal, coking quality coal used for electric power. IEA 1978 does not report coking and steam output and they are calculated as consumption less imports.

World Coal contains two page summaries of forecasts for the participating countries. These provide figures for 1990 and 2000 corresponding to all the categories listed in the table. However, only partial forecasts are given for the rest of the OECD. In particular, an "other western Europe" number is available on total use, steam use, steam imports, coking coal imports, electricity coal use, industrial coal use, and case B production but only for the year 2000. These numbers were manipulated to yield all the year 2000 other OECD Europe categories needed for the tables. These were added to data on separately reported countries to yield the OECD Europe numbers shown. Calarco shows actual coal tons so his steam coal figures are not comparable with those in other studies.

BARRIERS AND OPPORTUNITIES IN THE APPLICATION OF COAL-QUALITY GEOSCIENCE

by

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Coal-quality geoscience means different things to different people. For most, even including many people in the geologic community and mining industry, it undoubtedly means the esoteric study of boring, black rocks. Yet for a growing number of electric-utility fuel managers and plant operators, coal-company mining engineers and coal marketers, policy analysts, and others, coal-quality geoscience is developing a decidedly practical flavor. The promise of cost savings, beginning with exploration and extending to combustion and environmental management, is exciting the interest of these "newcomers."

Misconceptions about coal-quality geoscience and poor communication among the mining industry, utility industry, coal-research community, and government are the principal obstacles to more widespread application of coal-quality geoscience in policymaking, mining operations, and utility fuel management. These same obstacles stand in the way of a rigorous and timely nationwide research effort into coal-quality geoscience. The approach taken in this paper is to examine nine of these misconceptions. They are presented as a series of "myths." Although I may overstate some of them, they illustrate the important role of attitudes, and not merely scientific fact or technological readiness, in determining the many possible applications of coal-quality geoscience.

MYTH NO. 1: COAL GEOLOGY IS AN ANTIQUATED SCIENCE

Most casual observers might assume that the science of coal geology has its roots in the Industrial Revolution. In the United States, we might suppose that the great strides in understanding coal geology and resources took place well before the 1950's, when coal gave way to oil as the principal energy source to the economy. Although this is largely true, reflected in the work of White and Thiessen (1913), Campbell (1903, 1906, 1912, and 1917), Cady (1915, 1933, 1939, and 1942), and others, the irony is that modern developments in petroleum geology have been responsible for much of the change and growth in coal geology over the past 15 years.

(For additional references to early publications on coal, see Eyster and others, 1980.)

The modernity and dynamic nature of the current state of coal geology can be illustrated in many areas, all having an important bearing on our understanding of coal quality. Three are discussed here: depositional environment concepts, geochemistry of coal quality, and coal geostatistics.

Depositional Environment Concepts

The 1960's was a period of growth in the understanding of depositional environments, stratigraphy and sedimentology. No doubt an important driving force was the need to better delineate oil reservoir beds and to extract more information from individual drill holes and core samples. Interpretation of sedimentary facies in terms of their environments of deposition gave geologists a powerful predictive tool. Moreover, it provided a framework for explaining otherwise discrete and seemingly unrelated lithologies in vertical and lateral succession (fig. 1). In the 1960's, these concepts were advancing the state of the art, and they had only just begun to be applied to coal.

The sedimentary deposits of the Mississippi Delta and Gulf Coast were the cradle for the development of these concepts, particularly with respect to the geometry and sedimentology of the full range of deltaic deposits extending from the upper delta plain to the lower delta plain and beyond. It is no accident that an understanding of the distribution and characteristics of lignites has enabled the Texas Bureau of Economic Geology to show a close analogy between these lignite-bearing sequences and the now-classic Mississippi delta depositional models. A case in point is their study, conducted between 1979 and 1981, of four densely drilled lignite properties, each representing a different paleogeographic environment (Tewalt and others, 1983). Examples of cross sections are presented in figure 2. The authors calculated the number of holes required to estimate the resources in each property to the same level of precision (20 percent) (table 1). The pattern of results confirms their prior notions at least in its general direction.

Obviously, if one could calibrate characteristics of seam thickness variation and continuity to particular environments and then identify these same environments in the rock record, one would have a powerful tool for exploration and resource assessment. Actually, this hasn't been possible. The rocks provide their own record of depositional environments which has defied simplification. Consequently, geologists are not all of one mind concerning the applicability of depositional-environment concepts. A retreat in scale can be seen in the work of John Ferm (for example, Horne and others, 1978, Ferm and Mathew, 1981, and Ferm and Staub,

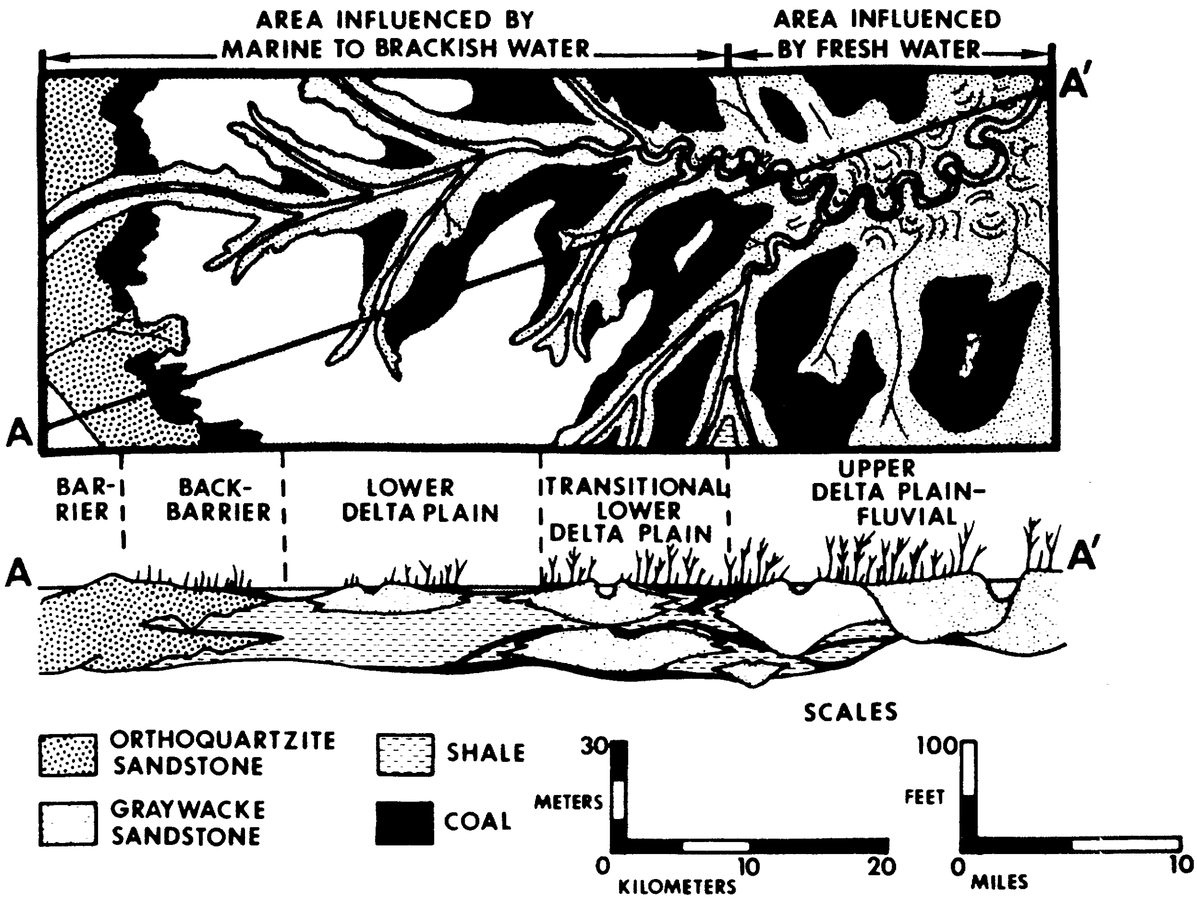


Figure 1. Depositional model for peat-forming (coal) environments in coastal regions. Upper part of figure is plan view showing sites of peat formation in modern environments; lower part is cross section (AA') showing, in relative terms, thickness and extent of coal beds and their relations to sandstones and shales in different environments (from Horne and others, 1978).

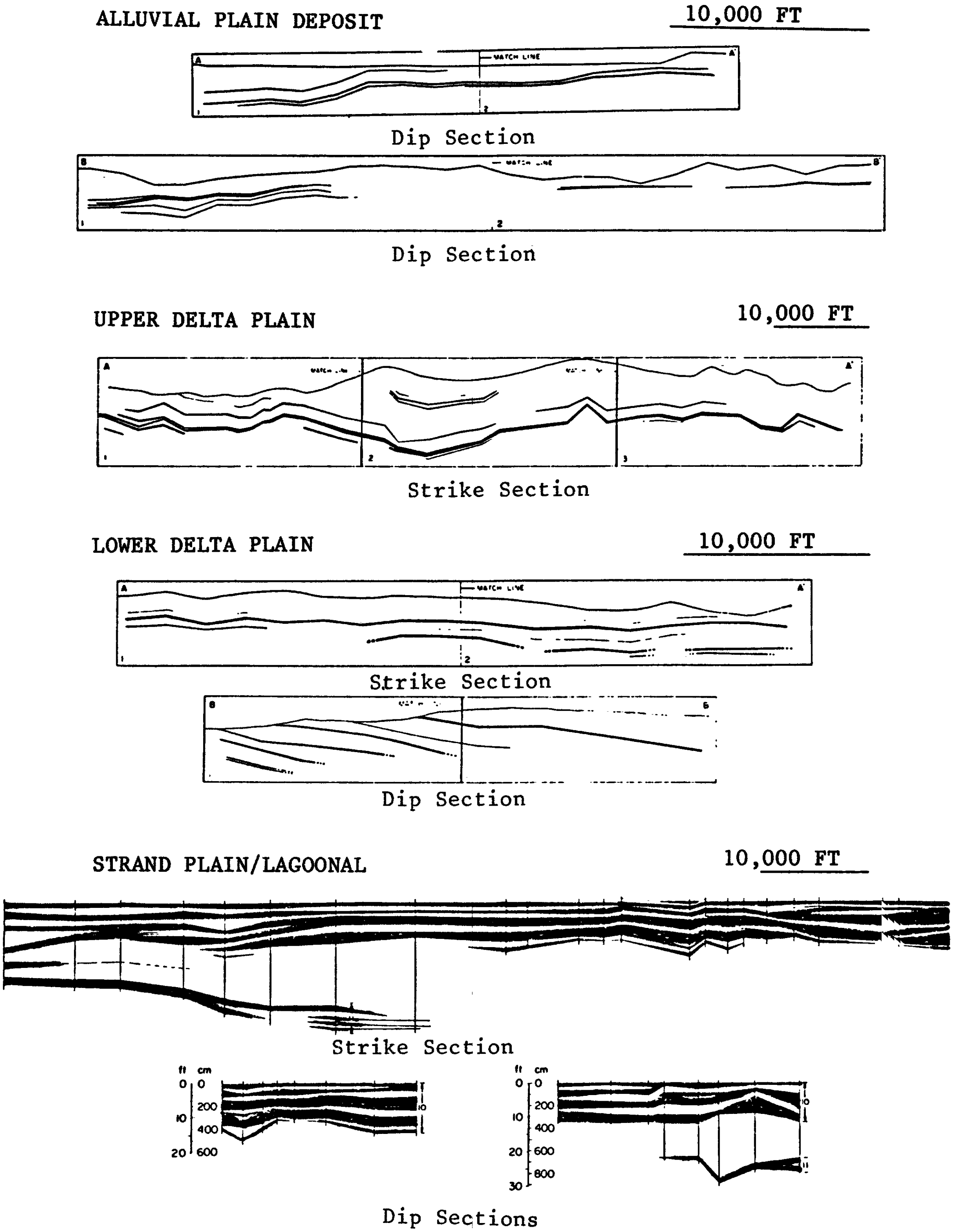


Figure 2. Cross sections of Texas lignite deposits (modified from Tewalt and others, 1983).

1984), who after dissecting many sites in the Central and Southern Appalachians from a depositional-environment perspective, has turned to a more descriptive and less interpretive approach to coal seam geometry--the concept of platforms and transition zones (fig. 3). Nevertheless, his evolution by no means condemns the usefulness of depositional-environment concepts as an explanatory and predictive tool in local applications and in supporting the detailed analysis of coal quality through paleobotanical and other means.

Not to be misleading, perhaps it should be said that in many applications the routine payoff from depositional concepts comes not so much from what they say about the coal itself, but from allowing an improved interpretation of the facies of the non-coal rocks within coal-bearing sequences. This is of great importance to correlation using geophysical logs and cores.

When we consider the extent to which depositional-environment concepts have penetrated the practice of coal geology, it is surprising how very short the history of these concepts are. The number of research studies is quite small, and the progress that has been made owes more to the perseverance of a relatively small number of individuals working in selected areas of opportunity (that is, good outcrops or good company cooperation) than to any widespread market shift in coal price, consumption, or public coal-quality consciousness.

Geochemistry of Coal Quality

The association of marine beds with higher sulfur coals is now widely recognized. The example given in figure 4 is typical of this association, where the coal underlying marine roof rocks has a high sulfur content and the coal that had been shielded from marine influences by an intervening wedge of terrigenous clastics has a low sulfur content. This association has been observed frequently enough that roof lithology has gained status as a predictive indicator of underlying coal quality. Another practical benefit is that the introduced sulfur is commonly in a form more amenable to cleaning; for example, that in the example in figure 4 is mostly disseminated framboidal pyrite. Although less practical, another use of this association is as an indicator of the depositional environment of the roof rocks where the sulfur content of the underlying coal is known.

So far, so good. In the intervening years since Williams and Keith's pivotal study in 1963--which is pointed to as the first statistical and definitive documentation of this roof-rock/coal-quality association--it would appear that these ideas have been proven by the test of time. The time, just as for depositional-environment concepts, has been quite short. But more alarming is the next chapter of the story, and how it illustrates ongoing

STUDY AREA DEPOSITIONAL SETTING	NO. OF BOREHOLES (PRECISION 20%)
ALLUVIAL PLAIN	33
UPPER DELTA PLAIN	9
LOWER DELTA PLAIN	5
STRANDPLAIN/LAGOONAL	7

Table 1. Borehole data requirements for reserve estimation in differing depositional settings (modified from Tewalt and others, 1983).

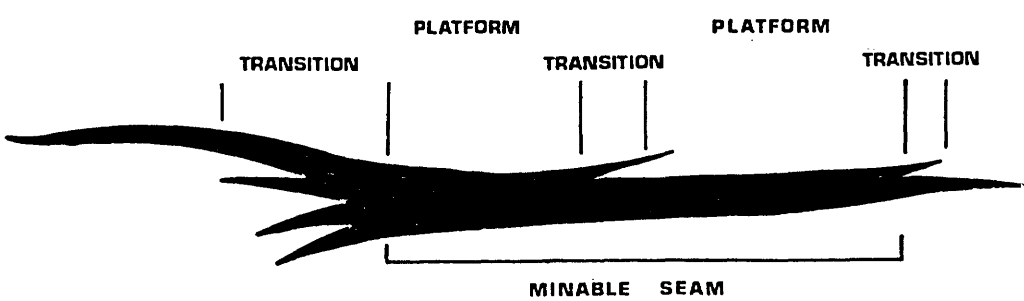


Figure 3. Model of Appalachian coal beds (from Ferm and Mathew, 1981).

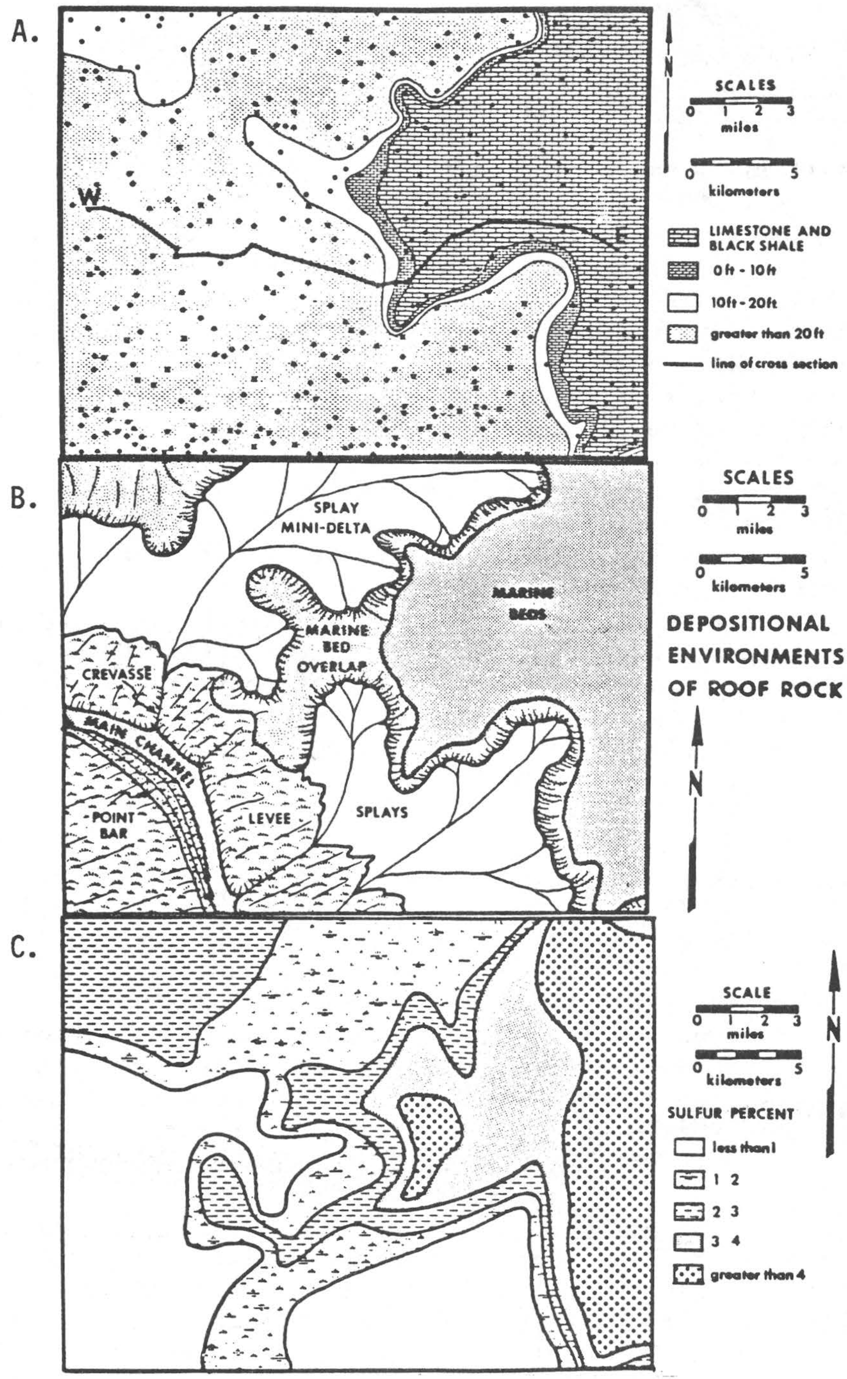


Figure 4. Roof-rock/coal-quality association. A. Distance to overlying marine rocks. B. Interpretation of immediately overlying rock. C. Sulfur content of coal (from Horne and others, 1978).

change in our understanding of the geologic factors controlling coal quality.

Cecil and others (1982), largely on the basis of detailed geochemical analysis of the Upper Freeport coal bed in Pennsylvania, have proposed that the primary control of both sulfur and ash in coal (with the exception of clearly indisputable terrigenous clastics) is the geochemistry of the peat-forming swamp. This might seem a minor distinction from the geochemical conditions present during deposition of the roof rocks, but it significantly changes one's view of the marine-roof/high-sulfur coal association to "a special case of the pH model" (Cecil and others, 1982)..."a special case within a more encompassing geochemical model" (Cecil and others, 1983).

The basic argument is that, under highly acidic and wet conditions, the dissolved mineral content of fresh water is very low and bacterial activity capable of either degrading the peat or reducing any sulfate present is low. These conditions produce low-ash, low-sulfur coal. Under drier freshwater conditions, the residual ash content is increased in proportion to oxidation of the organic matter. And under the more alkaline conditions characteristic of brackish and marine waters, bacterial activity is enhanced, simultaneously degrading the peat and reducing the sulfates present. These conditions produce high-ash, high-sulfur coal.

Support for these new theories is seen in the exceptions to the traditional roof-rock/coal-quality associations and in the new associations of ash and sulfur. For example, exceptions to a 1:1 roof-rock/coal-quality relationship have been found not only in Williams and Keith's work on the Lower Kittanning, but also in recent work on the upper Elkhorn No. 3 and Fire Clay coal beds by Currens (1981). This led Currens to propose a model linking the sulfur and ash distributions during peat formation (fig. 5), and to propose further that the association of marine rocks with high-sulfur coal is more of a coincidence than a consequence.

It is too early to tell where these new ideas may lead. Their relevance to finding low-sulfur and low-ash coals or coals that can be cleaned to compliance levels is readily suspected but remains to be demonstrated in a significant number of case studies. One direction that Cecil and others have taken (1983, 1985) is to examine the broad paleoclimate changes that have ultimately controlled local pH and coal quality. In turn, notions of what constitute properly analogous depositional environments have been expanded.

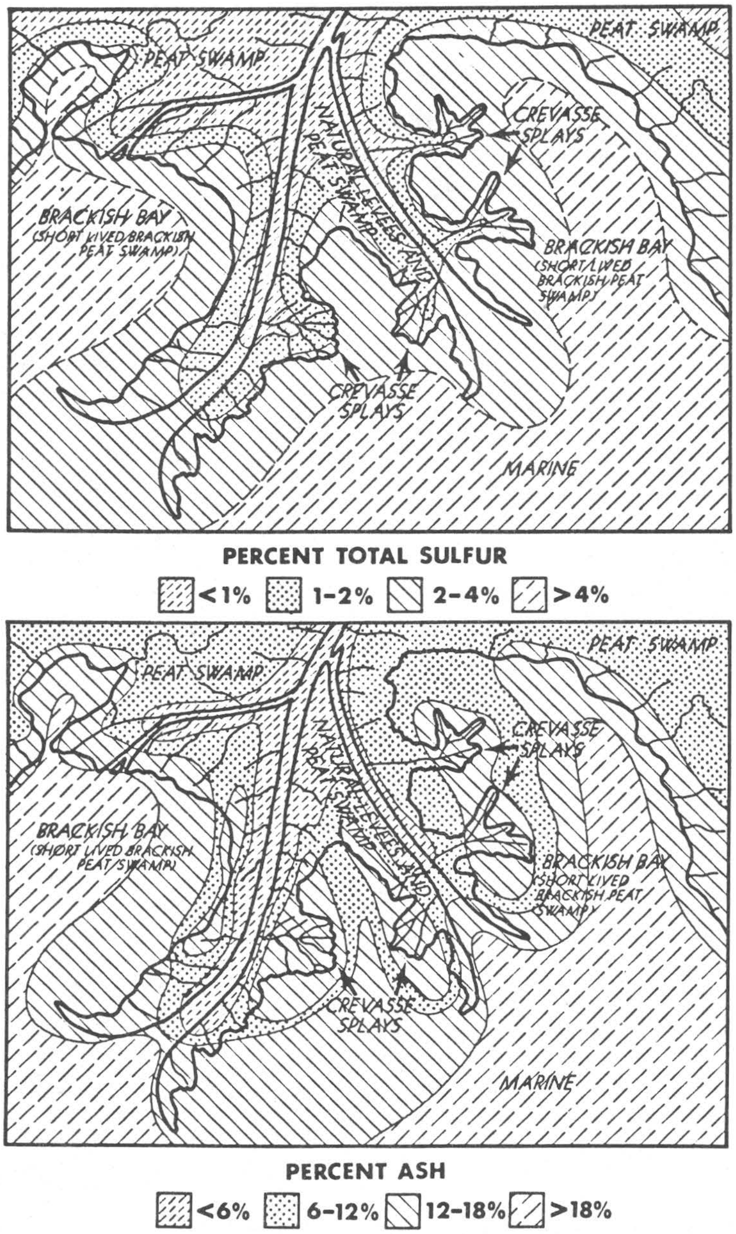


Figure 5. Speculative relationship of coal quality to contemporaneous peat-forming environment (from Currens, 1981).

Coal Geostatistics

Coal geostatistics is another, perhaps more clearcut, example of the modernity of the tools of coal geoscience. As far as I know, no applications of mining geostatistics--itself a relatively new discipline--to coal were made before 1978 in the United States. Now, several mining companies have become conversant with geostatistical techniques. As Rendu (1982) pointed out, "There are strong indications that geostatistics is going to play an increasing role in the evaluation of coal projects." Unfortunately, the adoption of these techniques has been impeded by the lack of thorough yet readable demonstrations, such as that provided by Buxton (1982). The mining industry's use and the utility industry's acceptance of geostatistical coal-reserve assessments will probably require many more examples of practical success before the mystique of coal geostatistics is overcome and the backlash from snake-oil applications, which can be anticipated, has subsided.

In our own studies of coal geostatistics (for instance, Tewalt and others, 1983, and Journel, in press), we have found that these techniques are hardly necessary for devising gross property tonnage estimates. Their promise, instead, is in how they can account for the varying degrees of uncertainty surrounding estimates of coal characteristics at specified locations anywhere in the coal property. This information can be of considerable use in optimizing drilling campaigns (Kim and others, 1980), as well as in simulating the quality of run-of-mine coal so as to assure continued compliance with emissions regulations or coal contract quality specifications (Knudsen and others, 1980).

The appealing thing about geostatistical techniques is that they don't superimpose an arbitrary weighting scheme on how the existing data on quality or thickness will be used to estimate characteristics away from the known data points. Instead, the available data for a particular property are analyzed to derive a "customized" weighting scheme. This is done by constructing a variogram, which shows the waning influence of a sample point at increasing distances from that sample point. An example of a variogram for coal thickness is given in figure 6. Other products of geostatistical analysis are more familiar, such as a map of sulfur distribution, (fig. 7). Their greatest practical value is probably in better understanding mined coal quality over time (fig. 8).

Given the paucity of studies to date, the future of coal geostatistics will be dynamic.

MYTH NO. 2: THE GEOLOGY OF COAL IS SIMPLE AND STRAIGHTFORWARD

Most geologists have had a brief exposure to coal geology during their education, although their careers have led elsewhere.

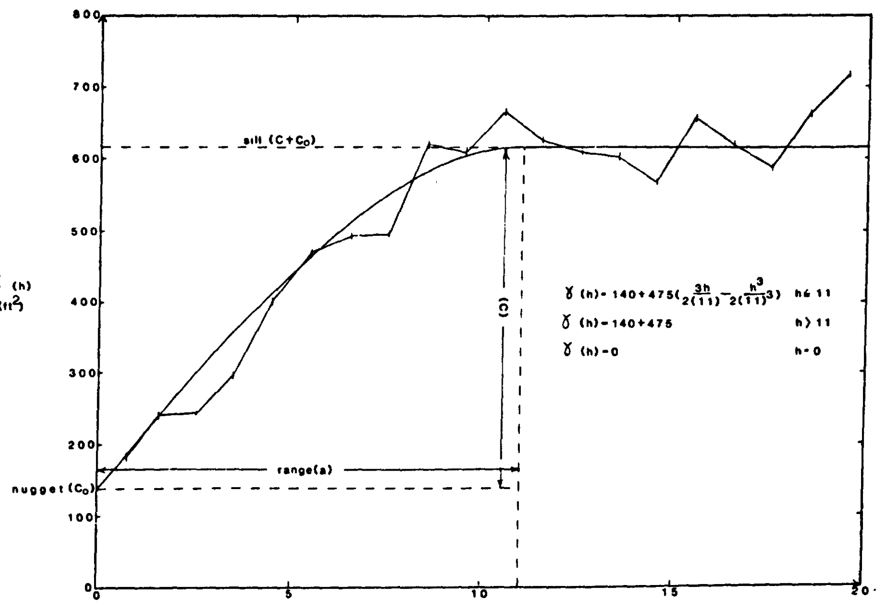


Figure 6. Variogram: variation in seam thickness measurements at increasing separation of sample points (from Pierce and others, 1982).

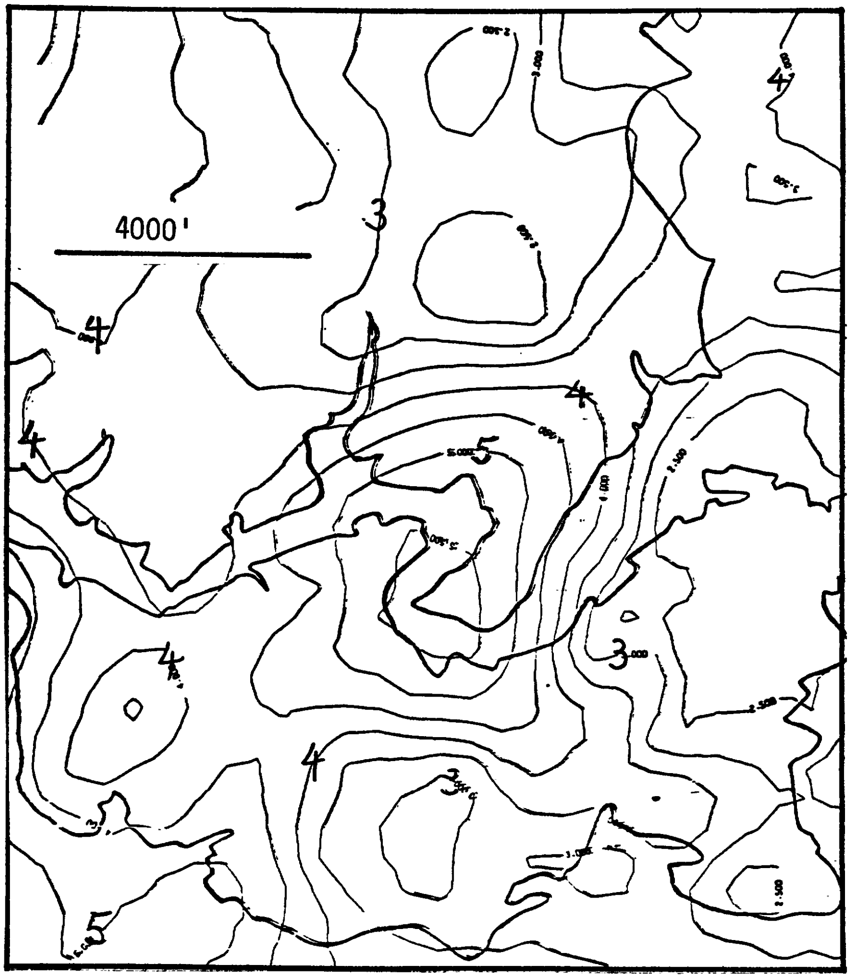


Figure 7. Contour map of Kriged sulfur values (in percent) plus two times standard deviation (from Kim and others, 1981).

The fact that there routinely has been more money in other fields explains a lot; but another reason for the lack of glamour of coal geology may be simply that it is viewed as intellectually barren. What better example of the monotonous nature of layer-cake geology than coal? A localized version of this layer-cake perception is illustrated by a road cut in figure 9; a regional version is the sketch in figure 10. Although only schematic, figure 10 leaves one with the impression of a single coal bed extending from West Virginia to Kansas! Under such conditions, it wouldn't seem that exploration takes much creativity.

In fact, the geology of coal-bearing sequences, although conforming to certain regularities, is anything but simple. The sedimentologic complexity of modern depositional environments, such as the views of the Mississippi Delta in figure 11 and the streamcourses of the Mississippi in figure 12, make this abundantly clear, as do many of the previous figures. The models of depositional environments, (figs. 1 and 2), do not eliminate this complexity--they simply make it a little easier to deal with.

Whereas most of the work to date has been aimed at the geometry of coal beds and intervening sequences, the variation in coal quality characteristics is no less complex and, for want of data, more poorly understood. An example of a much smaller scale of variation than illustrated in previous figures is that of ash within an 8-foot-thick coal bed over a 10-acre mine site in West Virginia (fig. 13). Needless to say, very few pictures of coal-quality variation are available at a scale anything like this. Yet, it is at this scale of fine-tuning where paleobotanical concepts and coal petrography are likely to yield important insights into the distribution and variation of ash, sulfur, and other characteristics, all having potentially tremendous commercial significance. (For a western example of a coal seam dissected at this scale of inquiry, see Warwick and others, 1984.)

MYTH NO.3: BY NOW, USEFUL APPLICATIONS OF COAL GEOSCIENCE HAVE BEEN EXHAUSTED

From an abstract perspective, once we recognize that much of the growth in the tools of coal geoscience has taken place so recently that not even the geologic community is fully aware of these developments, it is a short leap to conclude that applications of coal geoscience in mining, quality control, and resource assessment must certainly be in their earliest stages.

A less abstract way of demonstrating this is to turn to anecdotes from mining and utility companies about some of their recent experiences, most of which are less than 7 years old. I have kept the company names confidential partly out of ignorance, but also not to scare away others from coming forth with other, hopefully more detailed, examples.

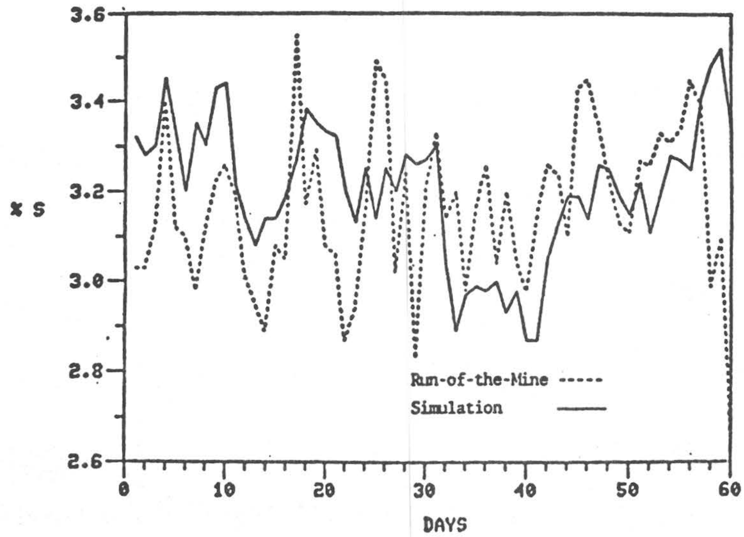


Figure 8. Simulated versus actual run-of-mine sulfur values (from Knudsen and others, 1980).

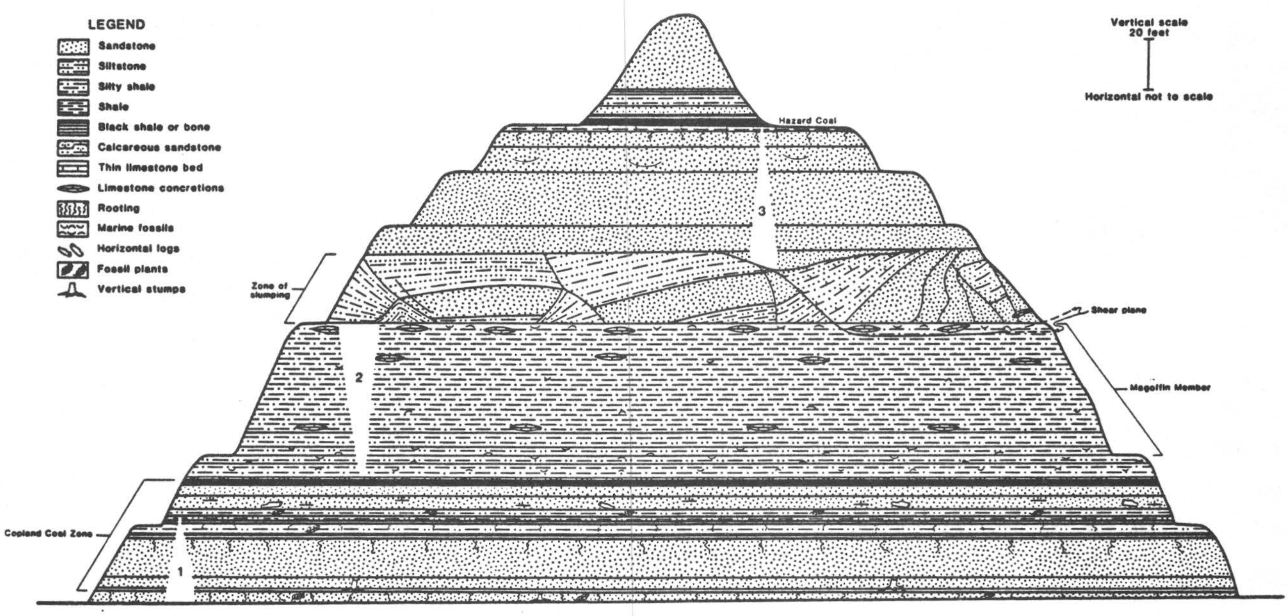


Figure 9. Sketch of a roadcut that could lead to a "layer-cake" interpretation of coal-bed stratigraphy on a local scale (from Kentucky Geological Survey, 1981, pl. 15).

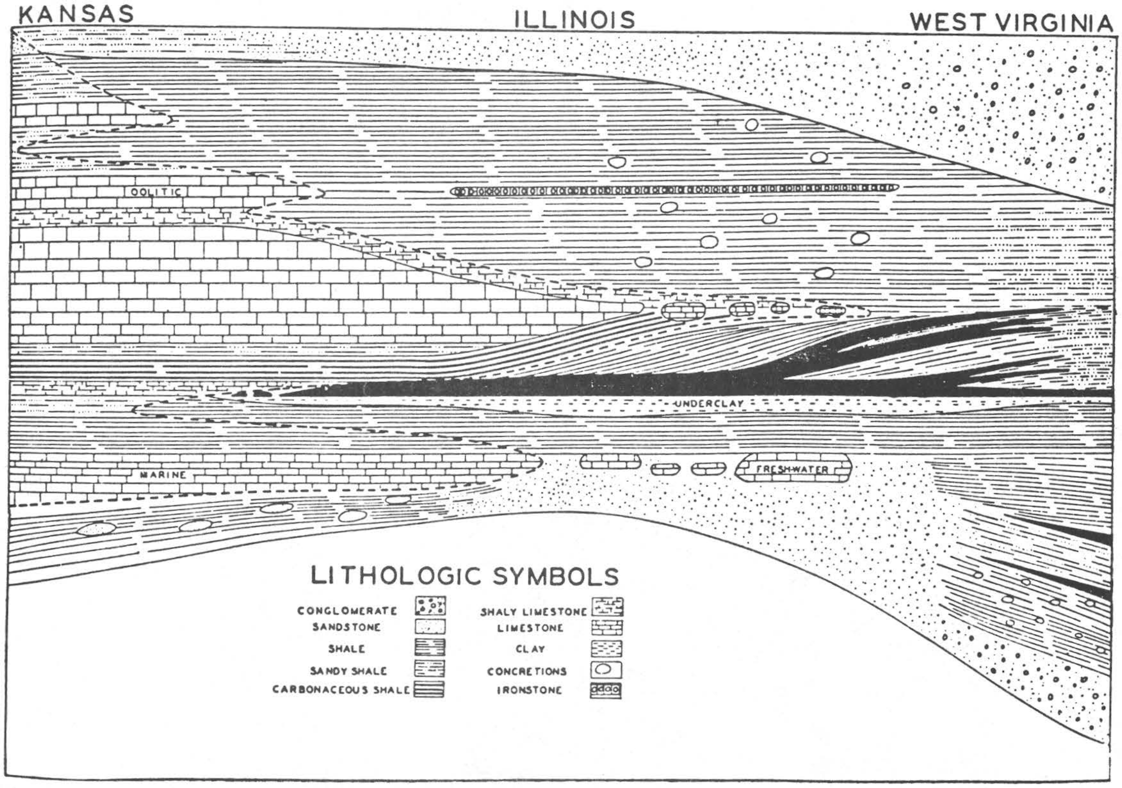


Figure 10. Diagrammatic regional cross section that could lead to the interpretation that coal-bed stratigraphy is "layer-cake" over large areas (from Wanless, 1950).

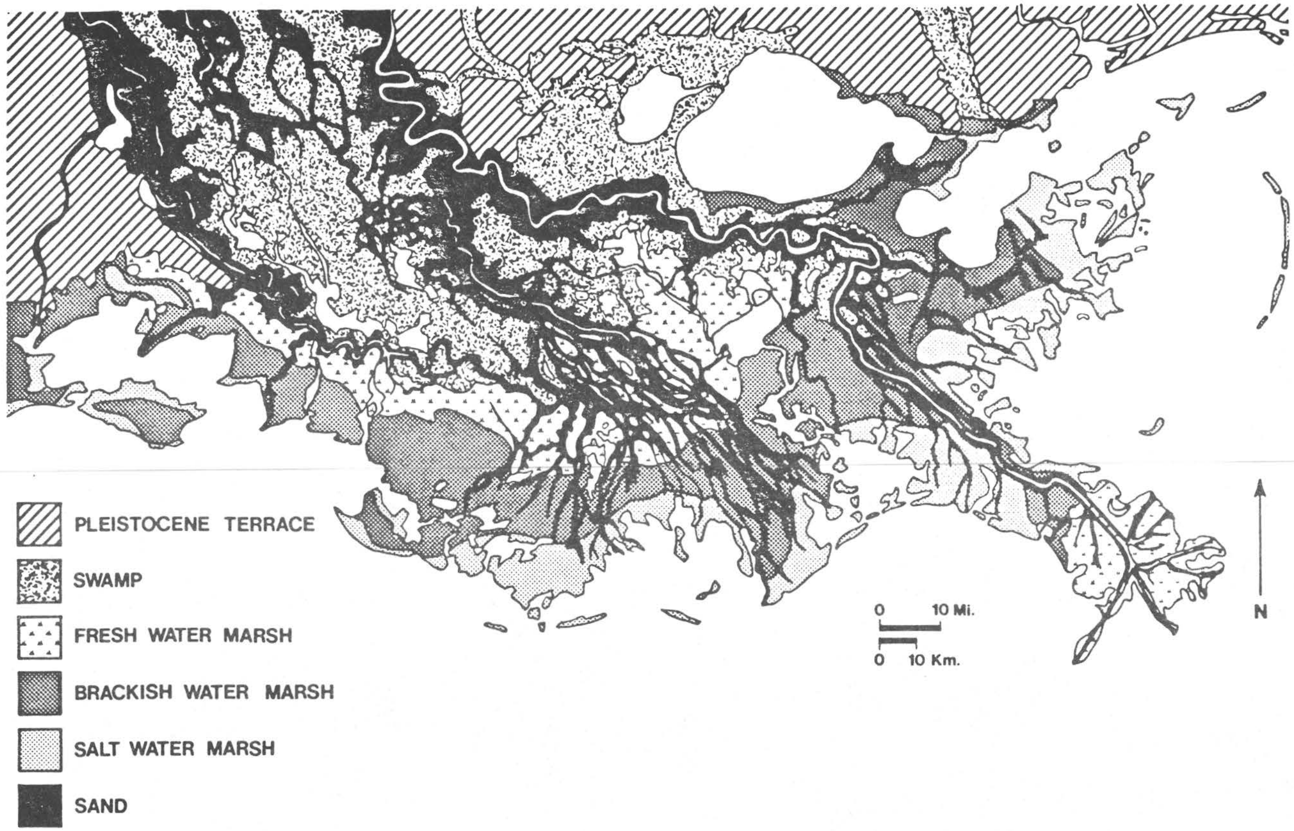


Figure 11. Mississippi Delta complex showing distribution patterns of channel sands to peats associated with marsh and swamp environments (from Frazier and Osanik, 1969).

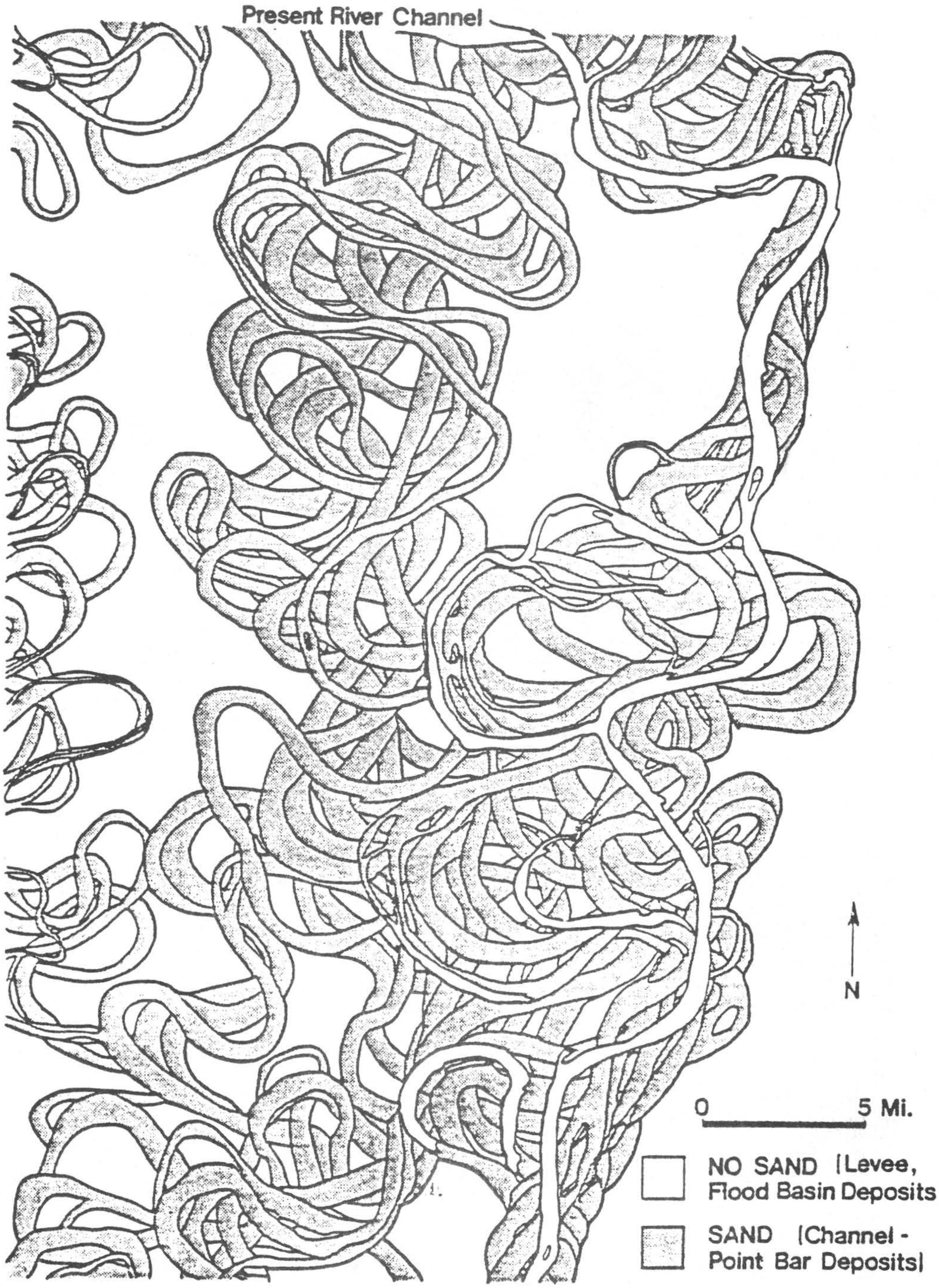


Figure 12. Modern and ancient stream courses of the Mississippi River as indicated by fluvial sand (point bar) deposits (from Fisk, 1944).

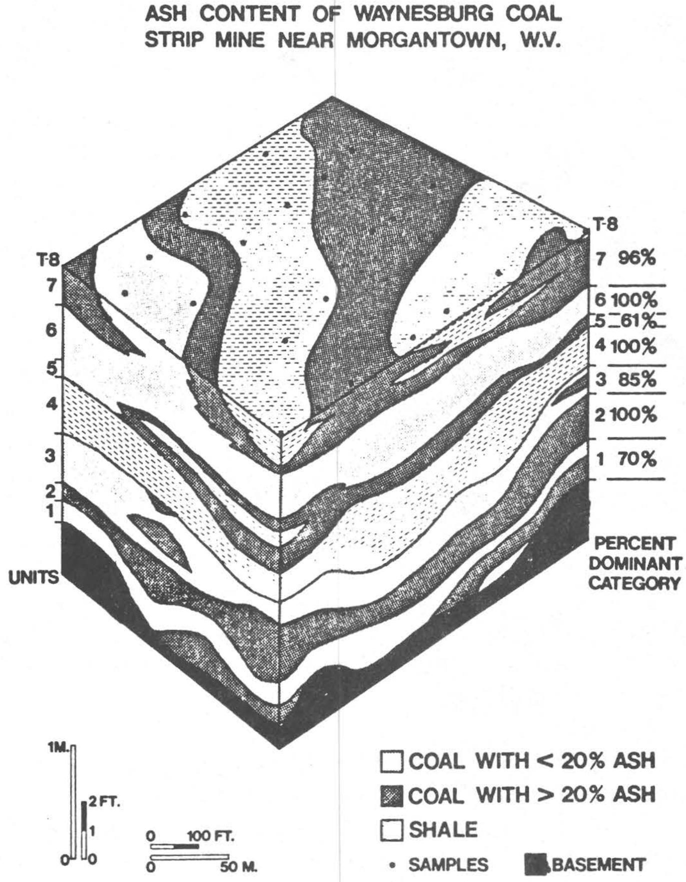


Figure 13. Small-scale variation in ash illustrated by a block diagram of a strip mine area displaying the low-temperature ash content for the Waynesburg coal near Morgantown, West Virginia. Seven units including the middle shale parting (Unit 4) represent subdivisions of seam based on ash content. Dots on surface are the 23 sampling locations. Percent dominant category refers to the persistence each unit extends throughout the strip mine area. T-8 represents an arbitrary plane constructed through Unit 7 so as to suggest the ash-peat accumulating simultaneously (an interpreted time horizon) (from Donaldson and others, 1979).

- A major coal company was willing to sell one-half of a western coal property to a utility. At the time, the coal company used essentially no geologists. The utility went to the trouble to map the property and located a major sand channel. In subsequent negotiations, the utility acquired the good half and the coal company was left with the channel.

- A coal company was investing in an eastern property that had been sparsely drilled. On adjacent property, a major sand channel and severe slumping problems had been encountered. Without making any observations on the adjacent property, the coal company developed the mine and ran into the same problems.

- Engineering consultants had drilled a western underground property. By coincidence, three holes intersected sandstone roof, leading to an estimate that 80 percent of the roof would be good, solid sandstone. Once the coal company got underground, they found that only 5 percent of the roof was sandstone. A look at electric logs revealed the sandstones were fluvial, not blanket. As a consequence of rotten-roof conditions, the company routinely had to take 1/2 to 1 foot of roof, diluting the mined coal. Safety problems were aggravated, and at the channel margins, up to 6 feet of roof came down. Ash ranged from 5-7 percent to as much as 30-40 percent.

- One member of a coal-company partnership wanted the other to put up $20 million for longwall development of a new western property. The other wanted to do more geology first. After driving the entry 200 feet, the coal disappeared in a meander-bend channel scour. This was the first of many geologic problems encountered as mining proceeded.

- An eastern coal company was selling a property showing 8-foot coal with 30 million tons recoverable resources. Reinterpretation of logging reduced this estimate to 10 to 15 million tons.

- A coal company projected run-of-mine quality from a western property on the basis of drilling cuttings. Black shale was misinterpreted as coal. The mined product was unacceptable, the property had to be redrilled and logged, and selective mining procedures with blending had to be introduced.

- In a similar eastern case, unsupervised coring operations resulted in incomplete measurement of the partings in the seam. The ash was understated, and the coal company had to build a coal-cleaning plant.

- o Unanticipated underground conditions nearly doubled the cost of supplying coal from an eastern mine over a 4-year period. Roof falls at another mine cost more than $1 million in cleanup and lost production. And because of these kinds of problems with quantity and also quality, a local utility buyer had to drastically reduce the amount of coal it could expect from these sources.

- o An eastern utility found that no suppliers could actually deliver coal in the required sulfur range. This was after $4-1/2 million had been spent to improve precipitator performance and after seven bids had been accepted from a field of 30 producers.

These examples, I am told, are a small sample. By their very recent vintage, they warn us not to assume that all possible mistakes have been made and that the lessons from these have been learned.

MYTH NO. 4: GEOLOGY AND COAL MINING DO NOT MIX

This attitude reflects the traditional barriers between geologic functions and mining operations--barriers that lie behind many of the lost opportunities in the previous examples. Traditionally, the proper role of the geologist is to find the coal in the first place or, if this has already been done, to serve as a "land man" handling leasing activities and keeping up with the competitors. Mining operations have been described as a sort of "men's club" of tradition among the operators, engineers, and so on, where the geologist is only brought in when things get really bad, as in some of the previous examples.

Certainly the fundamental orientations of operations and geology are different. The mining engineering approach to a problem is to mine through it or around it and keep producing. The approach is "can do"; one that geologists call "exploring with a continuous miner." In this environment, geologic analysis is a luxury, probably irrelevant, and what's more, a safety headache. Yet the blame does not rest entirely with the engineers and operators. Some mining engineers have accepted, and even instigated, geologic analysis as an adjunct to operations. The exacting nature of the mine environment is not one that tolerates geologic imprecision. A mining college professor pointed out to me that one of the obstacles was the legacy of bad mining geology.

As bad as this situation sounds, it now appears that a mix of geology and mining is occurring at an increasing rate. The phrase "coal mining geologist" need no longer be considered a simple contradiction in terms. Much of the leadership in this must be attributed to recent oil-company involvement in western mining. Not only have oil companies had a different approach to the role of geologists and a higher tolerance of overhead costs, but also the scale of quality variation and seam discontinuities has required a tighter control than in the principal midwest and eastern seams.

The contribution of geology to mining operations is most apparent in roof control. As several of the previous examples illustrated, the impact of bad roof on mine dilution can be severe. Examples of roof conditions related to different types of roof rock are shown in figure 14, an Illinois mine in the Herrin (No. 6) coal bed and in figure 15, a Utah mine. The coming of age of geology in mining is indicated by recent activities of the U.S. Bureau of Mines (USBM) (for instance, Jeran and Jansky, 1983) and by the remarks of a USBM geologist in a mining trade journal (Moebs, 1985). He writes:

> Studies directed toward increasing the utilization of geologic methods in coal mine ground control are becoming more important. It is commonly recognized that geology is the key to effective ground control. That is, a sound knowledge of the character and structure of rock provides a sound basis for mine planning and selection of appropriate roof-support methods.
>
> For example, studies by the U.S. Bureau of Mines have identified geologic structures in mine roof rock that contribute to many roof falls in Appalachian coal mines. These structures, including paleo-channels, kettlebottoms, scours, pinchouts, slickensides, clay veins, crevasse splays, and joints, can often be identified during, and sometimes before, mine development. Mine projections can be revised to reduce the adverse effects of discontinuities in roof structure, large roof areas of laminated sandstone or incompetent strata generally can be delineated or inferred from exploratory drill-hole data, and the need for supplementary support can be anticipated. Accurate descriptions of roof geology also provide some indication of optimum length and type of roof bolts that should be installed.

An instructive example of the geologist's role was described by Horne and others (1978). A coal bed was found to be split above and below by a channel sand. Mining followed the lower and thicker split, where the roof was composed of channel-margin sediments and severe roof falls were encountered. Advances were made three different times before a geologist was consulted, recommending driving through the upper split because of better roof conditions and in spite of the mining engineer's deeply rooted aversion to mining rock.

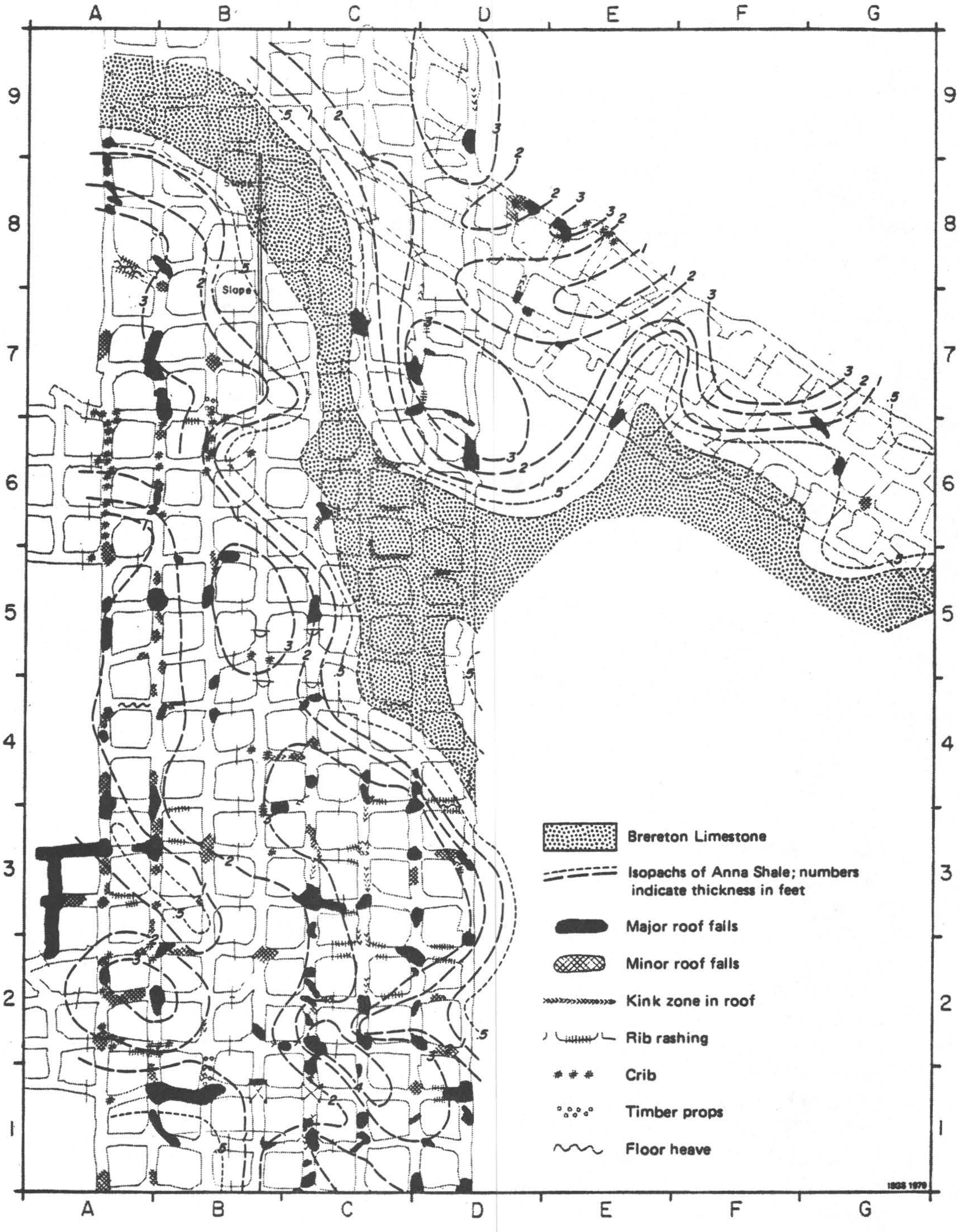


Figure 14. Distribution of roof falls and their relation to the immediate roof strata in west-central Illinois. No roof falls occur where Brereton Limestone directly overlies the Herrin (No. 6) Coal, although some shallow flaking of "clod" may occur locally. Grid interval is 200 feet (61 m). (From Krausse and others, 1979).

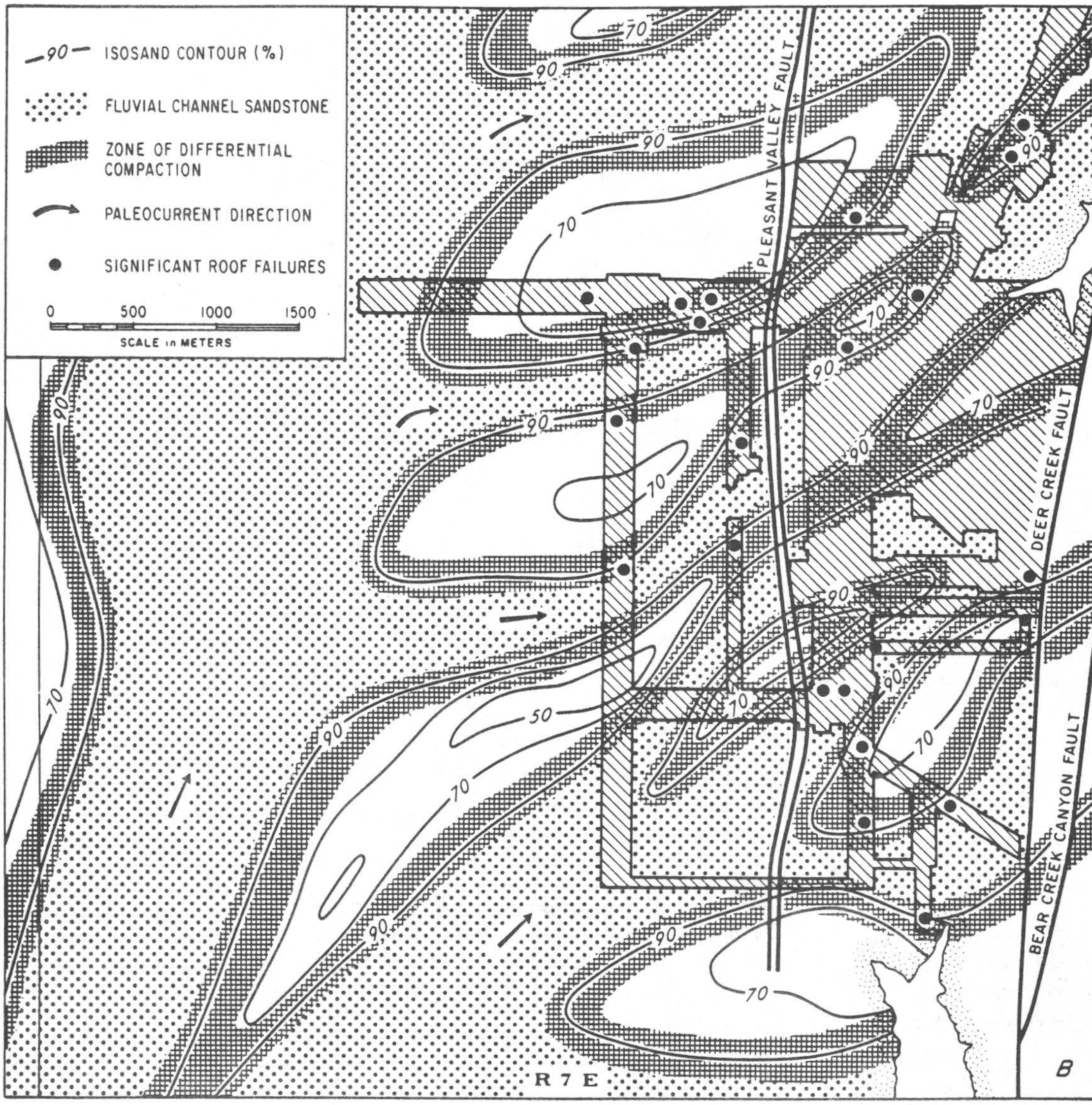


Figure 15. Roof-rock/roof-fall relationships, Utah (from Mercier and Lloyd, 1981).

MYTH NO. 5: FOR UTILITIES, COAL GEOSCIENCE IS THE MINING COMPANIES' BUSINESS

The only generality one can make about utility attitudes toward, and technical involvement with, coal geoscience is that they span a broad spectrum. The degree of involvement certainly swings with market conditions. There is a tendency toward locking up supplies through long-term contracts and captive operations under sellers'-market conditions and a tendency toward short-term contracts and spot purchases, along with selling captive operations that have suddenly become bad business, under buyers'-market conditions. Accompanying these swings in purchasing patterns is an ebb and flow in utilities' involvement with geoscience.

Vaninetti (1981) has characterized the tradeoffs between different purchasing patterns and the associated risks as seen by utilities (fig. 16). Individual circumstances have had a lot to do with how sensitive utilities are to these different sources of risk. For utilities that have long-term contracts and few hitches resulting from adverse mining conditions or coal-quality changes, coal geoscience is a distant memory, accounted for at the time of initial contract selection and negotiation. The situation is not quite the same for utilities that have many sources of coal, as in much of the midwest, east, and south. Although it is much easier for them to replace one supplier with another, there are costs in doing so. One utility executive summed up this situation with the comment, "You can't burn coal contracts!" Nevertheless, these utilities' involvement in applications of coal geoscience is by no means uniform or intense. Finally, there are examples in the east and west where making do with existing sources of coal--either contract, equity or captive--has required much more geoscientific information to be developed than was initially envisioned. Once the need for this information has been demonstrated (often painfully) to these utilities, their expertise and knowledge of the value of this information is carried forward into their future purchasing activities even as they shift toward shorter term and more flexible coal-supply arrangements.

Institutional considerations also influence utilities' extent of involvement in coal geoscience. Knowledge of geologic conditions is much more important to the buyer in a cost-plus contract where the costs will automatically be passed through than it is in a fixed-price contract where the seller carries the risk (as well as the reward). In the latter case, knowledge by the utility of geologic conditions may even prove detrimental to their own interests, as one utility planner suggested, because it muddies up the question of who has knowledge of the risks and, consequently, incurs the responsibility for any remedies. Yet, even in this case, a minimum of geologic knowledge on the part of the buyer is essential when interpretations have to be made about whether

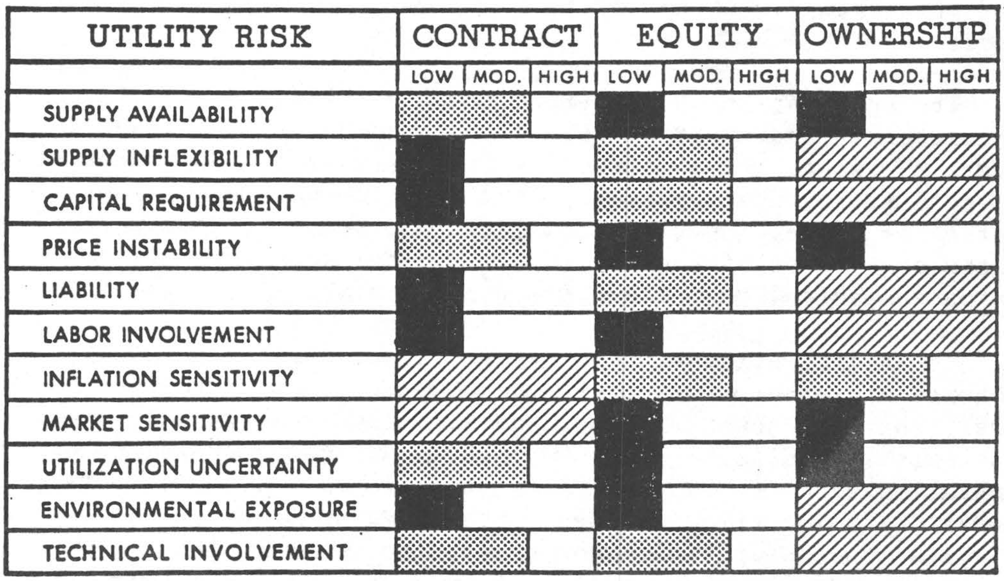


Figure 16. Risks associated with different coal procurement methods (from Vaninetti, 1981).

certain conditions encountered during mining are "acts of God" or--another example--whether clauses that pass through the unanticipated costs of compliance with regulatory requirements are properly invoked. Such clauses might be a convenient mechanism to fund more costly mining practices in response to adverse geologic conditions.

The combination of market forces, individual purchasing circumstances and experiences, and contractual styles leads to the diversity of utilities' current attitudes toward, and awareness of, coal geoscience. These factors alone do not lead to any particular trend. Another consideration, however, does portend continued erosion of the attitude that coal geoscience is just mining companies' business: plant performance.

To an increasing extent, utilities and their regulatory agencies are attempting to improve power-plant performance. Generating more power, longer, and with lower maintenance costs from existing units pays off in postponing costly additions of new generating capacity and in holding the lid on rising costs of plant operations. The trick has been to achieve desired performance levels without sacrificing these economic gains to the higher costs of better quality coals. At the same time, utilities have been under pressure to hold down their fuel costs, but not at the expense of degrading plant performance through using lower quality coals and incurring a higher net generation cost. Consequently, utilities are in the midst of a revolution, going from purchasing coal on a simple basis of dollars per ton or dollars per million Btu to determining the appropriate cost in terms of cents per kilowatt-hour. There is no simple formula for doing this given the variabilities of coal quality, the idiosyncrasies of complex engineering systems, and the human dimension. Yet it is easy to see how this trend places a premium on thoroughly understanding and being able to anticipate coal-quality characteristics.

What cost savings might come from this?

- Five years ago an eastern utility estimated that better control of sulfur and ash content of coal would improve boiler availability by 5 percent. At that time, this translated to a savings of $1,500,000 per year on a typical 650 MW unit.

- A western utility estimated 2-3 years ago that for every 1 percent increase in the coal-ash content above the design levels, there was a 1 percent reduction in plant availability. This translated to a cost of approximately $1 million per percentage point.

- An eastern utility spokesman pointed out that the cost savings on their system from improved coal quality are not reflected in any clear-cut changes in operating conditions. Rather, he suggested they may be reflected in extended plant life.

- An eastern utility estimates that each point loss in their coal supplies' grindability index is equivalent to a 200 Btu loss in heat content. This is because of curtailments due to the inability to feed coal to their boilers at a sufficient rate. Systemwide, their use of nondesign grind coals is costing them a 10 percent loss in generating capacity. Although this loss is currently offset by the lower cost of these coals, the value of that capacity will increase significantly in coming years.

MYTH NO. 6: UTILITIES KNOW WHAT COALS ARE BEST FOR THEM

This statement is basically true with a few exceptions. One industry-wide exception already mentioned is the difficulty in making extremely fine-tuned evaluations of the engineering and economic impacts of small changes in the many dimensions of coal quality. Other recent and notable exceptions concern the use of coals with which the industry has a relatively short track record and/or the performance of environmental control technologies with which the industry has accumulated much less experience than with the basic operations of coal combustion. The reason for citing examples of these exceptions is twofold: (1) to demonstrate that utilities, boiler manufacturers, and electrostatic precipitator manufacturers are fallible (the geology and mining professions do not have the only corner on uncertainty); and (2) to suggest that there may yet be further change in our understanding of the identity of important coal characteristics (some of which we may have come to take for granted), particularly as newer technologies come into play.

- An eastern utility purchasing premium low-sulfur coal found that the sulfur content was too low to impart a necessary charge to the fly ash particles for them to be captured effectively by the electrostatic precipitators. A higher sulfur coal had to be purchased and blended with the premium supplies to achieve acceptable precipitator operation.

- A southern utility's first experience with a new coal source was that the sodium content was too low, causing much the same problems as in the previous example. A higher sodium coal was obtained from a new mine for a new power plant and it was delivered on spec. This time, the sodium content was too high and caused serious, unanticipated fouling on the precipitator plates and wires. To mitigate the problem, only a fraction of the original coal could be accepted and detailed analysis of the sodium distribution was required to maintain an acceptable blend of coals.

- An eastern utility's coal units were designed to burn soft coal. In broadening the geographic range of their coal supplies over the past 10 years, the Hardgrove Grindability Index proved to be an inaccurate guide to coal-milling characteristics because of its poor reproducibility. Now the utility must perform test burns on all their serious candidate coal sources.

MYTH NO. 7: WITH THE RIGHT TECHNOLOGY, QUALITY VARIATION DOES NOT MATTER

Whatever breakthroughs we may have already made or will yet make in combustion technologies, it is clear we will be using the technologies we've got now for a long time to come. In every case, an understanding of coal quality and variation is important to designing these technologies at an economic optimum. With sufficient knowledge, we might even be able to forego or postpone the investment in a technological fix.

An extreme example of this, which illustrates the role of geoscientific techniques and the criterion of economics in ultimately justifying a technology, was a coal-cleaning plant evaluation for a western underground mine. This evaluation involved preparing detailed maps of seam thickness, ash content, faulting, roof and floor lithologies, and the mine design (fig. 17). Mine dilution corrections were calculated and an integrated picture of run-of-mine ash developed (fig. 18). After all this, it was decided a preparation plant was not necessary--at least not for the present. A detailed knowledge of the run-of-mine coal quality was critical to this determination.

MYTH NO. 8: THE RESEARCH ISSUES BEHIND ACID RAIN REGULATION CONCERN THE ENVIRONMENTAL SCIENCES, NOT COAL-QUALITY GEOSCIENCE

A prodigious amount of research into acid rain, its causes and effects is taking place around the country. A hint of the mind-boggling complexity of this issue, particularly for determining the payoff of specific mitigation measures, is given in figure 19. Figure 19 is based on calculations of where an oxygen molecule would arrive if released every 2 hours from a central location over the course of 1 year. Obviously, source-receptor relationships are difficult to determine, and as a result, a vast effort is going into the very tedious job of taking many measurements of wet and dry deposition at many sites mainly in the eastern United States.

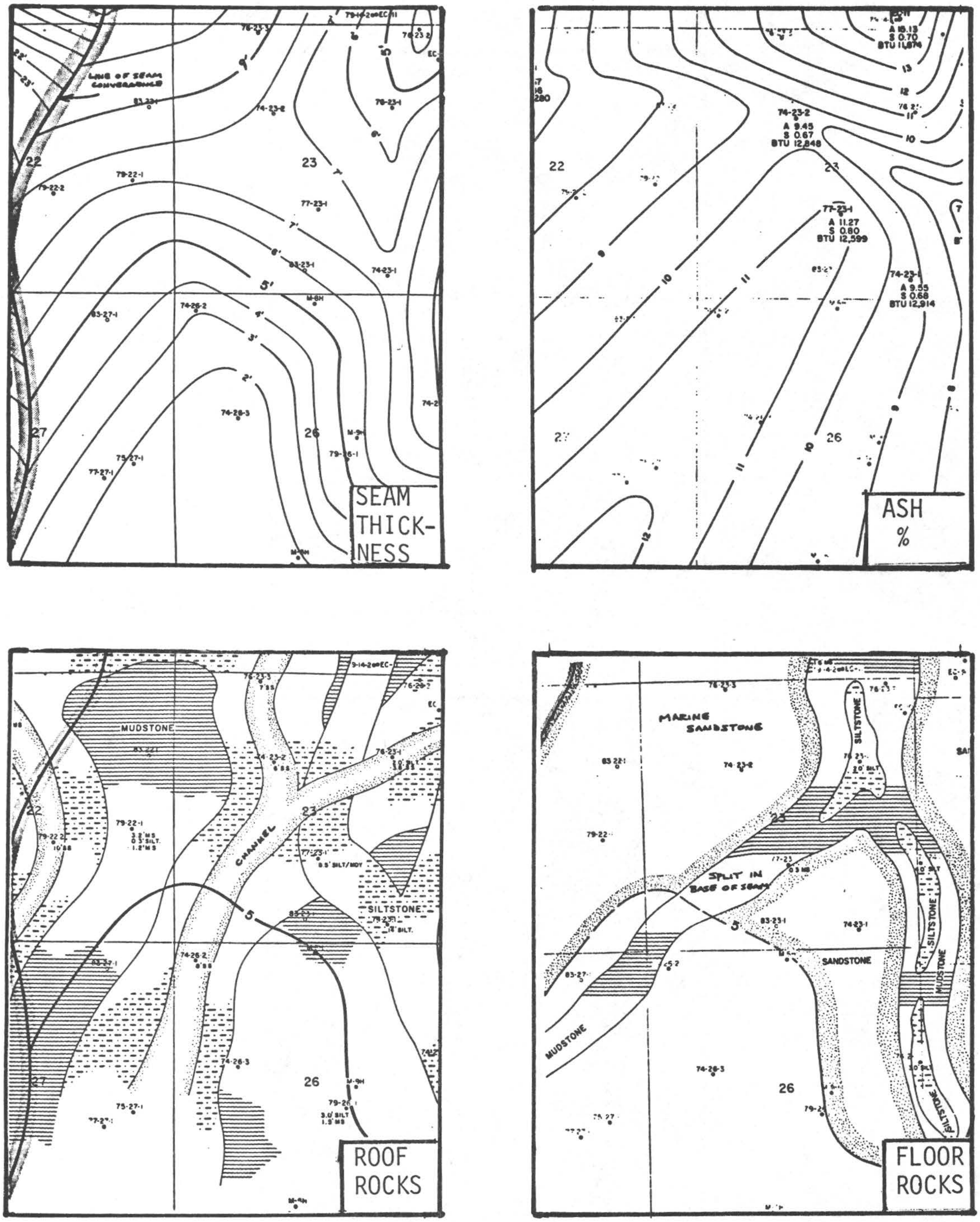
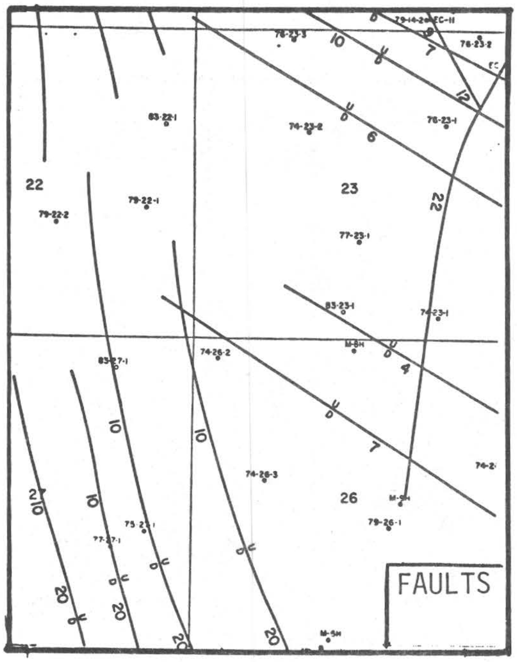


Figure 17. Geologic information contributing to run-of-mine coal-quality assessment (proprietary mining-company data; details undisclosed).



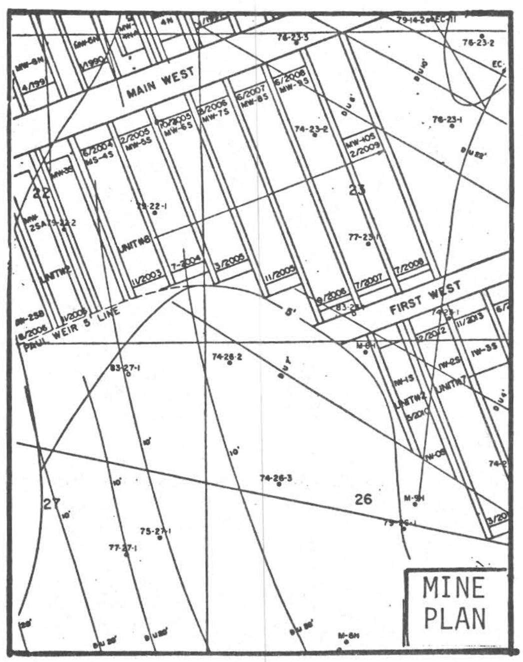


Figure 17. (Continued) Geologic information contributing to run-of-mine coal-quality assessment (proprietary mining-company data; details undisclosed).

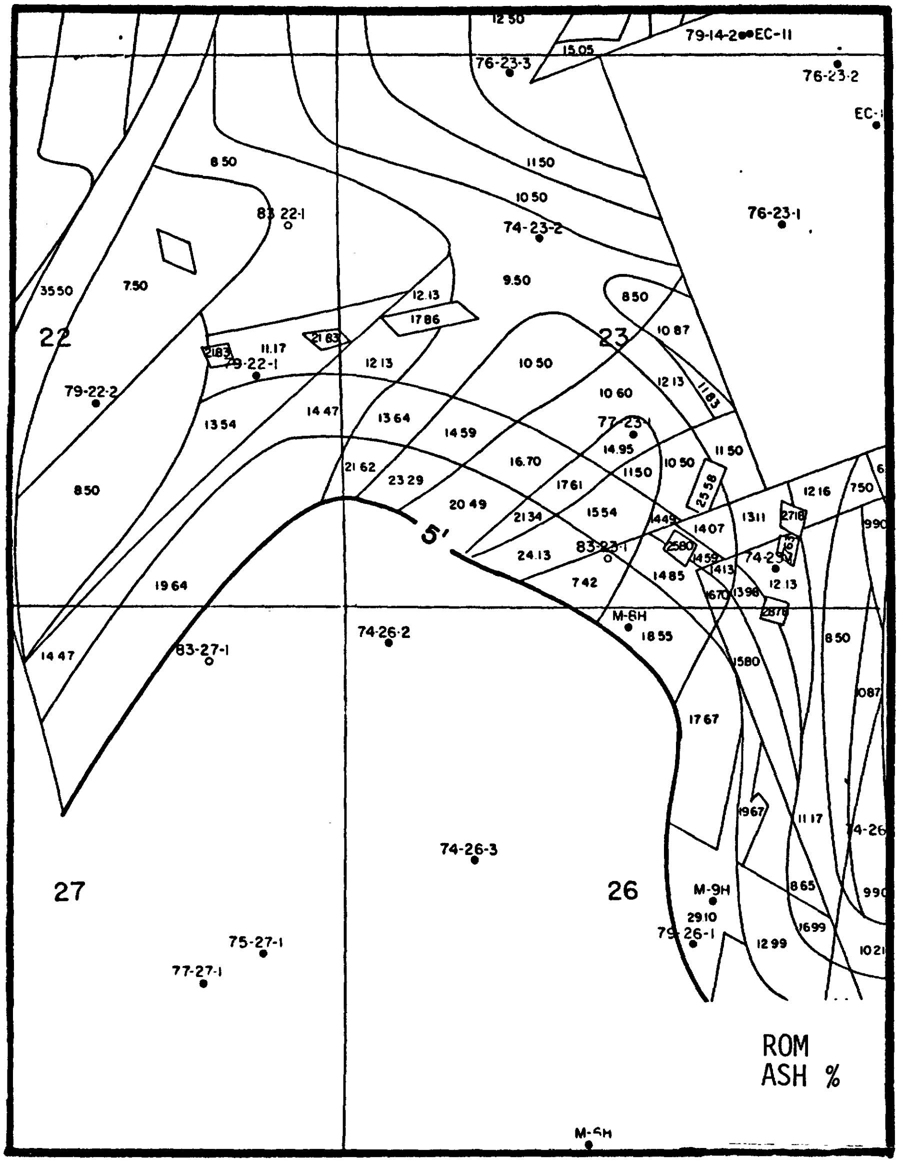


Figure 18. Expected run-of-mine (ROM) ash content of coal. Expected ash content reported in percent to two decimal places in the center of each block. (proprietary mining-company data.)

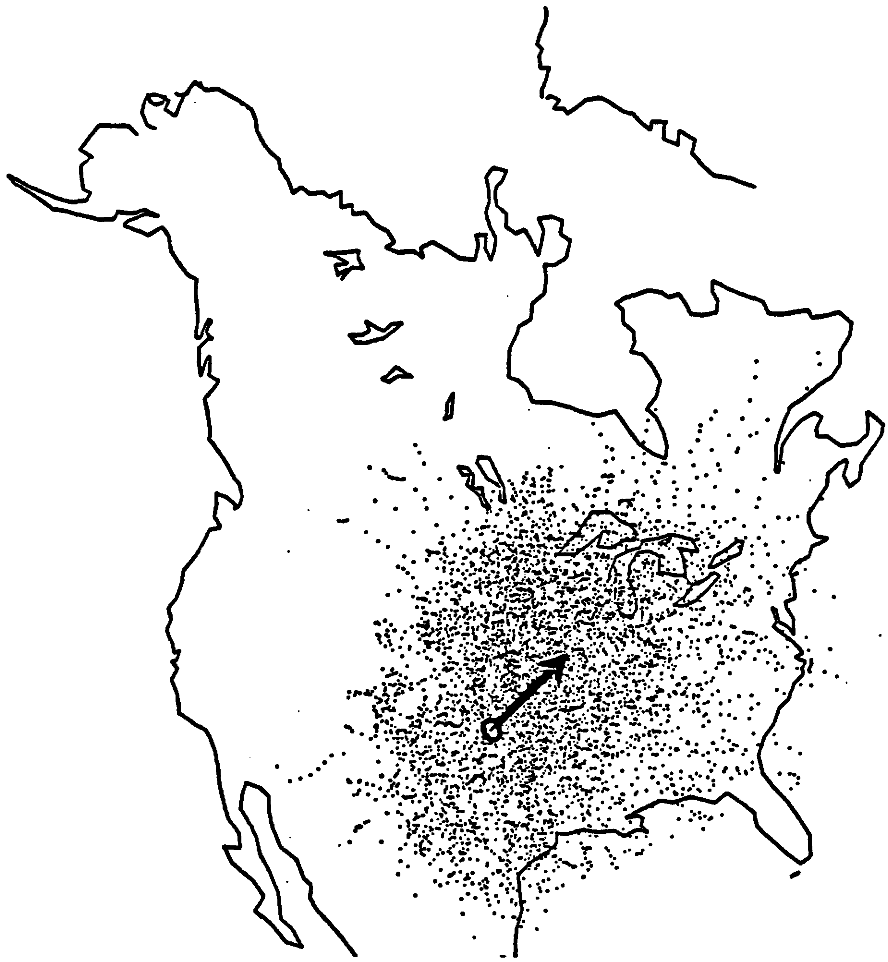


Figure 19. 48-hour destinations of oxygen molecules released every 2 hours from a central U.S. location. (R. Husar, Washington University, written communication, 1985.)

Although this research is central to developing the scientific rationale for acid-rain mitigation measures, the other side of the equation--the costs of reducing sulfate and other emissions--has not been as thoroughly investigated. Here, geoscientific information in the form of a sound understanding of the extent, quality, recoverability and costs of low-sulfur coal supplies is badly needed.

The compliance strategy decision dilemma facing utilities looks something like the sketch in figure 20. They face a choice--exaggerated and simplified in this figure--between switching from higher to lower sulfur or cleaned-to-compliance coals and installing scrubbers or other, newer technologies. A 1983 survey of utilities revealed a wide range in their perceptions of how high the premium for low-sulfur coal might go under acid-rain legislation (figure 21). Since then, several studies focusing on eastern low-sulfur coal availability have indicated that a more optimistic view of the low-sulfur coal premium may be warranted (table 2). The strongest indicator was the procurement experience of Detroit Edison last year, which smoked out bids that totaled a production of 75 million tons per year of low-sulfur coal. All of this came from the Central Appalachian region.

As encouraging as this experience was, it could reflect a number of factors that would undermine its reliability as an indicator of long-term supply potential. However, little other information is available to resolve this important question other than second-hand analyses of earlier studies.

MYTH NO. 9: THE GOVERNMENT IS PROVIDING FOR PUBLIC INFORMATION NEEDS ON THE NATION'S COAL SUPPLIES

This attitude obtains some support from the fact that the coal resources of the United States are enormous. An estimate as high as 11.6 trillion tons has been published (Ferm and Muthig, 1982). A pessimistic estimate of 120 billion tons of steam coal recoverable by mining has also been published by Schmidt (1979). However, even this very low estimate, an improbable number by all accounts, is high enough that neither cries of impending shortage nor a call for Congressional scrutiny are likely to emerge in the foreseeable future. If having enough resources were all that mattered, then a negligible government role would appear justified.

The problem is that the adequacy and urgency of understanding coal quality are quite different from concerns over raw tonnage levels. Apathy over the latter has no place rubbing off onto the former. The significance of coal-quality information to public policy became apparent relatively recently with passage of the Clean Air Act of 1970. Responding to this need, the U.S. Bureau of Mines and the Environmental Protection Agency conducted analyses

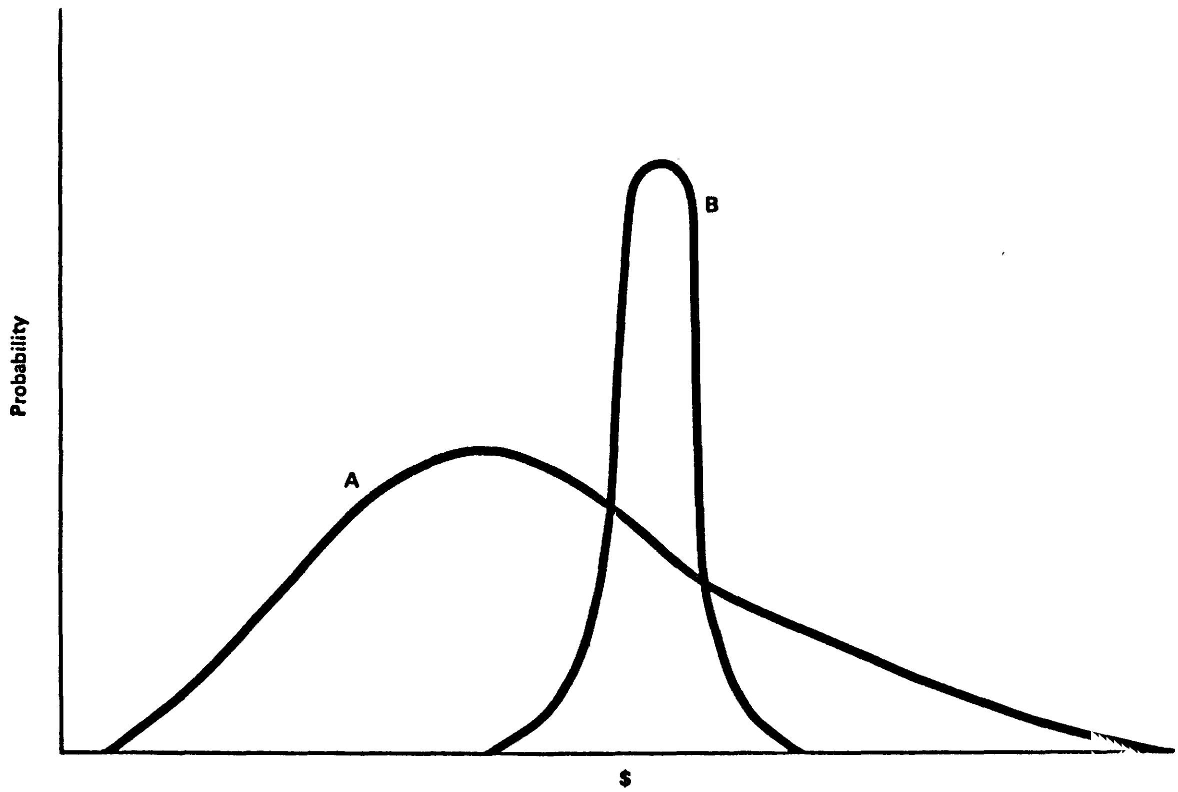


Figure 20. Example of compliance strategy, decision dilemmas facing electric utilities as illustrated by probability distributions for two events--A and B. The cost of building a flue-gas scrubber might be high, but fall into a narrow range, such as event B, whereas the costs of switching to a lower sulfur coal are less well known giving them a much wider range such as event A. In this example there is a finite possibility that the costs of switching could exceed the costs of scrubbing, although the probabilities favor the opposite.

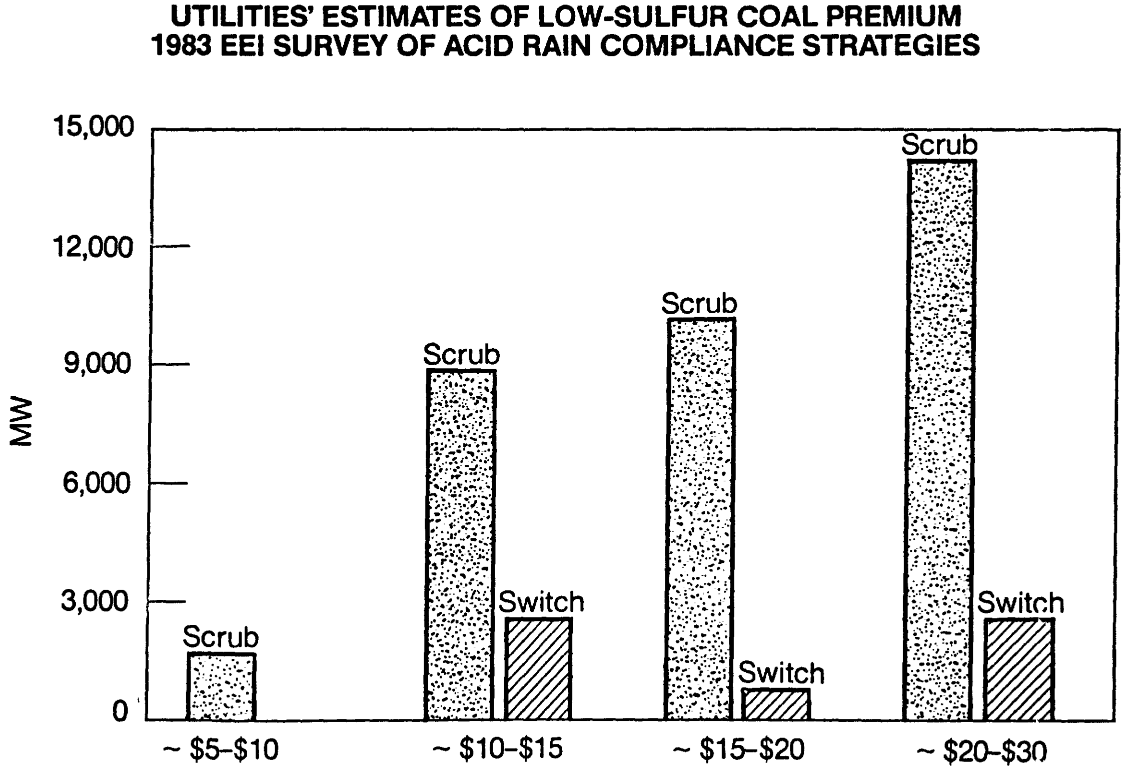


Figure 21. Wide range of views of price premium for low-sulfur coal provided by 24 utilities responding to Edison Electric Institute (EEI) survey, as interpreted by the author.

Table 2. CHANGING VIEWS OF LOW-SULFUR COAL AVAILABILITY IN THE CENTRAL APPALACHIAN REGION

Central Appalachia Production Increases for Coal-Switching Scenarios

(Estimates in this part of table not comparable because developed for different regulatory assumptions.)

SO_2 rollback (million tons)	6	8	10	10	12
Production change (million tons per year)	+34 (Klein, 1984)	+51 (ICF, Inc., 1985)	+78 (Klein, 1984)	+35 to 50 (Parker & Thompson, 1984)	+49 (ICF, Inc, 1985)

Conflicting Evidence of Low-Sulfur Coal Availability

Source	Outlook
SOHIO, 1981 (Keady and Rimstidt, 1983)	Pessimistic
ICF, Inc, 1981-82 (Klein and Meany, 1984)	Unclear
Electric Power Research Institute Workshop, 1983 (Tennican, Wayland, and Weinstein, 1984)	Optimistic
Edison Electric Institute Survey, 1983 (National Economic Research Assoc., 1983)	Mixed, Pessimistic
Informal Survey, 1983-84 (Platt, 1985)	Mixed
Congressional Research Service, 1984 (Parker and Thompson, 1984)	Optimistic at mine; Pessimistic delivered
Detroit Edison, Bids, 1984 (Tennican, Wayland, and Weinstein, 1984)	Optimistic
Temple, Barker, and Sloane, Inc., 1984 (Tennican, Wayland and Weinstein, 1984)	Optimistic
Skelly & Loy, Mining block studies, 1984 (Hughes, Gunnett, and Rathbun, in press)	Pessimistic, Mixed
Boulder Exploration Group, Inc., Production capacities, 1984 (Hughes, Gunnett, and Rathbun, in press)	Optimistic

of the sulfur distribution and washability characteristics of U.S. coals in the mid-1970s; and the U.S. Geological Survey (USGS) initiated a program of coal sampling and chemical analyses to address many of the deficiencies in the existing, coal-quality data. Ten years later, it is appropriate to ask what we have learned.

The situation appears to be that current knowledge about coal-quality parameters as they relate to coal resources is limited by a small number of samples, incomplete characterization of coal quality, and an unrepresentative distribution. Most data on coal quality refer to mined-out areas, and there is little data on the quality of deeper coals yet to be mined. This paucity of coal-quality data is reflected in estimates that have been made of the number of existing coal-quality samples per billion tons of resource (one to five samples), the number of years the USGS analytical program would have to continue before the desired number of analyses is reached (20 to 40 years), and the number of coal samples tested for washability characteristics (600 samples by 1981, not many more today) (J.H. Medlin, USGS, oral communication, 1984).

In light of these facts, it is sobering to reflect on the course of government programs to characterize coal quality and recoverability. This symposium appears to be poised, not at the beginning of a Federal and State effort to characterize coal resources, but at its end:

- o Historically, the USGS has been the primary source of information on in-place coal resources. The Bureau of Mines estimated the recoverable resource portion of in-place coal. With the creation of the Department of Energy, all coal-resource-related work at the Bureau of Mines ceased. In the Department of Energy, coal-resource-related work dwindled to negligible levels by 1981. Before that, modest funds had been directed to updating resource numbers for several States in cooperation with the USGS and State surveys.

- o Historically, the Bureau of Mines carried out a coal-washability testing program. The work maintained momentum after the creation of the Department of Energy, largely due to the support of the Environmental Protection Agency which reached a peak during the 1977-79 period. The funding for this program effectively ceased at the end of FY 1984.

Reinstatement or expansion of government's role in characterizing the Nation's coal resources is as much a responsibility of the mining and utility industries as it is of government. The private sector's responsibility is to convey to government its needs for research and information.[1/] These needs do not stop at preliminary assessment of coal quantity and quality. They extend to information about coal marketability, recoverability, and recovery costs. To communicate these needs constructively, mining and utility companies will have to overcome some of their traditional distrust of and sense of irrelevance of government programs. This symposium is an excellent start to this process.

CONCLUSION

The preceding myths span a broad spectrum of activities. No group is immune to their influence. Recognizing that these and similar myths are real obstacles to the application of coal-quality geoscience is important, not only in designing a national coal-quality research agenda, but also in winning the public and private support and cooperation crucial to implementing such an agenda.

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[1/]Several recent reports highlight some of these needs through illustrating the deficiencies of existing information. Examples are a nationwide overview of coal-supply uncertainties that impede determination of future coal price and availability (Klein and Meany, 1984); an evaluation of the critical research issues underlying the coal market outlook (Tennican, Wayland, and Weinstein, 1984); and a methodology for making regional coal recoverability and cost estimates (Hughes, Gunnett and Rathbun, 1985).

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COAL QUALITY AND POWER-PLANT PERFORMANCE

by

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INTRODUCTION

Coal is a generic term referring to a family of solid fuels that varies widely in both composition and physical characteristics. Although it does contain hydrocarbons, sulfur, nitrogen, oxygen, and most inorganic elements, these are not distributed uniformly. Ideally, the suitability of a coal for use in power generation should be based upon its type and rank. However, the correlation between coal rank, type, and combustion properties is tenuous, necessitating the use of empirical relationships which apply to specific applications and are based upon the "quality" of coal. Rank and type are fundamental properties of coal, but quality is an economic value established by the relationship between these fundamental properties and the specific process application. For example, a high-quality coal for power generation need not, and most probably will not, be a high-quality coal for coke production.

High interest rates, increased construction costs, and reduced demand for power emphasize the need for the utility industry to maximize the utilization of existing embedded capital. Consequently, any reduction in power-plant availability because of coal quality must be avoided. However, Blackmore (1980), Anson (1977), and Phillips and Cole (1980) have presented evidence indicating that the performance of existing power plants has deteriorated steadily in recent years. Nationally, the availability of generating units fell from 78 to 63 percent over the 10-year period from 1968 to 1978. Blackmore argues that this deterioration is linked to coal quality because the average Btu level of coal delivered also decreased from approximately 11,750 Btu to 10,600 Btu. Blackmore used an 800 MW unit in the American Electric Power system to demonstrate that this national trend applies to specific units. Figure 1 shows that the availability of this unit parallels closely the Btu content of the coal being fired. However, as illustrated in figure 2 (also due to Blackmore), Btu content is not the sole coal-related factor affecting availability. A comparison of two units of the same size, design, and age indicates that the unit fired with a coal

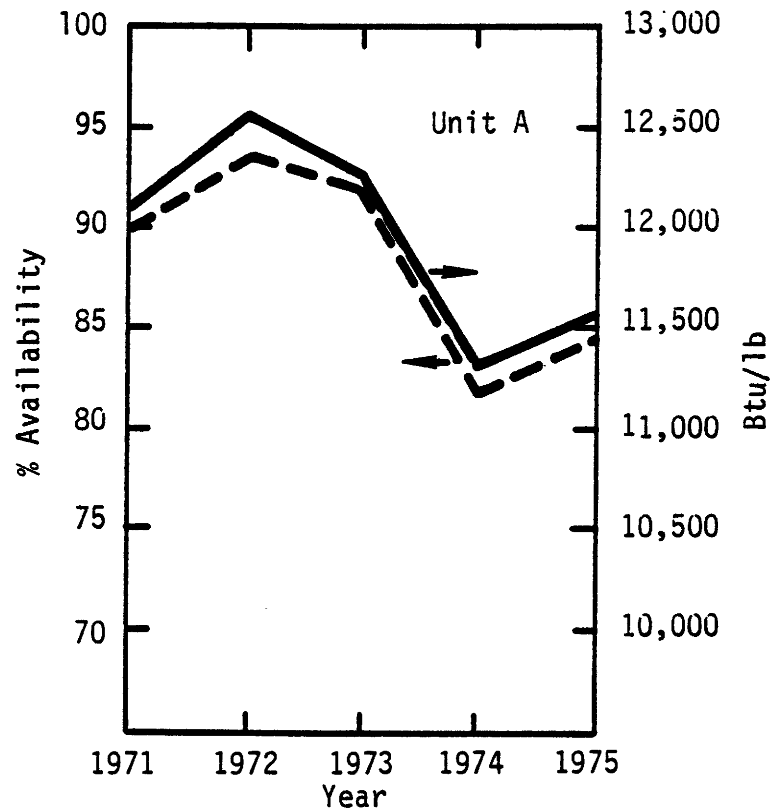
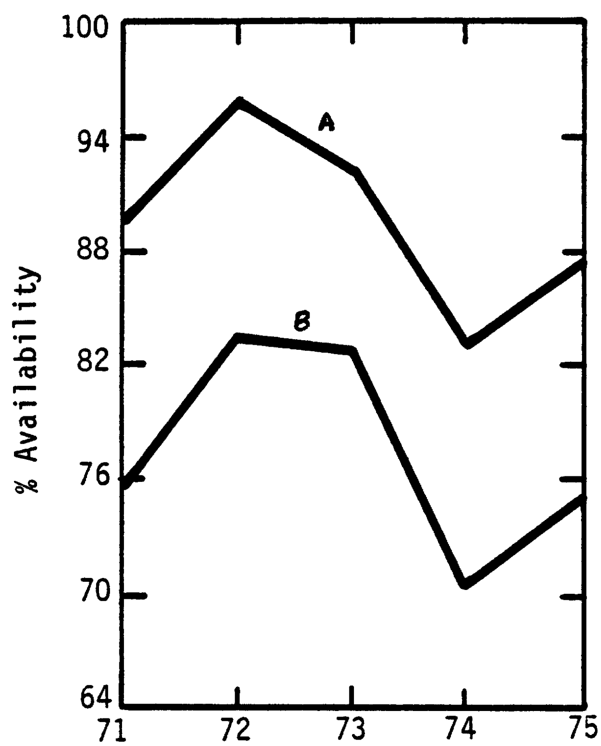


Figure 1. Availability versus heat content of one 800 MW Unit in the American Electric Power system (Blackmore, 1980).



Unit A versus Unit B
1971 - 1975

	Unit A	Unit B
Ash and sulfur	15.2%	19.7%
Heat index	11,810 Btu/lb	11,460 Btu/lb
Slagging index	Low to medium	Very high
Ash fusion temperature	More than 2700°F	Less than 2500°F

Figure 2. Comparison of coal properties and the availability of two similar 800 MW Units (Blackmore, 1980).

which had a greater tendency to slag (lower ash-fusion temperature and higher slagging index) had a lower availability. It has been estimated (Budder et al., 1981) that a loss of 1 percent availability could cost in excess of \$1.5 million per thousand MW_e per year or approximately 0.4 mills per kWh (averaged over 30 years). Consequently, there is considerable incentive to establish which properties of coal reduce availability and thereby establish the real cost of coal.

This paper discusses the impact of coal quality on power-plant performance and costs and the influence of coal properties on the heat-release processes.

COAL-QUALITY IMPACTS

Several investigations of the relationship of coal quality to power-plant performance have been conducted by utility companies and other organizations. Table 1 shows the results of an analysis conducted by Blake and Robin (1982) to evaluate the impact of increasing coal-ash content from 15 to 20 percent. The analysis was based on a detailed review of internal records as well as published reports correlating coal quality with power-plant performance and assumed no change in the delivered cost of the coal. The largest cost factors were maintenance and ash-pond costs, followed by availability loss. The cost impacts on boiler efficiency and operation and auxiliary power are much smaller. The following sections discuss the methods which can be used to calculate the cost impacts of coal quality on the following power-plant performance factors:

- Heat Rate - This includes boiler efficiency and auxiliary power.

- Availability Loss - This includes capacity limitations as well as component failures leading to partial or full outages.

- Maintenance and Operational Costs - These costs include routine repair following equipment failures, and costs for scrubber reagents, ash disposal, and so on.

Coal Quality and Heat Rate

Coal quality can affect heat rate by changing the boiler thermal efficiency, auxiliary power consumption, and turbine cycle efficiency (via changes in steam conditions). The key boiler heat losses affected by coal composition are the dry flue gas loss, losses due to moisture in the flue gas, and losses due to incomplete combustion. All are dependent on coal quality. Dry flue gas loss is calculated easily given the excess air. However, excess air requirements depend on flame stability, carbon burnout,

Table 1. Evaluation by Southern Company Services (SCS) of the cost impact of increasing coal ash content from 15 to 20 percent on a utility boiler. The cost impact corresponds to 7 percent of the coal cost. (From Flake and Robin, 1982).

	Cost ($1000)
Boiler efficiency	148
Operation and auxiliary power	67
Maintenance	957
Availability loss	529
Ash pond cost	905
Total	2,605

slagging, and heat-transfer patterns in the furnace and convective pass and are difficult to predict with existing correlations. Moisture losses are calculated easily by means of standard engineering relationships. Incomplete combustion is manifested primarily by carbon in the bottom and fly ash. The carbon remaining in the bottom and fly ash is due to incomplete oxidation of coal char remaining after devolatilization. The dynamics of char combustion depend on the coal composition and particle-size distribution, the rate of fuel/air mixing, the furnace thermal environment, and the amount of excess air.

Power-plant auxiliaries consume power for coal handling, feeding, pulverizing, ash removal, precipitation/scrubbing, and air moving (fans). Coal quality affects power consumption for most of these components in a straightforward manner (given the excess air level), with the exception of the pulverizer. The parameter used most often to link coal quality to pulverizer performance is the Hardgrove Grindability Index (HGI). Manufacturers have developed empirical relationships which relate coal characteristics to pulverizer capacity and power consumption.

Normally, turbine-cycle efficiency is not considered to be affected by coal quality as the steam-cycle components do not contact the coal. However, the steam conditions depend on the heat-absorption pattern in the furnace and convective pass which is affected by coal composition and excess air requirements. Changes in the heat distribution may result in an inability to achieve superheat or reheat temperatures or require excessive attemperation, which can degrade turbine-cycle efficiency significantly.

Coal Quality and Availability

The costs of availability losses due to coal-quality degradation can be many times larger than costs of heat-rate increases, depending on a utility's economic situation. In the short term, an availability loss at one unit requires the utility to operate another unit with a higher net power generating cost. In some cases the differential costs will be small; for example, if a sister unit can be brought on line. In other cases, the utility may need to purchase power or use peaking gas turbines at significantly increased cost. In the long term, chronic availability loss will require construction of new units. Thus, the net cost of availability loss expressed as the cost of differential power can range from essentially zero to several mills/kWh.

Availability losses are related to many factors including plant design, operating and maintenance procedures, and, of course, coal quality. Availability losses can be divided into two major categories: capacity limitations which are related to specific input conditions (such as a mill capacity limitation due to a low-heating-value coal); and failures which can reduce capacity (partial outage) or cause a shutdown (full outage). Ideally, capacity limitations should be predictable based on the specific coal characteristics. However, there is considerable uncertainty in calculations of capacity limitations, especially due to an inadequate understanding of the mineral-matter effects on phenomena such as slagging and fouling. Availability loss due to failures includes a certain degree of randomness. For example, the specific locations and times of tube failures due to erosion or corrosion cannot be predicted currently. Because of the probabilistic nature of such availability loss, at present the only effective way to correlate it with coal properties is to evaluate a data base using statistical techniques.

Coal Quality and Maintenance Costs

The relationships between coal quality and maintenance costs are difficult to assess because of three factors: the records maintained by utilities, the impact of non-coal-related factors, and plant-design variations. Utilities use a variety of procedures to account for maintenance costs in coal-fired units. Although these procedures generally meet utility needs, they often make it difficult to evaluate coal-quality impacts. For example, although the maintenance cost resulting from a tube failure may be identifiable, it may not be possible to determine whether the tube failure was related to coal quality, water quality, structural problems, or other effects. Maintenance costs depend on the utility's specific situation as well. If a unit is required for power generation, routine maintenance may be bypassed, reducing maintenance cost and vice versa. Power-plant components of varying design have different maintenance requirements.

COAL PROPERTIES AND COMBUSTION

During combustion, chemical energy in the coal is converted to thermal energy. The function of the radiant section of the steam generator is to provide the equipment to ensure that this is accomplished in a safe and efficient manner and the volume to ensure that heat is transferred from the combustion products so as to reduce ash-particle temperatures to some "safe" level, thereby preventing problems due to ash deposition. The fates of three coal components during the combustion process have a significant impact on efficiency and availability and, therefore, upon the cost of power generation. These are carbon, mineral matter, and trace organic species (nitrogen and sulfur).

Coal Char Combustion

Char is that fraction of the coal which remains after the volatiles have evolved from the coal particle. Char burnout is usually greater than 99 percent in boilers operated in the United States. However, the rate of char combustion influences the properties of the fly ash, heat-release patterns, heat-absorption patterns, and boiler efficiency. The carbon content of ash influences fly ash precipitability because the presence of carbon lowers the fly ash resistivity and increases the solids loading. The rate of char oxidation affects heat release and absorption patterns, primarily because of its impact on ash properties. The melting point of most ashes is lower under reducing conditions. Thus, an ash particle containing significant quantities of carbon will have more probability of producing molten ash particles. In addition, if carbon is present on wall deposits, depletion of available oxygen promotes the formation of a molten deposit (slagging).

Mineral Matter

Mineral matter in the coal is converted to ash during the combustion process. Many of the availability problems associated with coal quality in the steam generator relate to the fate of coal mineral matter and involve three closely related phenomena: slagging, fouling, and corrosion. The mechanism of slag formation is not well understood. A simple heat-transfer analysis shows that heat flux to the walls of a typical modern utility furnace covered by a thin layer (on the order of 1 mm) of powdery ash can result in a temperature drop of approximately 1000°F. If conditions are such that ash particles reach the furnace wall in a molten or sticky state, and if they wet the wall surface or otherwise adhere, the temperature of the surface exposed to the flame will increase. Thus, for slagging to occur, it is necessary that ash particles of the appropriate composition be transported and adhere to the furnace wall. If the surface temperature rises beyond the melting point, then the deposit layer begins to flow. The formation of fouling deposits on superheater tubes also requires that particles of particular composition be transported to the tube surface and adhere. The difference between slagging and fouling is that fouling is normally considered to take place because of a build-up of dry deposits. However, both phenomena are associated with the composition of the coal ash contacting the solid surface.

Many indices based upon coal properties have been calculated to assess the potential of coals to slag, foul, and corrode furnaces and superheater tubes. The Electric Power Research Institute (EPRI) is currently conducting a study to develop an improved understanding of the knowledge of slagging and fouling as affected by coal characteristics, boiler design, and operating conditions. As part of this study, a 24-page questionnaire was circulated to utilities to solicit information on the frequency of problems resulting from slagging and fouling. During the initial statistical analysis, the relationships commonly used for slagging and fouling were examined. Figure 3 compares the frequency of slagging by plotting slagging indices as a function of steam generation per unit plan area for the coal being fired. The slagging factor is that used by Babcock and Wilcox and is defined as the base to acid ratio (calculated based upon American Society for Testing and Materials ash properties) multiplied by sulfur content. The boundaries between the regions were drawn empirically to maximize the number of points located with correct areas. Using the boundaries shown, 61 percent of the data points are located within the correct areas. However, it should be noted that for any given steam flow per plan area, there are examples of boilers with rare and frequent problems with very similar slagging factors. The initial results from this EPRI study indicate that the slagging frequency of many boiler/coal combinations can be accurately categorized using almost any of the parameters reported in the literature. Also, some combinations appeared to be impossible to categorize properly using any of the recognized parameters.

The limited success of slagging, fouling, and corrosion indices in correlating coal performance in field-operating systems is probably due to the complexity of the process. As the indices used to assess slagging, fouling, and corrosion potential are based upon analysis of coal samples, they fail to take account of:

- The heterogeneity of the coal and mineral-matter mixture that is being fired.
- The relationship of mineral forms to each other and the variation in mineral composition of the individual coal particles.
- The mechanism of particle transport.
- Selective deposition within the furnace.
- Variation of composition of the deposit as a function of time.
- The strength of the deposits and the ease of removal by soot blowing.
- The influence of operating and design variables on properties other than furnace exit temperature.
- Reactions of ash particles with vaporized mineral matter which could occur prior to deposition on the walls.
- Interaction of ash particles in the free stream, which could form low-melting point eutectics.

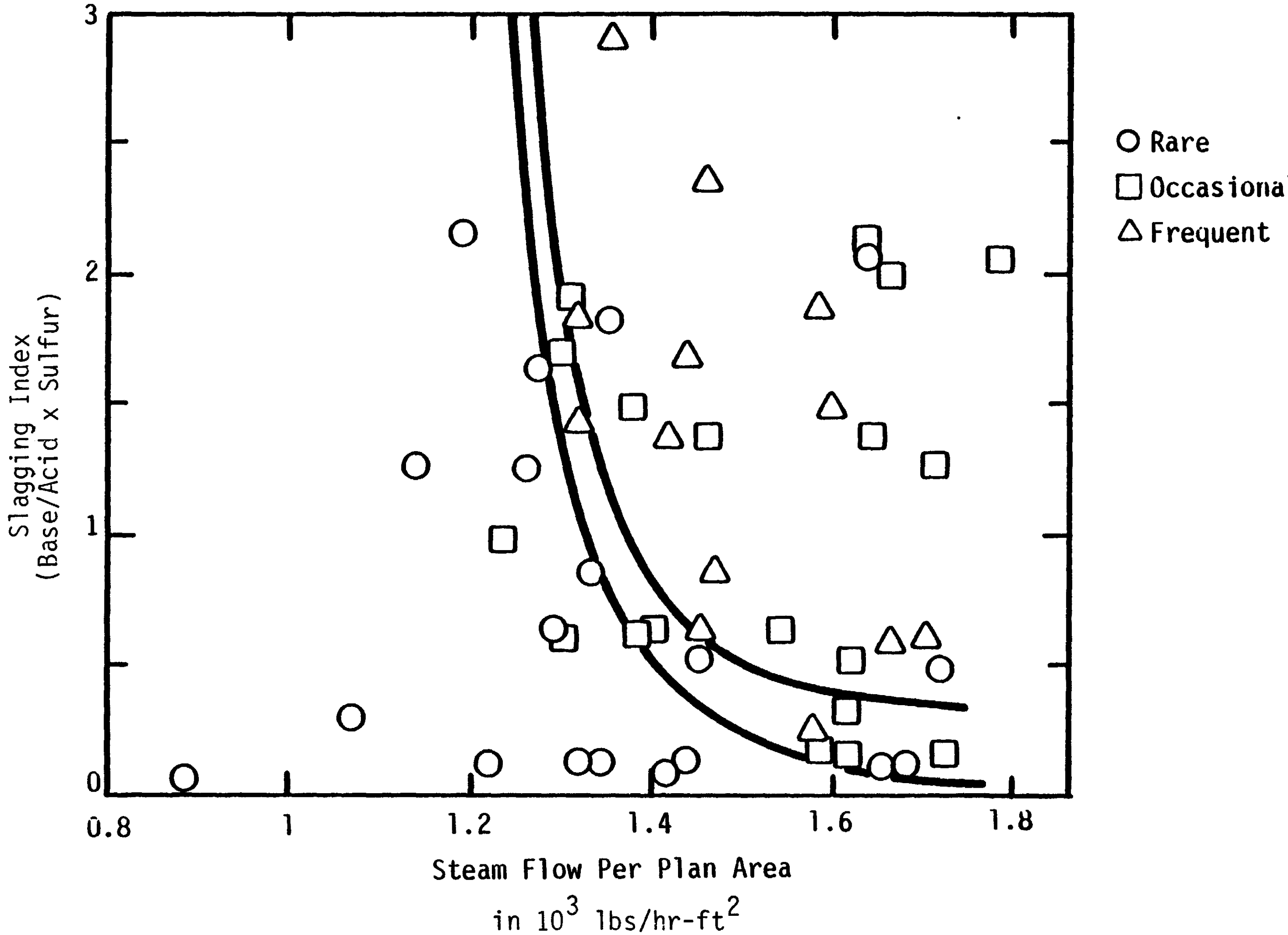


Figure 3. Slagging frequency (Barrett, 1983).

Efforts have been made to overcome some of these difficulties by evaluating the characteristics of portions of the mineral matter and coal ash. This involves separating the coal into several specific gravity fractions and examining the characteristics of the various gravity sink fractions. Research at Combustion Engineering indicates that the slagging potential of coals can be correlated with the iron content of ash for the 2.9 specific gravity sink fraction. Iron (as Fe_2O_3) contents of more than 70 percent indicate a coal that has severe slagging potential. American Electric Power, on the other hand, correlates the slagging potential of run-of-mine and washed coal based on the following whole coal characteristics:

o Pounds of ash per 10^6 Btu, as received, base to acid ratio, and

o Ash softening temperature.

There is some disagreement as to whether the total quantity of ash influences the slagging potential. Intuitively, it would appear that problems due to ash deposition would be greater for larger quantities of ash.

Nitrogen and Sulfur

Two of the organic trace species present in coal create environmental problems and thereby influence power costs. An efficient combustion process converts nitrogen and sulfur present in the coal to nitrogen and sulfur oxides. Sulfur is contained both in the organic matrix and as part of the mineral matter and is readily converted to SO_2, which is normally removed from the combustion products by flue gas scrubbing equipment. However, if the coal mineral matter contains alkalies, some of the sulfur forms alkali-metal sulfates and is retained in the fly ash. Nitrogen contained in the coal can be oxidized to nitric oxide. However, the conversion efficiency to nitric oxide is dependent upon the availability of oxygen, particularly in the early stages of combustion, because under fuel-rich conditions, nitrogen species can be converted to N_2. Those coals containing higher quantities of volatile nitrogen are most likely to produce higher levels of NO under normal conditions.

SUMMARY

Coal quality can have a profound impact on the performance of coal-fired power plants and there is a need to establish relationships which allow coal quality to be related to the cost of power. Improved methods of coal characterization are required that define the fate of mineral matter during combustion as a function of plant design and operating conditions.

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THE WHY AND HOW OF COAL-QUALITY RESEARCH IN THE U.S. DEPARTMENT OF ENERGY

by

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I'm very pleased at the opportunity to participate in this Symposium on Coal Quality. There is a close scientific relationship between the work of the U.S. Geological Survey and the U.S. Department of Energy (DOE), and this is particularly true in the area of fossil energy. Here we are dealing with the same fossil energy materials, and we have mutual interest and concern about the properties that determine their quality.

I have been asked to talk about the DOE research relating to coal quality. I could easily use all my time telling you about what we are doing to clean and prepare coal to optimize its performance in combustion equipment, minimize its impact on the environment, and extend its application. But, most of you know all that. Besides, you will be hearing later from specialists in these areas. Let me instead talk to you about one specific aspect of our work that, by its nature, requires major coal quality research. I'll start with the "why" of this research area.

During the latter half of the 19th century, coal gradually displaced wood as the major energy form fueling the industrial revolution. By the turn of the century and for nearly three decades into the 20th century, coal reigned as the major fuel form supplying all of the major energy use sectors. It was not until the mid-1920's that petroleum, spurred primarily by the advent of the automobile, began to capture a significant percentage of the total energy market. As oil production increased and prices fell to as low as 10 cents per barrel in the following years, coal began to seriously lose ground in all but the electric utility sector. With the concurrent growth of natural gas usage and the convenience of both oil and gas, coal sales in the nonutility markets plummeted. The result was that over the past 50 years, the coal industry has gone from a position of being the Nation's energy-supply industry to the current position of being the utility industries' primary energy supplier. No longer is coal used to heat water, homes, apartment buildings, offices, warehouses, stores, hospitals, and the like. In short, coal has lost out in the residential, commercial, and light industrial sectors. In retrospect, this loss of market was a major factor, along with growing transportation fuel requirements, that has led to our current dependence on oil (much of it foreign) and our major imbalance in fuel use as compared with our resource base. However, it also defines an opportunity for the coal industry.

It is an opportunity to recapture a major fraction of over 25 quads (excluding transportation) of the Nation's 80 quads of energy consumption. If coal could capture 25 percent of this 25 quad fraction, it would represent a 50 percent increase in the U.S. coal consumption. Any movement in this direction would improve our national security and fuel-use balance.

Let's take a closer look at the anatomy of this opportunity. First, it is made up of a multitude of small users who use energy in a relatively limited number of ways, and it is far different from the electric utility supply sector. The two most important opportunities for coal in this sector are for use in water heating and space heating.

In order for coal to penetrate the light industrial, commercial, and residential markets, four conditions are required:

1. An assured supply of coal.

2. A desire by the customer to use coal rather than oil or gas; that is, a financial incentive and adequate fuel quality.

3. A coal delivery and ash management infrastructure.

4. A catalog of competitive coal-use technologies, primarily furnaces and water heaters.

The first condition, an assured coal supply, is no problem. The capability to supply almost any increased demand up to the full requirement of these sectors now exists. The second requirement, a customer desire to use coal, that is, primarily an economic incentive, is satisfied by the fact that a major advantage of coal over oil and gas is that it can be delivered to most places at a cost of from 30 percent to 50 percent of its competitors. Environmental-quality requirements must also be met by either improved coal quality or applicable pollution-control technology. The third condition, the need for a fuel supply and ash management infrastructure, is not likely to be a problem. If the economic demand develops, this infrastructure will appear. Here again, coal quality could be a factor in relation to ash management.

The main problems arise with the last item. Coal-use technology has not kept pace with oil, gas, and electric-use technology. As a result, there are almost no modern technologies in the fuel-use areas required by these use sectors. Even more important, there is practically no technology base or cadre of expertise in this area. It will take time to build a competitive position for coal. It is possible, however, to translate much of the gas and oil technology directly to coal systems and possibly take advantage of some of the foreign expertise that has continued to develop. Nevertheless, a great opportunity exists for coal to get back into areas now dominated by gas and oil--successful penetration could easily double the use of coal in the United States. This is the "why" DOE is pursuing research in this area, and why coal quality is an important part of that R&D.

Now let's consider the "how."

A good description of the U.S. reaction to the energy crisis of the early 1970's was that we "jumped on our technological horse and rode off in all directions." After a decade and several billion dollars later, I'm afraid the world changed around us more than we have changed the world--but we are much smarter.

Among the things we learned is that, technically, we can make synthetic natural gas and liquids from coal, but we can't afford the products. They cost from two to five times the price of naturally occurring gas and petroleum. Another thing we learned was that the quality and performance specifications for coal-derived gas and liquids are set by the petroleum-based products they are trying to emulate. This is because our energy-conversion machines, such as gasoline and diesel engines, turbines, boilers, furnaces, water heaters, and so on, have been developed to use petroleum products.

If we are to make progress in the area of developing coal-derived fuels, we must first recognize that there is nothing sacred about the petroleum-based fuel forms. The quality and specifications of these petroleum fuels are as they are only because they have been optimized to fit their energy-conversion machines and, conversely, the energy-conversion machines have been optimized to the unique properties of the available petroleum fuels. Couldn't these petroleum-based fuels and their energy-conversion machines just as well have been optimized to different specifications? Of course they could and they were. This has given rise to such fuel and machine combinations as high-compression gasoline engines; diesel-fueled diesel engines; turbines that use fuels that range from distillate through residual fuels; gasoline heaters/lights; kerosene heaters/lights; and so on. Why, then, couldn't coal-derived fuels and machines be developed if it were economically and strategically desirable to do so? Again, the answer is, not only is it possible, it has been done. Coal-oil fractions and even powdered coals were used for all kinds of heating and engine systems long before petroleum forced them from the marketplace.

Of course it can be done, technically, but can it be done economically now that the price of oil is several times the price of coal? Again the answer is yes. We recently did a study in which we compared the life-cycle cost of various coal-derived fuel forms. Costs for a number of processes ranging from the direct use of coal through coal liquefaction were adjusted to a common basis. When we compared the results (fig. 1), there were really no surprises--the general rules applied that (1) the higher the process capital cost, and (2) the more work that is done on the coal, the more costly the product. Because of our inability to put all studies on a common basis, the absolute values of the cost of products should not be taken too seriously. What is important is that the trends and relative costs are about right and that clearly some of the coal-based products are much less costly than the "premium" petroleum-based products. If energy-conversion machines were developed and optimized to the specifications of coal-derived fuel forms, it is likely that they could economically displace the petroleum products. This is not an argument for a return to coal stoves, coal pyrolysis, and coal-oil products (although many of these need to be reconsidered). Rather, it is a call to the scientific and coal community to recognize that very little new work has been done during the past 50 or so years in the coal-science areas except for that which has been directed toward trying to make coal-derived fuel forms look like petroleum-based products. It is also a reminder that coal is capable of producing an almost infinite variety of products, many at low costs that could potentially be used as unique fuel forms.

Coal liquid mixtures (CLM) are an example of a new commercial form of coal fuel which has achieved a level of acceptance and success when used in appropriate energy-conversion machines.

In its current application as a boiler fuel, CLM quality requirements need not be very high because most applications will be equipped with dust collectors to control ash. To expand the application of CLM to the nonutility sectors such as commercial and residential applications, however, will require much higher quality or highly beneficiated coal. In its extreme application, CLM would be used as a fuel for internal combustion engines. Quality standards for these fuels must approach those of petroleum fuels. Obviously, as the quality of CLM fuels improves, the cost of their preparation increases, approaching the price of petroleum products.

As we have already observed, fuel-use machines have been optimized to the quality and specifications of existing petroleum products. And, as we have also observed, different machines can accommodate fuels of different quality levels and different

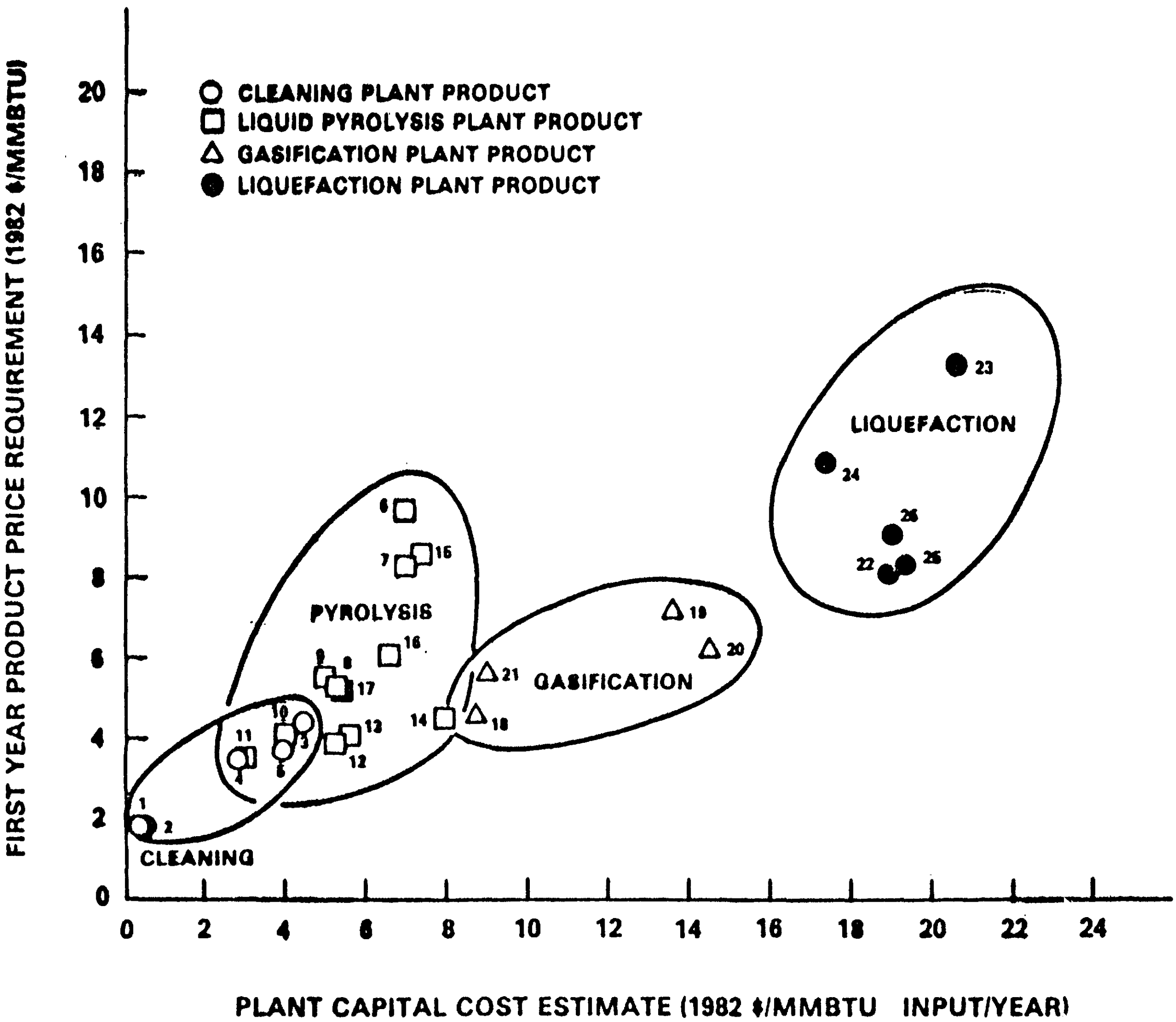

Figure 1. Cost of various coal-derived fuel forms.

specifications. The job then becomes one of adapting the appropriate machine to accommodate the different fuel forms and different operating conditions. Fortunately, most of our machines are readily adaptable over wide ranges of fuel and operating conditions. Examples include diesels that run on powdered coal (the fuel which diesels were originally invented to use); distillate, residual, vegetable, and other oil; as well as natural and coal gas.

The key point that we should keep in mind is that we are not bound to energy-conversion machine designs or operating conditions that are the results of their having been optimized with petroleum-based fuels. Our research and development objectives in this area, therefore, are to adapt and optimize energy-conversion machines to permit the use of coal-derived fuel forms, thereby displacing oil and gas with coal.

It is important that we keep in mind that we will not displace oil and gas with coal quickly even when we have attractive technical alternatives in hand. This is probably a blessing in disguise. As scientists, politicians, suppliers, processors, and users, we would like to see developments adopted quickly, but this is almost never achieved without great cost. We cannot afford to lightly scrap the national inventory and capital investment we have in our energy-conversion machines in favor of a new technology. So we see that the timeframe for the introduction of new technologies is consistent with the timeframe that will be required for stepwise evolutionary development with the necessary attention to coal and product quality. While this helps provide perspective regarding the patience we will need once options are in hand, it also gives rise to a sense of urgency for getting on with the job of developing these options.

There is no reason why coal must be dirtier than oil for the user, or why it should be more difficult to use, less safe, more complex, or require a more costly first investment. The problem is that there has been very little R&D support in the United States to make it otherwise. Attention to the quality of coal and coal-derived products is essential if we are ever to realize the opportunity for coal to regain some of its position as an energy source in the nonutility market. It will take a positive commitment and action by government and the people who stand to gain by these technologies--the coal industry itself.

The rationale for DOE's coal-research program is derived, at the highest level, from the National Energy Policy Plan which calls for a balanced and mixed-energy resource system and data on a suite of technologies from which the private sector, based upon market forces, can make demonstration and commercialization decisions suiting their needs. The program further derives from the Office of Fossil Energy strategy which calls for, among other things, the increased utilization of coal in an environmentally acceptable manner and the development of technological options for the utility use of coal if needed to meet the potential electric-utility-capacity shortfall of the 1990's.

On the basis of this guidance, technological options representing significant advances to conventional systems are identified, research programs defined and costed for the life of the programs and competed against other programs for research monies on a year-to-year basis. The competition involves consideration of factors such as compliance with national energy policies and fossil-energy program objectives, resource requirements, private cost-sharing available, potential for moving coal in new market areas, stage of development, and so on. Of course, DOE works closely with other Federal agencies, the private sector, and the international energy community to ensure that our programs are potentially useful and do not duplicate the work of others.

Coal liquid mixtures are clearly in our immediate commercial future. This product is a significant step in allowing coal to again move into the light industry, commercial, and residential markets. But this is only a start. Many more coal and coal-derived fuel forms are needed to realize coal's fair share of the energy market. Coal characteristics and quality, as well as the quality of the coal-derived products, are keys to success of these energy forms. Some, perhaps most, of the return on these R&D investments will be a little (but just a little) beyond today's commercial horizon. But we must not forget that the future has an insistent way of becoming our tomorrow, our today, and then history before we know it.

COAL QUALITY AS IT RELATES TO AIR POLICY ANALYSIS

by

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I appreciate the opportunity to participate in this symposium on coal-quality data and related research. I will try to provide a view of coal-quality data issues from the perspective of air-quality policy concerns. This is not a comprehensive overview of all the coal-quality research issues of concern to the Environmental Protection Agency. I am not technically competent to do that and am not sure that it would be particularly helpful. What I would like to do instead is to briefly discuss the environmental policy-making process and illustrate how coal-quality information is or could be used in the process.

I will use the particular policy issue with which I am most directly involved--acid deposition--as an example. This policy debate is very likely the most important current environmental issue related to coal use. I will review the major policy questions related to acid deposition and potential control measures. To the extent possible, I will suggest where these policy questions imply need for coal data. My hope is that these suggested general data needs will then be addressed in greater detail in the subsequent workshop sessions.

Before turning specifically to the acid-deposition debate, I would like to briefly review the general relationship between coal use and environmental concerns. Figure 1 is a graph of historic U.S. energy consumption by fuel type. It illustrates that during the first half of this century coal was the dominant fuel nationally. In the post World War II period it was rapidly displaced by oil and natural gas. However, since the early 1960's, coal use has begun to increase again, and this trend is expected to continue.

Figure 2 is taken from a Department of Energy forecast published in October 1983. It clearly shows the expectation of significant increases in coal use in the future. The reasons for this turn-around have been analyzed widely. Coal is a domestically abundant fuel, and since the oil price shocks of the 1970's, it has become attractive relative to oil and gas for both economic

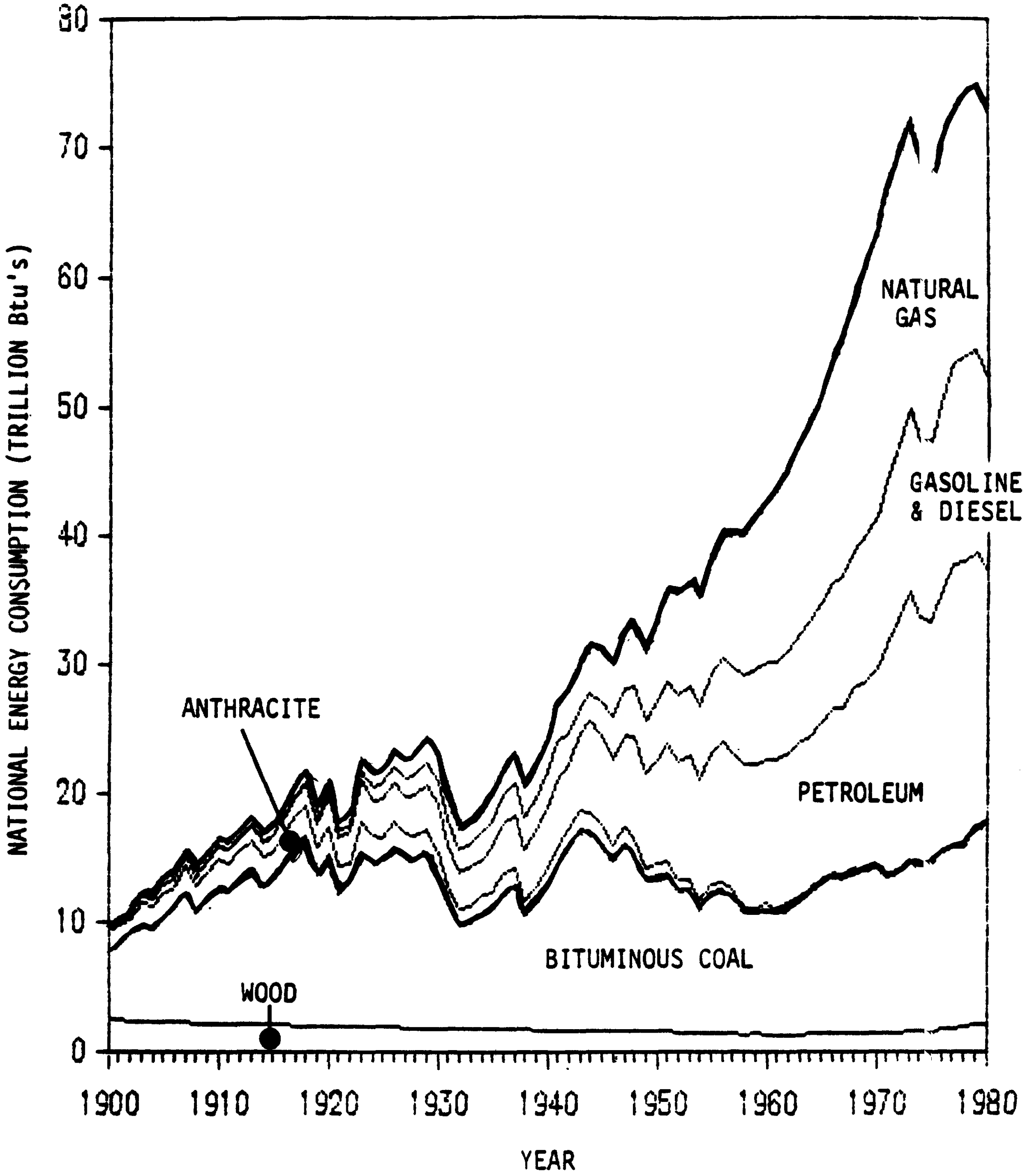


Figure 1. U.S. historic energy consumption by fuel type. (Source: Gschwandtner et al, Historic emissions of sulfur and nitrogen oxides in the United States from 1900 to 1980, U.S. EPA Report No. EPA-600/7-85-009, April 1985.)

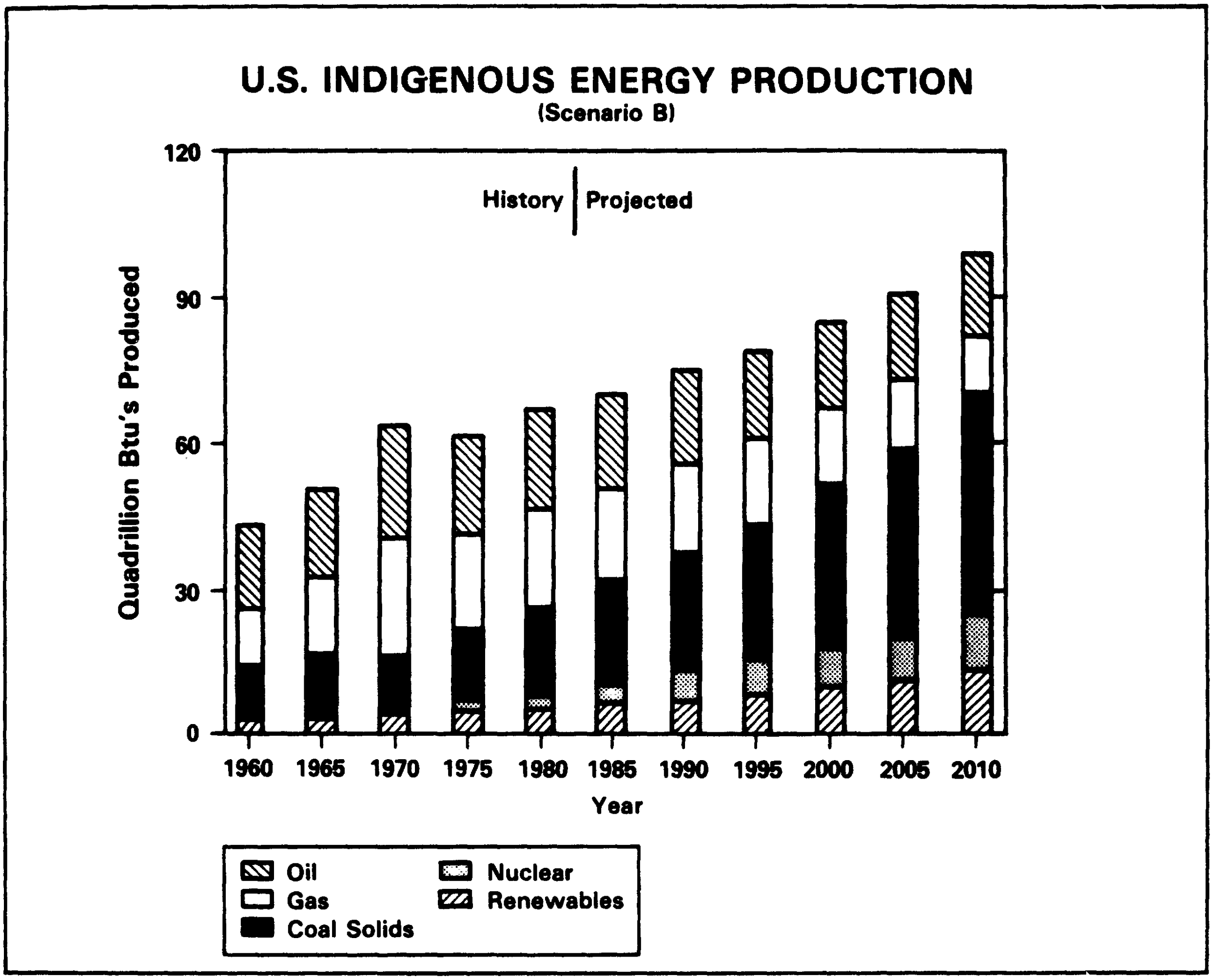


Figure 2. Projected energy production by fuel type. (Source: Energy projections to the year 2010, U.S. Dept. of Energy Report No. DOE/PE-0029/2, October 1983.)

and national policy reasons. Clearly, we should be prepared for coal use to increase.

Coal is, in many ways, a more difficult fuel to use, although technologies are available to deal with its problems. These difficulties include a range of potential environmental problems associated with coal mining, preparation, transportation, and utilization. Figure 3 (taken from a 1979 report by the Office of Technology Assessment) illustrates the range and complexity of environmental issues associated with coal and its impacts on air, land, and water resources.

Coal-quality data or assumptions are important inputs to forecasting cost and market penetration of coal in the future. In addition, virtually all of the potential environmental impacts of coal are sensitive to coal characteristics. Thus, there is a close relationship between environmental-quality concerns and the need for accurate data on coal quality. As coal use increases in the future, the data requirements for environmental analysis will no doubt also increase.

The current policy debate over acid rain (or acid deposition) provides a good example of the relationship between coal quality and environmental analysis. Figure 4 is a simplified diagram designed to illustrate the major components of the extremely complex acid-deposition phenomenon. Concerns about acid deposition are, of course, directly related to possible adverse effects. In addition to possible effects on forests and surface waters shown in the diagram, acid deposition may cause damage to man-made materials, agricultural crops, and human health.

Problems related to concentrations of acid deposition precursors in the atmosphere, such as visibility degradation, are also closely linked with the acid deposition scientific phenomenon and its possible policy solutions. In addition, other pollutants, such as ozone and heavy metals, may also play a role in the potential adverse effects of concern related to acid deposition. Thus, a variety of possible effects and causes must be considered in evaluating the acid deposition phenomenon.

Many of these effects are dependent on regional or local environmental characteristics such as meteorology or soil type. The possibility of adverse effects is greatest in specific locations which are environmentally sensitive to acid deposition. To understand the cause of adverse effects and their possible remedies, it is necessary to understand the atmospheric transport, transformation, and deposition processes, occurring both locally and over large regions, which lead to acid deposition in sensitive receptor regions. Our understanding of the science of acid deposition must include a range of emissions of relevant chemical substances from both natural and man-made sources. In addition to

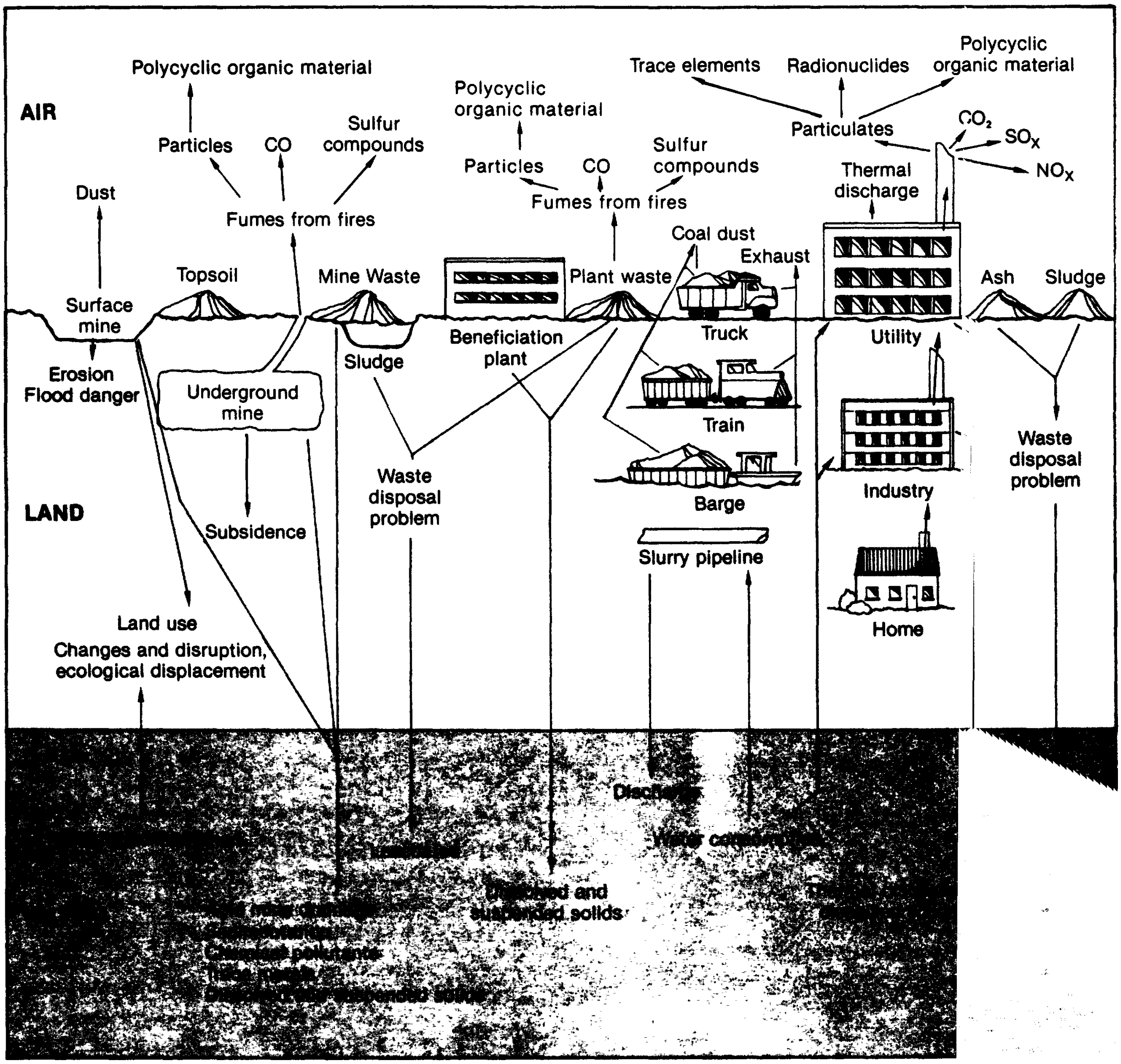


Figure 3. Environmental disturbances from coal-related activities. (Source: Office of Technology Assessment, The direct use of coal, Washington, D.C. 1979.)

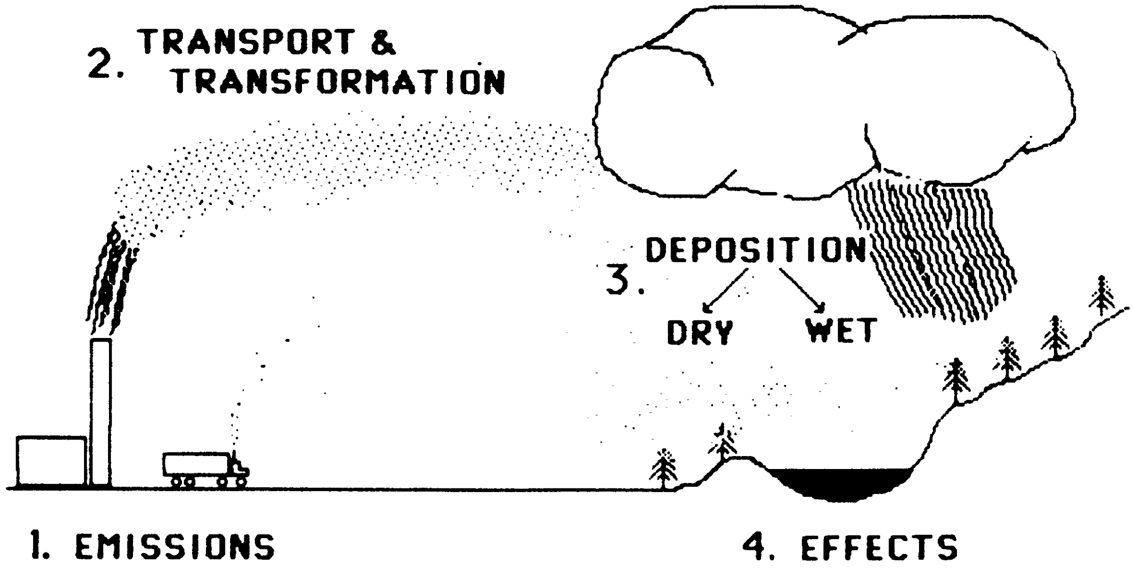


Figure 4. Schematic diagram illustrating major components of the acid deposition phenomenon.

sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which are the principal precursors of acid deposition, other relevant substances include natural emissions of reduced sulfur compounds, volatile organic compounds (or hydrocarbons) from both natural and man-made sources, heavy metals such as lead and mercury, alkaline dust, and ammonia. Volatile organic compounds (VOC) are important precursors of ozone and other oxidants, which in turn play a role in converting sulfur and nitrogen oxides to acidic sulfate and nitrate in the atmosphere. Also, ozone and its precursors are important as alternative or synergistic causal agents for some categories of effects, as is the case for heavy metals. Alkaline dust and ammonia can act to neutralize acidity in the atmosphere or after deposition on land or surface waters.

Virtually all parties in the policy debate agree that acid deposition is related to man-made emissions, particularly in eastern North America. Great uncertainty exists over the extent of acid deposition, its effects on various categories of receptors and the detailed processes which result. The broad policy decisions which must be made are whether to control precursor emissions, how much and of what pollutants, when to implement a control program, where to control, and who should pay for controls.

The current widely varying positions on these issues exist for two basic reasons. First, there are very large technical or scientific uncertainties about key aspects of the acid-deposition phenomenon. In particular, the magnitudes of current and potential effects and cause and effect relationships are very poorly understood. Second, major economic and regional interests would be heavily affected by any control policy (including a policy of no control).

Table 1 summarizes some of the major interests which affect the politics of acid rain. In general, Congressional delegations quite legitimately represent the major interests of their constituents. Regions which have actual or potential adverse impacts are in favor of emission controls as soon as possible. Regions and industries which have high emissions are naturally opposed to "hasty control action" and sympathetic to cost-sharing options, whereas regions with few large sources favor a "polluter pays" approach.

Within this context of scientific uncertainty and competing political interests, several alternative proposals have emerged. The range of proposals which have emerged in the Congress is illustrated by table 2. Most proposals fall within one of the four categories ranging from no controls to reductions on the order of 10 million tons. The most recent bill (S. 52) and an earlier bill (H.R. 3400) illustrate the major alternatives for implementing major reductions.

Table 1. Congressional positions on acid rain control.

If constituency contains:	Congressional delegation favors:
* Affected areas-lakes, forest damage	* Control soon, freedom to choose expeditious control alternative, polluter pays
* No large emitters	* polluter pays
* No large emitters but anticipated high growth	* no emissions cap * geographically constrained program
* Large emitters	* More justification through research * Federal financing of controls
* High sulfur coal producers	* Mandatory scrubbing
* Low sulfur coal producers	* freedom of choice on control alternative (i.e.,switching)

Table 2. Summary of major legislative alternatives.

A) ADDITIONAL RESEARCH AND EFFECTS MITIGATION

* SEN. BYRD (S. 454)
  - calls for further resolution of scientific uncertainties through research before controls
  - provides grants to the states for lake liming and other effects mitigation

B) LARGE REDUCTION - FREE TO CHOOSE CONTROLS

* SEN. STAFFORD (S.52)
  - 10 million ton SO_2 control program within 10 years within 31 eastern states
  - allows sources to choose least-cost control measures
  - likely to result in significant coal switching
  - polluter pays, requires study of fee system

C) LARGE REDUCTION - MANDATORY SCRUBBING

* CONG. WAXMAN/SIKORSKI (H.R. 3400)
  - 10 million ton SO_2 and 4 million ton NO_x control program within 10 years in 48 states
  - strikes a compromise by requiring scrubbing for the 50 largest emitters
  - allows the remaining sources to choose the least-cost control measure
  - fee system to subsidize scrubbing

D) PHASE I - EVALUATION - PHASE II

* SENATORS HUMPHRY AND PROXMIRE (S. 503)
  - reflects the National Governors Association's compromise approach
  - requires an initial 5 million ton reduction within 6 years
  - a three year evaluation period for EPA to assess the results
  - an additional 5 million ton reduction during Phase II, if warranted

S.52 allows for affected States and industries to choose among available control measures to meet their targeted emission reductions with the assumption that this will allow for the least-cost economic solution. The costs are to be borne by the sources and presumably passed on to their customers.

H.R. 3400, although calling for roughly equivalent sulfur reductions, differs in other ways. To protect mining employment in the high-sulfur coal regions of Appalachia and the Midwest, this bill would require technological controls for most reductions. In addition, the bill would spread the cost of controls more broadly, using a national tax on electricity generation to help pay for the controls. The proposal introduced recently by Senators Humphrey and Proxmire adds the concept of spreading emission reductions out over two phases. This is a compromise approach which has been endorsed by the National Governor's Association.

Another, somewhat different approach has been discussed but not yet formally introduced in the Congress. This is the concept of requiring emissions reductions from large utility sources as they reach a specified age, such as 30 or 40 years. This approach is based on a recognition that most sulfur dioxide emissions associated with acid deposition come from plants which started up prior to the introduction of New Source Performance Standards in 1971 and that the current trend is toward extending the service lives of these high-emissions plants. This control approach would require each unit or plant to either retire or meet a more stringent standard upon reaching the specified age.

Major components of the present Administration's policy on acid rain are outlined in table 3. Acid deposition is recognized as a serious environmental problem. Decision on appropriate additional action, if any, has been postponed until more information becomes available. This does not imply that acid rain controls are unnecessary or that they are too expensive, but only that it is premature and unwise to make a decision limited by our current understanding. Additional scientific information is needed to make a prudent choice regarding the best course of action. As stated in recent Congressional testimony, "when the fundamental scientific uncertainties have been reduced, this Administration will craft and support an appropriate set of measures to solve the acid rain problem."

Considerable evolution in the details of this policy over the past year and a half has been due to intensified policy analysis efforts within EPA and the Cabinet Council on Natural Resources and the Environment. A thorough review of the problem and issues has been conducted in an effort to reach a consensus on control options which might be considered. This process allowed for more

Table 3. Administration position on acid deposition control.

POSTPONE CONTROL DECISION PENDING
IMPROVEMENTS IN SCIENTIFIC INFORMATION

ACCELERATE RESEARCH TARGETTED ON KEY
POLICY QUESTIONS

- SURFACE WATER ACIDIFICATION
- FOREST EFFECTS
- DRY DEPOSITION
- ATMOSPHERIC MODELING

ONGOING POLICY ANALYSIS

IMPLEMENTATION PLANNING

- STAR PROGRAM
- CONTROL TECHNOLOGY RESEARCH

explicit identification of the critical uncertainties affecting policy development. On the basis of this experience, several new activities have been initiated. The following are the key points of the Administration's current acid-rain policy:

1. The question of adopting an emissions reduction program for acid rain control has been deferred without prejudice. The deferral is based on uncertainties in two general areas (a) what is the nature and magnitude of the problem, and (b) how effective are the proposed solutions in solving these current or potential problems? Definitive answers to these questions will not be forthcoming in the near or middle term. Therefore, decisions about acid rain will have to be made in an environment of scientific uncertainty. The goal of deferring the decision is an opportunity to make some interim gains in knowledge that can significantly improve the chances that correct choices will be made.

2. To allow for a decision as expeditiously as possible, major new or expanded research efforts are being targeted toward the key questions. To address the question of the nature and magnitude of effects, the EPA has begun an extensive survey of current and potential surface-water acidification across the Nation. In addition, a major survey of current and potential forest and vegetation effects is now being designed. To respond to the effectiveness question, there are accelerated programs to produce dose-response information for various types of effects, to improve our ability to monitor dry deposition, and to model the atmospheric processes which relate emissions sources to deposition in sensitive regions.

3. It is impossible to predict when enough will be known to make a decision, as it is very much dependent on the kinds of answers which come from the research. Establishing when enough is known to make a decision is not a research or scientific question, it is a policy question. Consequently, policy analysis is an ongoing and high-priority function. Two major objectives of this effort are 1) to assimilate the results of the research and revise the possible options accordingly, and 2) to identify additional policy-relevant information needed from the research program. In the meantime, we are beginning to evaluate possible results in advance, thus reducing response time once the results are in.

4. The policy calls for beginning to plan for possible implementation without waiting for final Congressional or Executive Branch action on a control program. By starting the implementation planning and analysis effort now, we can ensure that any program adopted in the future would be more effective than if implementation were an afterthought. In addition, this program could save a year or more in actual implementation time should a control program be adopted. One aspect of the implementation effort is the State Acid Rain (STAR) grant program which

provides funds to State agencies to support detailed analysis of implementation problems and issues which would face each particular State should a major control program be enacted.

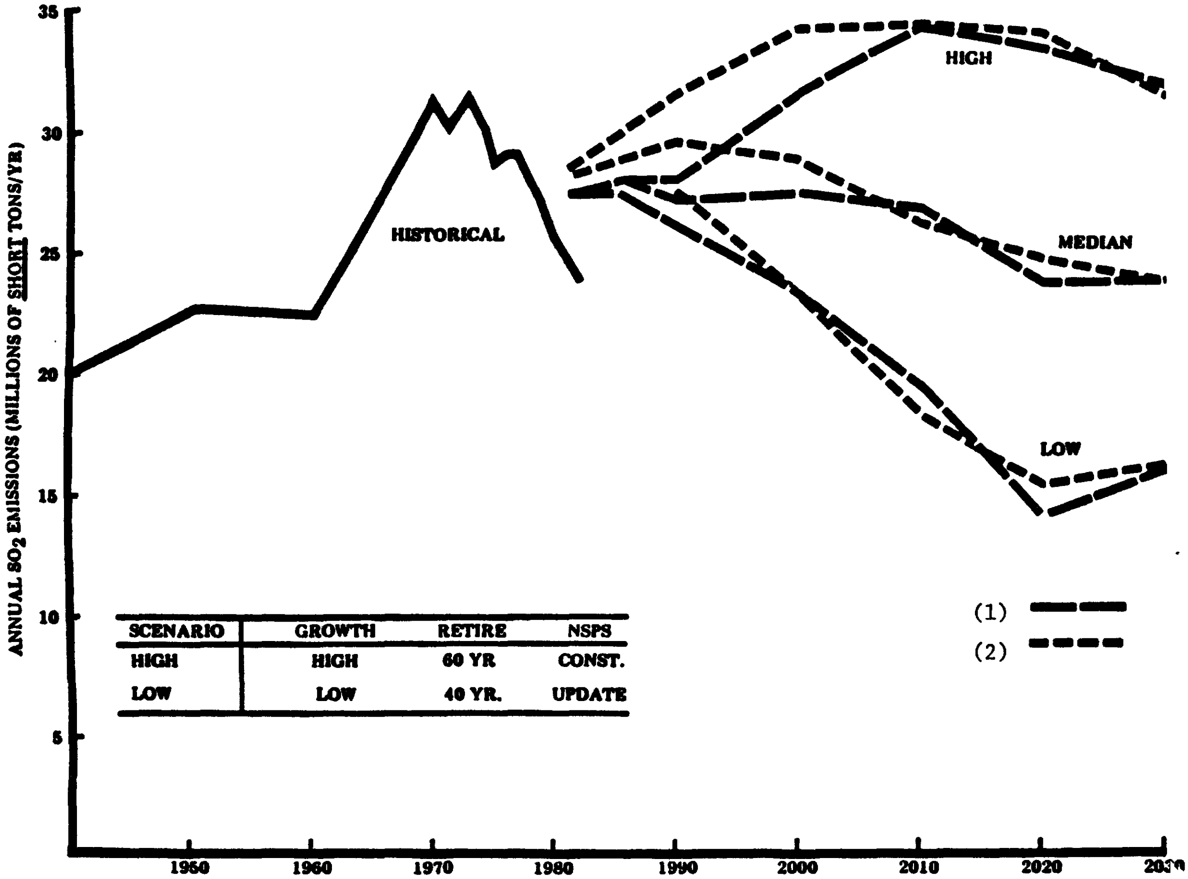
Another aspect of implementation planning is embodied in the Administration's commitment to a program of control technology research being carried out by EPA and DOE. As a result of these efforts, a broader range of cost-effective control technology options should be available in the future, including some designed specifically for the retrofit requirements of an acid-rain control program. Should major reductions actually be required, the availability of alternative control technologies could substantially reduce the total cost and/or associated economic disruption.

5. Critical to the position of waiting for more information before deciding, is the premise that we are not facing an ecological emergency. Although there is a general consensus among EPA scientists and policy analysts that current evidence does not indicate such a crisis, the evidence is not conclusive. Consequently, a major priority of the near-term research effort is to confirm or disprove this conclusion. If research shows that an emergency does exist, a control decision will be made based upon whatever information is available at the time.

The largest and most critical scientific uncertainties related to acid rain revolve around the actual and potential effects and the atmospheric processes by which acid deposition is created. However, there are important uncertainties and issues concerning the man-made emissions, and the cost and other impacts of possible control actions. These uncertainties can affect the distributional and equity aspects of a policy; that is, which regions, industries, consumer groups, etc. are affected. For this reason, they may be extremely important in the policy debate, although of lesser significance from a purely scientific point of view.

In the remainder of my time, I would like to focus on the man-made sources of emissions relevant to acid rain, especially SO_2, and the control options and issues associated with reducing these emissions. These are the policy questions which relate to the need for coal-quality data.

As indicated in figure 5, there is considerable uncertainty about the baseline levels of SO_2 emissions to be expected over the next 25 years or more in the absence of acid-rain control legislation. These alternative projections were presented by the Secretary of Energy in recent Congressional testimony. For several reasons, it seems that the high end of this range is more likely. The Administration is forecasting strong and sustained economic growth, lifetimes of coalfired power plants are being extended, and we do not yet see evidence that new technology will cause emissions standards for new plants to be reduced further.



(1) Strategic Environmental Assessment System

(2) Environmental Trends Analysis Model

Figure 5. Projections of future national SO_2 emissions with alternative input assumptions. (Source: Donald P. Hodel, U.S. Secretary of Energy, Testimony before the Subcommittee on Health and the Environment, Committee on Energy and Commerce, U.S. House of Representatives, March 29, 1984.)

All of this would argue for a future in which SO_2 emissions may be expected to remain high or to increase for some time.

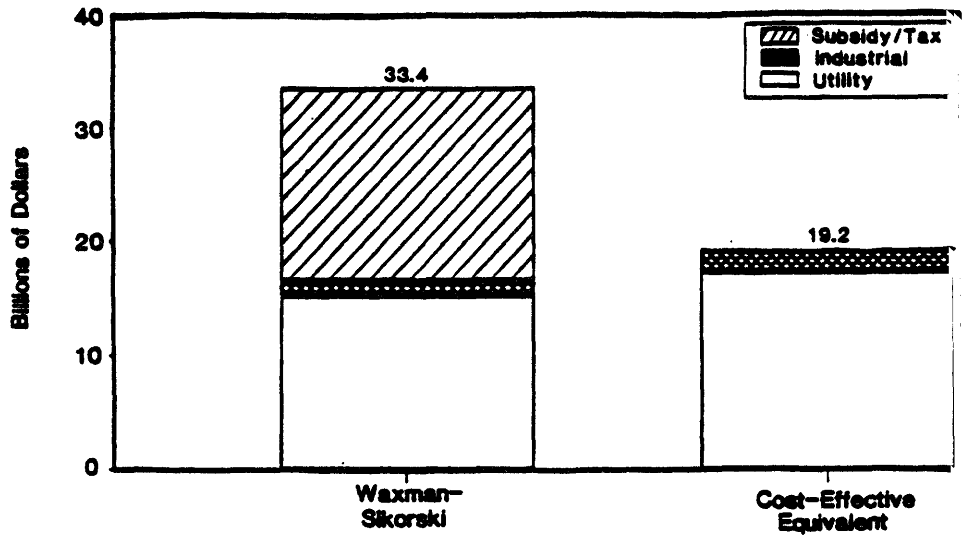
Whatever baseline projection one uses, there is the real possibility that a major reduction of emissions will be required in the 1990's to alleviate acid rain and other air-pollution effects. Given our current understanding of the economics of the coal and electric utility industries and available control technologies, it appears that alternative approaches to implementing such reduction could have markedly different impacts on industries and regions. Figures 6 through 8 show results of some analyses conducted for EPA by ICF, Incorporated. This analysis compared the Waxman-Sikorski Acid Rain Bill (H.R. 3400) with a "cost-effective equivalent." The cost-effective equivalent was developed using a computer model of the utility industry to achieve the same level of emission reduction while minimizing the total direct cost to electric utility companies. It should be emphasized that only direct costs to the utilities are included in this calculation. The analysis also assumes that coal and electric-utility industries respond smoothly to economic market forces. In reality, there are probably many constraints which limit the operation of these markets. However, the comparison of the two fairly extreme cases--mandated scrubbers versus least-cost market response is an informative analytic effort.

Figure 6 shows that the cost-effective equivalent can substantially reduce direct utility costs and almost eliminate the need for capital expenditures. This is because the model finds shifting to low-sulfur coal to be the least-cost option for nearly all affected plants. As shown in figure 7, this has dramatic effects on regional coal markets causing high-sulfur regions, especially the Midwest, to decline while increasing low-sulfur coal production from Central Appalachia and the West. As shown in figure 8, this translates into large reductions in employment in the high-sulfur coal regions although net national employment changes very little.

These two cases clearly illustrate one of the major dilemmas facing policy-makers in the acid-rain area. If and when there is a consensus that major control action is required, there is still a tradeoff to be made in implementation. The available options are (a) costly or (b) very disruptive to some regions. This is the area in which the development of more cost-effective technology can make a contribution. This is where there are current policy-related needs for coal-quality research. Several key policy questions in the acid-rain area appear to be closely connected with coal data. Examples are:

1) What is likely to happen to the cost of producing coal under future levels of demand--by regions, by sulfur content?

INCREASE IN PRESENT VALUE OF COSTS
(in 1982 Dollars)



INCREASE IN CUMULATIVE CAPITAL COSTS - 1995
(in 1982 Dollars)

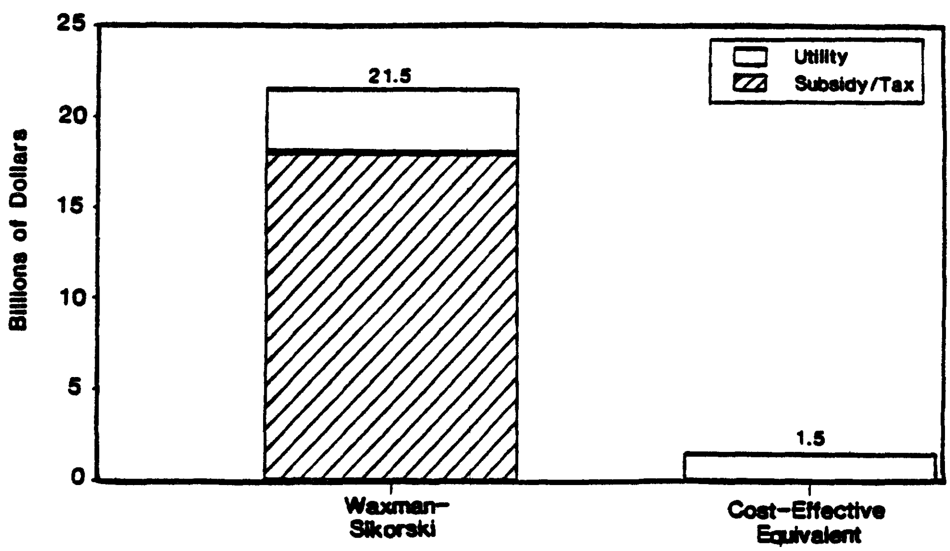
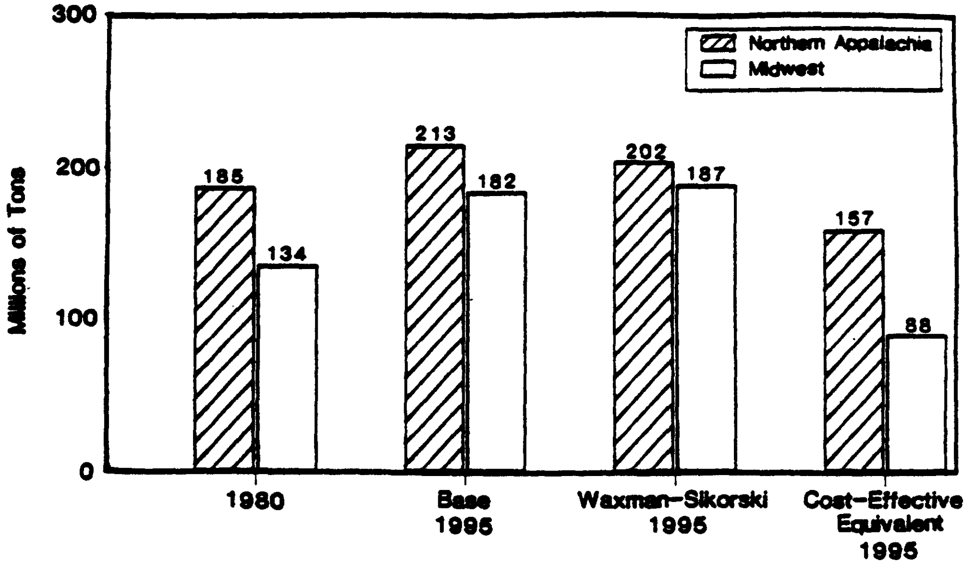


Figure 6. Comparison of Waxman-Sikorski Acid-Rain Bill (H.R. 3400) with a cost-effective equivalent. (Source: ICF, Inc., Analysis of the Waxman-Sikorski Sulfur Dioxide Emission Reduction Bill (H.R. 3400), April 1984.)

HIGH SULFUR COAL PRODUCTION



LOW SULFUR COAL PRODUCTION

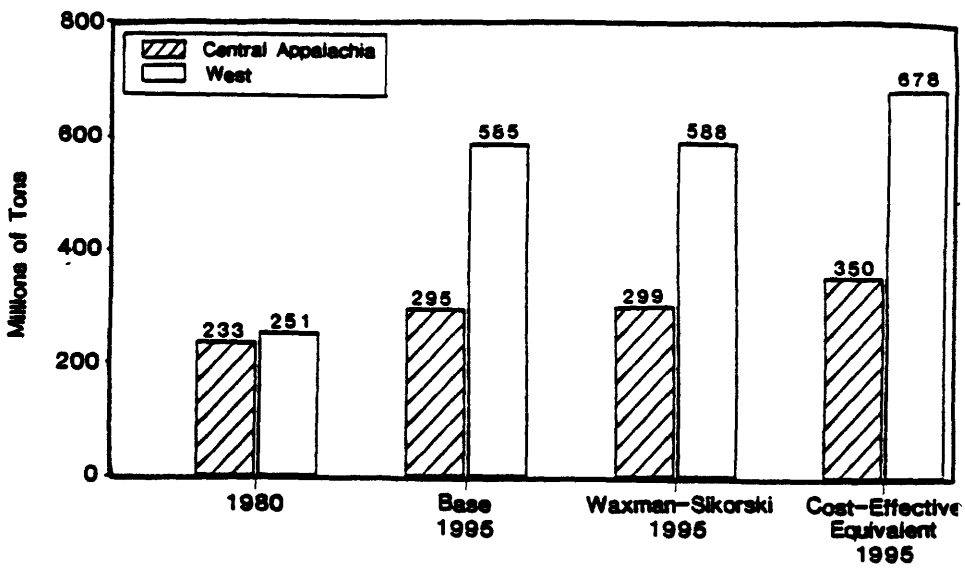
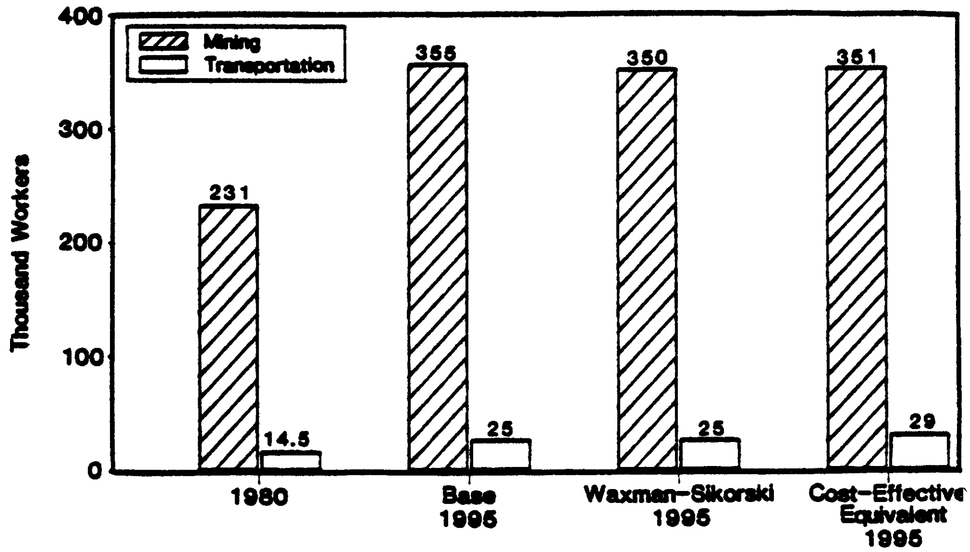


Figure 7. Effect on regional coal markets of alternative approaches to acid rain control legislation. (Source: ICF, Inc., Analysis of the Waxman-Sikorski Sulfur Dioxide Emission Reduction Bill (H.R. 3400) April 1984.)

TOTAL COAL MINING AND TRANSPORTATION EMPLOYMENT



HIGH-SULFUR COAL MINING EMPLOYMENT

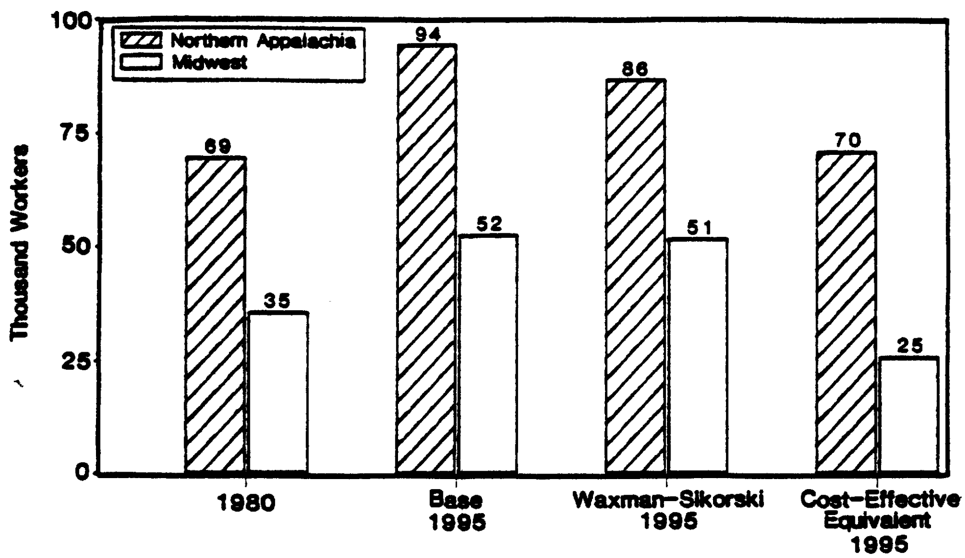


Figure 8. Effect on employment of alternative approaches to acid rain control legislation. (Source: ICF, Inc., Analysis of the Waxman-Sikorski Sulfur Dioxide Emission Reduction Bill (H.R. 3400) April 1984.)

2) How accurately can we estimate current and future emissions of SO_2 at a given facility based on coal-quality data?

3) What are the technical constraints/costs associated with fuel switching--to western low-sulfur sub-bituminous coal, to eastern low-sulfur coal?

4) How can new technologies modify the cost, employment, and other economic impacts of major control programs?

5) Can physical coal washing play a larger role in acid-deposition control programs than currently projected?

Answers to these questions are limited by available data on distribution of coal reserves, sulfur content in coals and its variability, etc. In all cases better data would be desirable.

Because of the importance of coal in the Nation's future, we need a continued long-term effort to ensure that the coal-quality data required to support energy and environmental research is available and as accurate as possible. The extreme complexity and magnitude of such a long-term research effort is beyond the resources of the EPA and probably of any single agency of government. What is needed is a coordinated effort involving cooperation of many governmental agencies and affected industries.

In addition to the long-term needs, there are short-term policy information needs which change frequently as different policy issues dominate the national debate. The current emphasis on acid rain has caused EPA's engineering research program to focus heavily on a limited number of control technology options for SO_2 and NO_x which have potential for retrofit in the near to medium terms. These include wet flue-gas desulfurization (scrubbing) with enhancements, improved dry scrubbing technologies, limestone injection with multistage burners (LIMB), and coal washing. Coal-quality data is an important input to development and evaluation of these technologies. Improvements in these data could make important contributions to the success of these technological efforts if they can be achieved within time and funding limitations. Short-term needs such as these must be carefully integrated and balanced, however, with long-term program needs.

This seminar offers an important opportunity to further cooperative efforts and to move toward consensus on the appropriate allocation of scarce resources among competing short-term and long-term research needs in the coal-quality area. It is my hope that the panel sessions on subsequent days of this seminar will be successful in identifying and organizing these competing needs and in moving toward a coordinated comprehensive program.

PREDICTING COAL PRODUCT QUALITY AND ITS EFFECT ON MARKETABILITY

by

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INTRODUCTION

Assessment of a resource is a dynamic process consisting of several phases that begins with exploration and continues throughout subsequent phases in developmental evaluation and exploitation (fig. 1). The goal of resource assessment is to provide a technical basis on which to make an economic evaluation of resources, whether for project financing, purchasing or selling, accounting purposes such as depletion or tax calculations, or final mine planning. Required input includes coal tonnage, quality, and mineability estimates to determine the economics of extraction and preparation, and marketability estimates of the resulting coal products to determine profitability.

Ideally, each phase produces information permitting "go/no-go" decisions on future exploration, development, and exploitation work to be made with greater and greater confidence. Resource-assessment budgets are established to gather information necessary to achieve a desired confidence level in mineability and marketability estimates. Amounts invested in each phase of the assessment must be balanced against the benefits to be realized from the information gathered or, alternatively, against the risks involved in not gathering the additional information required.

The resource assessment necessary in opening a coal property is fundamentally different from that of oil and gas exploration. In exploring for oil and gas, there is nearly always a significant "value of discovery." In other words, there is an immediate market for oil and gas at a price which would yield an attractive return on investment. The point at which a coal property has an equivalent value is reached only after a resource has been characterized and the mining project has been engineered sufficiently to predict with reasonable confidence the cost of production, and when a buyer has committed to purchase the mine production at a price level that results in an attractive investment for the mine construction. Unlike oil, coal is a user-constrained commodity.

- DYNAMIC PROCESS; SEVERAL ITERATIONS
- SEVERAL PHASES
  - EXPLORATION
  - DEVELOPMENTAL EVALUATION
  - EXPLOITATION
- GOAL:
  - PROVIDE A TECHNICAL BASIS ON WHICH TO MAKE AN ECONOMIC EVALUATION OF RESOURCE EXPLOITATION POTENTIAL

    i) PROJECT FINANCING
    ii) PURCHASING OR SELLING
    iii) ACCOUNTING (DEPLETION, TAX, ETC)
    iv) FINAL MINE PLANNING
- GET INFORMATION TO PERMIT GO/NO-GO DECISION ON FUTURE PHASES AND ACTIONS

Figure 1. Coal resource assessment process.

RESOURCE-ASSESSMENT STRATEGY FOR PREDICTING COAL QUALITY

Several phases of assessment are usually used to determine the potential profitability of a resource (fig. 2). Initial phases are necessarily broad, with each successive phase becoming narrower in scope and more detailed in nature (figs. 3-9). Data gathered in the initial phases of resource assessment establishes a foundation on which each successive phase must be based. Ideally, each phase produces information required to decide whether or not to go on to the next phase.

Figure 10 represents an algorithm for combining data from all completed stages to assess the potential profitability of a given resource in a given market at any stage of evaluation.

Economic constraints limit the amount of sample obtainable from a reserve, especially in deep reserves. Thus, exploration programs for coal-reserve evaluations must be designed to gather the greatest possible amount of geologic information (for the allotted budget) in order to permit prediction of anticipated mining conditions and coal-product quality over the area of the reserve.

MINING CONSIDERATIONS

The first step in evaluating the mineability of a particular reserve is to determine the geologic factors that affect mining costs (fig. 11). During the initial phases, these factors can be ranked from highest to lowest in importance to identify the pieces of information that are essential to reserve evaluation. During later phases, the impact of these geologic factors on mining costs must be quantified on a $/ton basis. Figure 12 illustrates the methodology used to optimize the selection of mining methods for an underground reserve. Costs for various geologic conditions existing at given localities are overlaid to prepare an estimate of anticipated mining costs for a particular mining method. Maps of mining costs are compared and the optimum method or combination of methods is selected. Often, in the early phases of resource assessment, areas will be identified where additional geologic information is required to select the optimum method of mining for that area. This information provides input into the types of information and, therefore sampling program, needed to complete the next phase of resource assessment.

COAL PRODUCT QUALITY

Figure 13 indicates where particular coal-characterization parameters are important to a utility power plant; however, no quantitative information is available at this time. It is quite probable that individual power plants have very different "use costs" associated with a particular parameter.

PHASE	TO ACCOMPLISH	INPUT REQUIRED FROM
PHASE I	MARKET OPTIONS REGION OF INTEREST	MARKETING REGIONAL COAL GEOLOGY
PHASE II	SELECT MOST FAVORABLE SITES	MARKETING REGIONAL COAL GEOLOGY
PHASE III	RECONNAISSANCE OF AREAS FEASIBILITY STUDIES & OPTION LAND	MARKETING COAL GEOLOGIST PHOTO GEOLOGIST FIELD GEOLOGIST MINING ENGINEERING LAWYERS FOR OPTIONS
PHASE IV	CONCEPTUAL MINE PLANNING • DEVELOP MODEL	DRILL HOLES COAL GEOLOGIST FIELD GEOLOGIST MINING ENGINEERING MARKETING
PHASE V	PRELIMINARY MINE DESIGN • USE MODEL TO LAY OUT ADDITIONAL SAMPLES REQUIRED • REFINE MINE DESIGN • REFINE MODEL	DRILL HOLES COAL GEOLOGIST FIELD GEOLOGIST MINING ENGINEERS EQUIPMENT MANUFACTURERS MARKETING ECONOMISTS
PHASE VI	FINAL PREMINING DESIGN • USE MODEL TO AVOID PROBLEMS WHICH MAY CAUSE DELAYS IN GOING TO FULL PRODUCTION	DRILL HOLES COAL GEOLOGIST FIELD GEOLOGIST MINING ENGINEERS EQUIPMENT MANUFACTURERS ECONOMISTS
PHASE VII	IN SITU MONITORING	MINING ENGINEERS COAL GEOLOGIST

Figure 2. A coal resource assessment strategy.

PHASE I

SELECT REGION OF INTEREST

- MARKET OPTIONS
  - MARKET OPPORTUNITIES
  - COAL SPECIFICATIONS
  - TRANSPORTATION REQUIREMENTS
  - OTHER
    - i) ENVIRONMENTAL CONCERNS
    - ii) OWNERSHIP CONSTRAINTS
    - iii) PREFERRED MINING METHODS, ETC.
- REGION SELECTION

Figure 3.

PHASE II

PRELIMINARY INVESTIGATION OF A REGION

- OBTAIN MORE DETAILED INFORMATION
  - REGIONAL TRENDS OF COAL CHARACTERISTICS
  - TRANSPORTATION
  - CUSTOMERS
  - REGULATIONS
  - LAND AVAILABILITY
  - MANPOWER AVAILABILITY
- SELECT THE MOST PROMISING SITES FOR MORE DETAILED EVALUATION

Figure 4.

PHASE III
RECONNAISSANCE/FEASIBILITY STUDIES

- GENERAL SITE EVALUATIONS
  - REVIEW LITERATURE & EXISTING DATA
    - i) GEOLOGY
    - ii) GROUNDWATER
  - STUDY NEARBY OPERATIONS
    - i) IDENTIFY POTENTIAL PROBLEMS
    - ii) IDENTIFY POTENTIAL SOLUTIONS
  - SATELLITE IMAGERY AND AERIAL PHOTOGRAPHY
  - RECONNAISSANCE
    - i) FLY OVER
    - ii) DRIVE THROUGH/WALK THROUGH
  - OPTION PROMISING PROPERTIES

Figure 5.

PHASE IV
CONCEPTUAL MINE/PREPARATION PLANT PLANNING

- EXPLORATION PROGRAM TO OBTAIN SAMPLES
  - PERMITS
  - DRILLING & SAMPLING PROGRAM
- DEVELOP MODEL OF DEPOSIT (GEOSTATISTICS)
- ESTIMATE COAL MINEABILITY
- ESTIMATE COAL QUALITY ATTAINABLE
- PRIORITIZE SITES; PURCHASE DESIRED PROPERTIES

Figure 6.

PHASE V
PRELIMINARY MINE/PREPARATION PLANT DESIGN

- REFINE EXISTING DATA
  - USE MODEL TO HELP IDENTIFY WHERE ADDITIONAL DATA IS REQUIRED
- ACQUIRE ADDITIONAL DATA
  - REFINE MINE DESIGN
    - i) STRATIGRAPHY
    - ii) STRUCTURE
    - iii) IN SITU STRESSES
    - iv) GROUNDWATER CONDITIONS, ETC.
  - REFINE COAL PRODUCT QUALITY ESTIMATE/ PREPARATION PLANT DESIGN
    - i) ASH AND SULFUR DISTRIBUTION
    - ii) MINING DILUTION CONTRIBUTION
- MARKET PRODUCT(S)

Figure 7.

PHASE VI
FINAL PREMINING DESIGNS

- FINALIZE PREPARATION-PLANT DESIGN
- FINALIZE MINE DESIGN
- GOAL IS TO PROCEED DIRECTLY FROM CONSTRUCTION WITH A MINIMUM OF DELAYS

Figure 8.

PHASE VII
IN SITU MONITORING

- MAINTAIN GOOD RECORDS
- PERFORMANCE EVALUATIONS
- CORRECTIVE ACTIONS TAKEN WHERE NECESSARY/FEASIBLE

Figure 9.

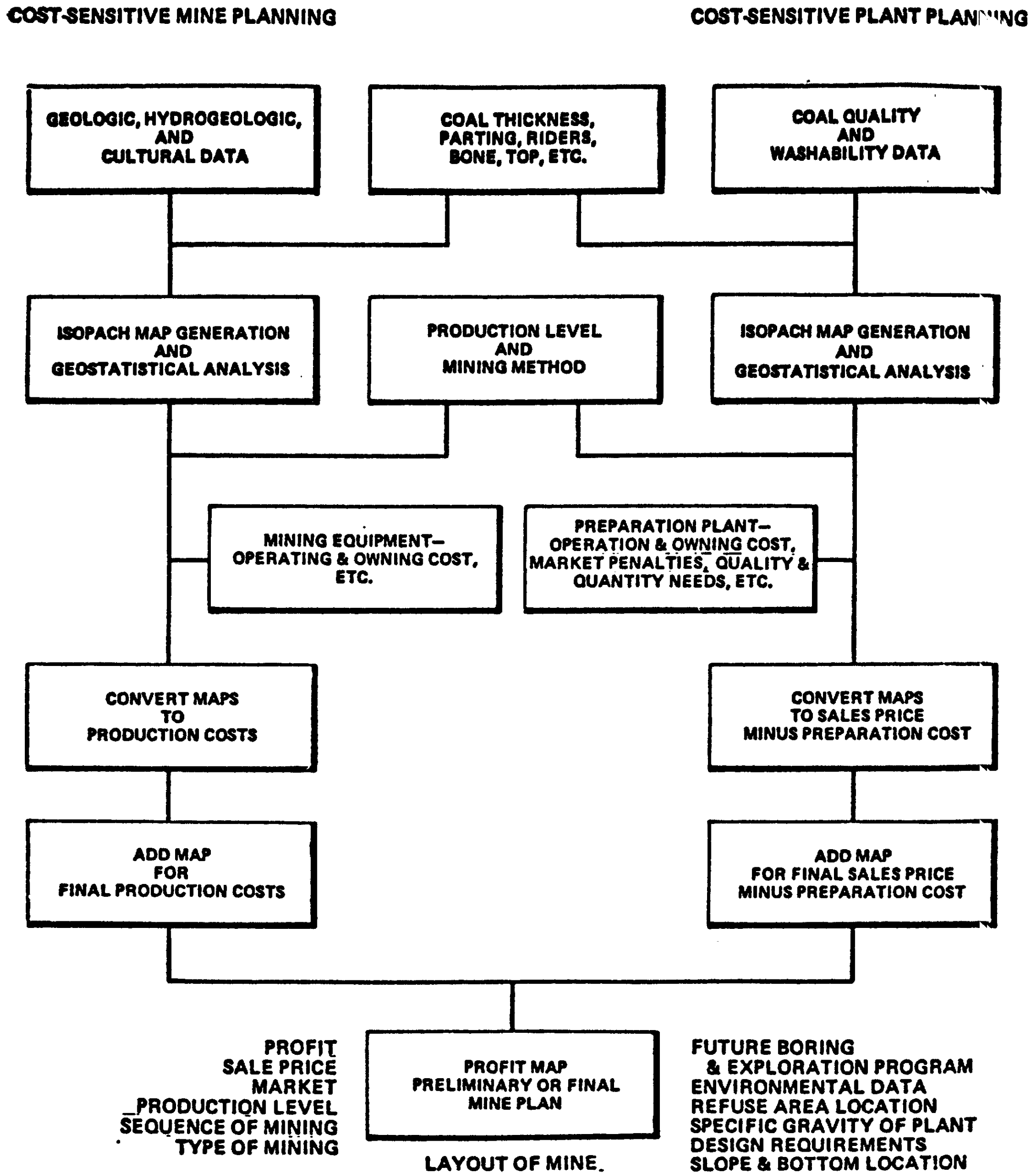

COST-SENSITIVE MINE PLANNING
COST-SENSITIVE PLANT PLANNING
GEOLOGIC, HYDROGEOLOGIC, AND CULTURAL DATA
COAL THICKNESS, PARTING, RIDERS, BONE, TOP, ETC.
COAL QUALITY AND WASHABILITY DATA
ISOPACH MAP GENERATION AND GEOSTATISTICAL ANALYSIS
PRODUCTION LEVEL AND MINING METHOD
ISOPACH MAP GENERATION AND GEOSTATISTICAL ANALYSIS
MINING EQUIPMENT– OPERATING & OWNING COST, ETC.
PREPARATION PLANT– OPERATION & OWNING COST, MARKET PENALTIES, QUALITY & QUANTITY NEEDS, ETC.
CONVERT MAPS TO PRODUCTION COSTS
CONVERT MAPS TO SALES PRICE MINUS PREPARATION COST
ADD MAP FOR FINAL PRODUCTION COSTS
ADD MAP FOR FINAL SALES PRICE MINUS PREPARATION COST
PROFIT
SALE PRICE
MARKET
PRODUCTION LEVEL
SEQUENCE OF MINING
TYPE OF MINING
PROFIT MAP PRELIMINARY OR FINAL MINE PLAN
LAYOUT OF MINE.
FUTURE BORING
& EXPLORATION PROGRAM
ENVIRONMENTAL DATA
REFUSE AREA LOCATION
SPECIFIC GRAVITY OF PLANT
DESIGN REQUIREMENTS
SLOPE & BOTTOM LOCATION

Figure 10.

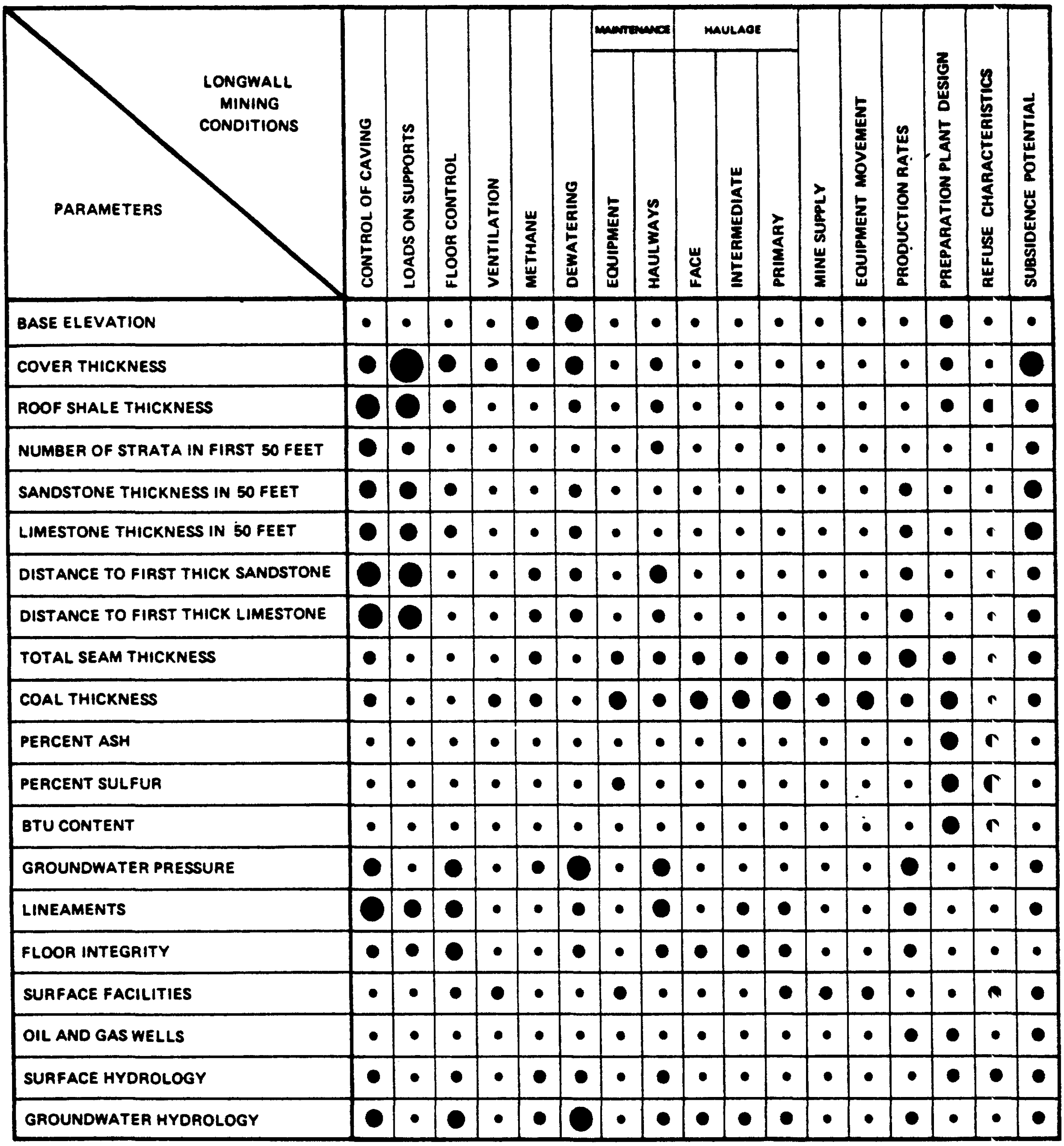


Figure 11. Effect of geologic factors on mining conditions. Size of circle indicates degree of importance.

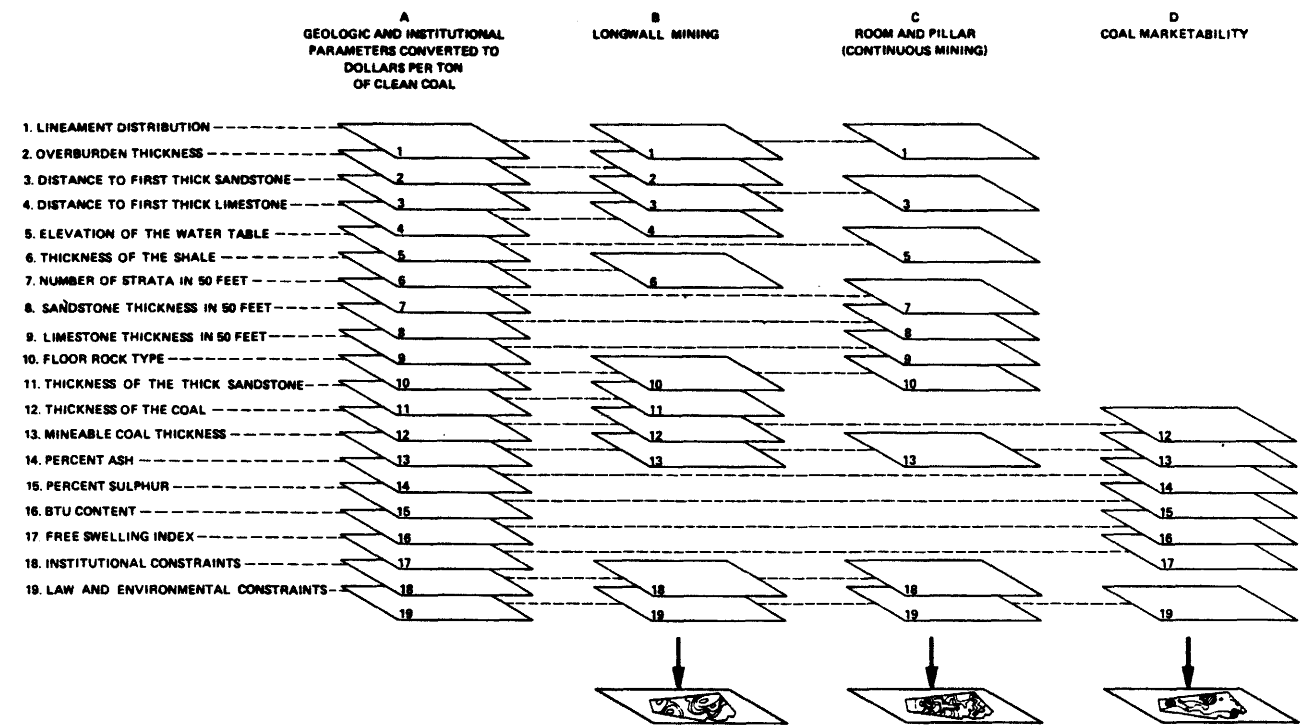


Figure 12. Methodology used to optimize selection of mining methods for an underground reserve.

SUMMARY TABLE OF WHERE PARTICULAR COAL-CHARACTERIZATION PARAMETERS IMPACT UTILITY BOILER SYSTEMS

COAL HANDLING

PROXIMATE (ASH AND MOISTURE)
ULTIMATE (OXYGEN)
BTU/POUND
BULK DENSITY

PULVERIZERS

PROXIMATE (ASH, MOISTURE, VM)
ULTIMATE (Σ S)
BTU/POUND
FORMS OF SULFUR
FSI
HGI
ABRASIVENESS (QUARTZ CONTENT)

BURNERS

PROXIMATE (MOISTURE AND VM)
ULTIMATE (N)
BURNING PROFILES
VOLATILE–RELEASE PROFILES

FURNACE DESIGN

PROXIMATE (MOISTURE, ASH, VM, FC)
ULTIMATE (C, H, N, S)
FORMS OF SULFUR
ASH ANALYSIS
ASH FUSION TEMPERATURES
ASH VISCOSITY
GRAVITY FRACTIONATION
BURNING PROFILES
VOLATILE RELEASE PROFILES

AIR HEATERS

PROXIMATE (MOISTURE, VM)
ULTIMATE (ASH, S)

CONVECTION PASS DESIGN

PROXIMATE (ASH, MOISTURE)
FORMS OF SULFUR
ASH ANALYSIS
ASH FUSION TEMPERATURES
TOTAL ALKALI ON COAL
ASH SINTERING STRENGTH
ACETIC ACID SOLUBLE ALKALIS

PRECIPITATORS

ULTIMATE (MOISTURE, S, AND GAS DENSITY)
ASH ANALYSIS

GAS SCRUBBER

PROXIMATE (MOISTURE, ASH)
ULTIMATE (S AND GAS DENSITY)
ASH ANALYSIS

VM=Volatile matter
FSI=Free swelling index
FC=Fixed carbon
HGI=Hardgrove grindability index.
S=Sulfur
N=Nitrogen
C=Carbon
H=Hydrogen

Figure 13.

To accurately assess the variability of each of these parameters over a 100 million ton reserve would require a very large number of very large samples. It is not feasible to collect such a suite of samples, thus indirect methods of assessment must be used to infer coal quality (and therefore, coal-product quality) obtainable from a particular reserve. Some of these methods are illustrated in the following discussions.

Figure 14 illustrates the results of attempting to correlate the ash content of various raw and clean-coal fractions with various other coal-quality parameters. It should be emphasized that although the ash content shows good correlation with Btu/lb, percent total sulfur, percent pyritic sulfur, percent organic sulfur, percent Al_2O_3, percent SiO_2, acid/base ratio, and percent volatile matter, these results are applicable only to this particular reserve. In fact, these correlations may not even exist for other deposits. By using the percent volatile matter value obtained from figure 14 and the correlations illustrated in figure 15, estimates of percent carbon, percent hydrogen, percent nitrogen, and percent oxygen can be obtained. Thus, one can infer a large amount of quality data by simply measuring one characteristic (that is, ash content) if enough data is available to generate these types of interrelationships among coal-quality parameters. Once a coal-characterization parameter is selected as important in evaluating a resource, it becomes necessary to project this quality parameter across the extent of the resource.

Figure 16 indicates the type of data on mineral-matter size distribution required to assess the grind necessary to liberate various amounts of this material. This type of information is useful for fine coal cleaning and essential if extremely low ash products (<1 percent) are to be produced.

It is thought that cleaning may remove some of the epigenetic "overprinting" (for instance, cleat pyrite, and so on) masking syngenetic relationships among coal-quality parameters. These parameters are less variable in the clean coal than observed in the raw coal; hence, fewer samples are required using the clean-coal data. Figures 17, 18, and 19 indicate the differences in variability observed in raw versus clean-coal fractions for the quality parameters ash, sulfur, and Btu for a particular reserve.

Two relatively new areas of characterizing coal deposits (and variability expected) are studies on depositional modeling and geostatistics. Figure 20 illustrates idealized models for environments of deposition for coal. Data from the literature indicates that correlations exist between geologic hazards that have an impact on mining costs (fig. 21) and coal quality (fig. 22). Thus, by determining the environment of deposition in which a particular coal resource was deposited, one can estimate the

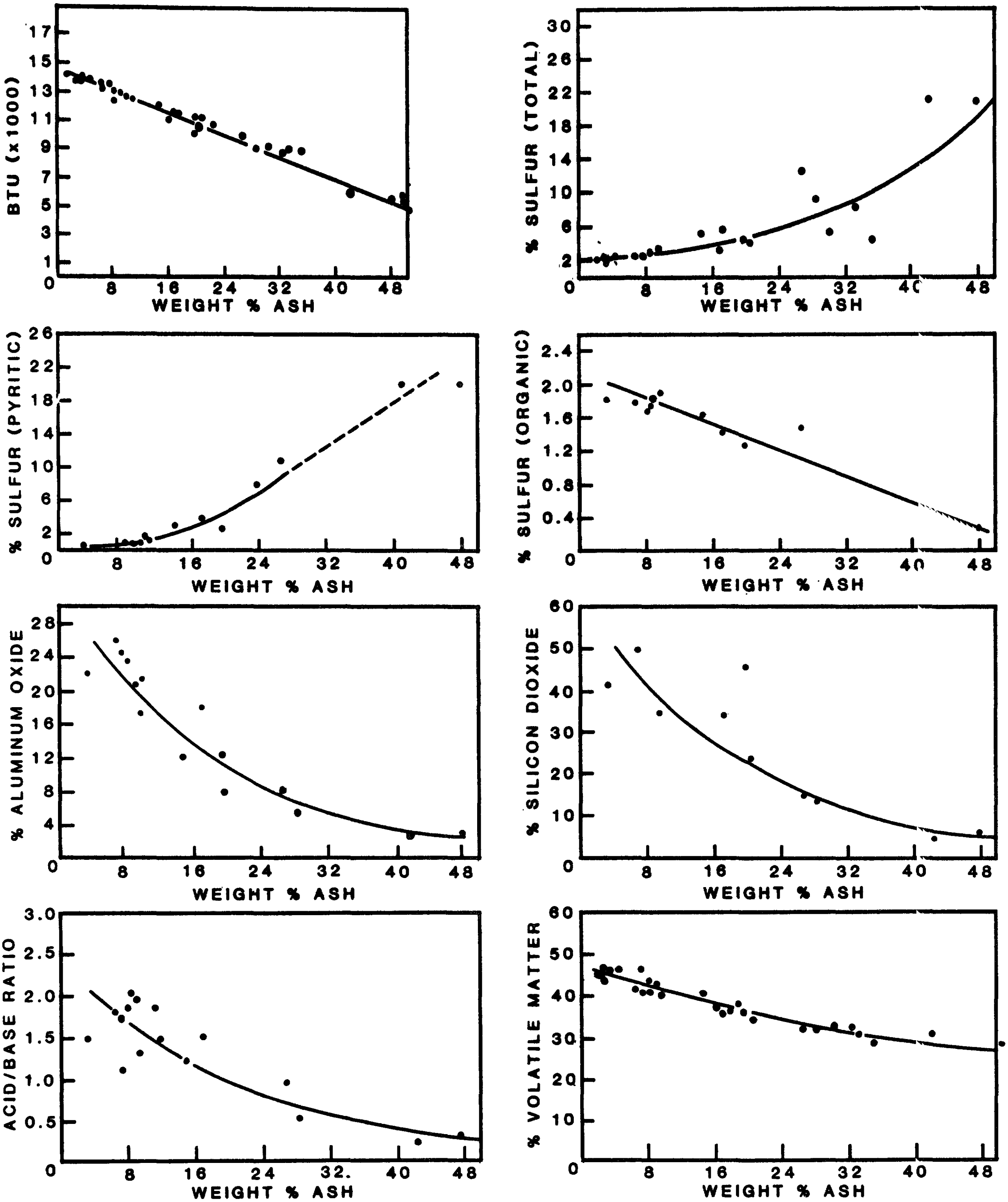


Figure 14. Correlation between ash content and other coal properties.

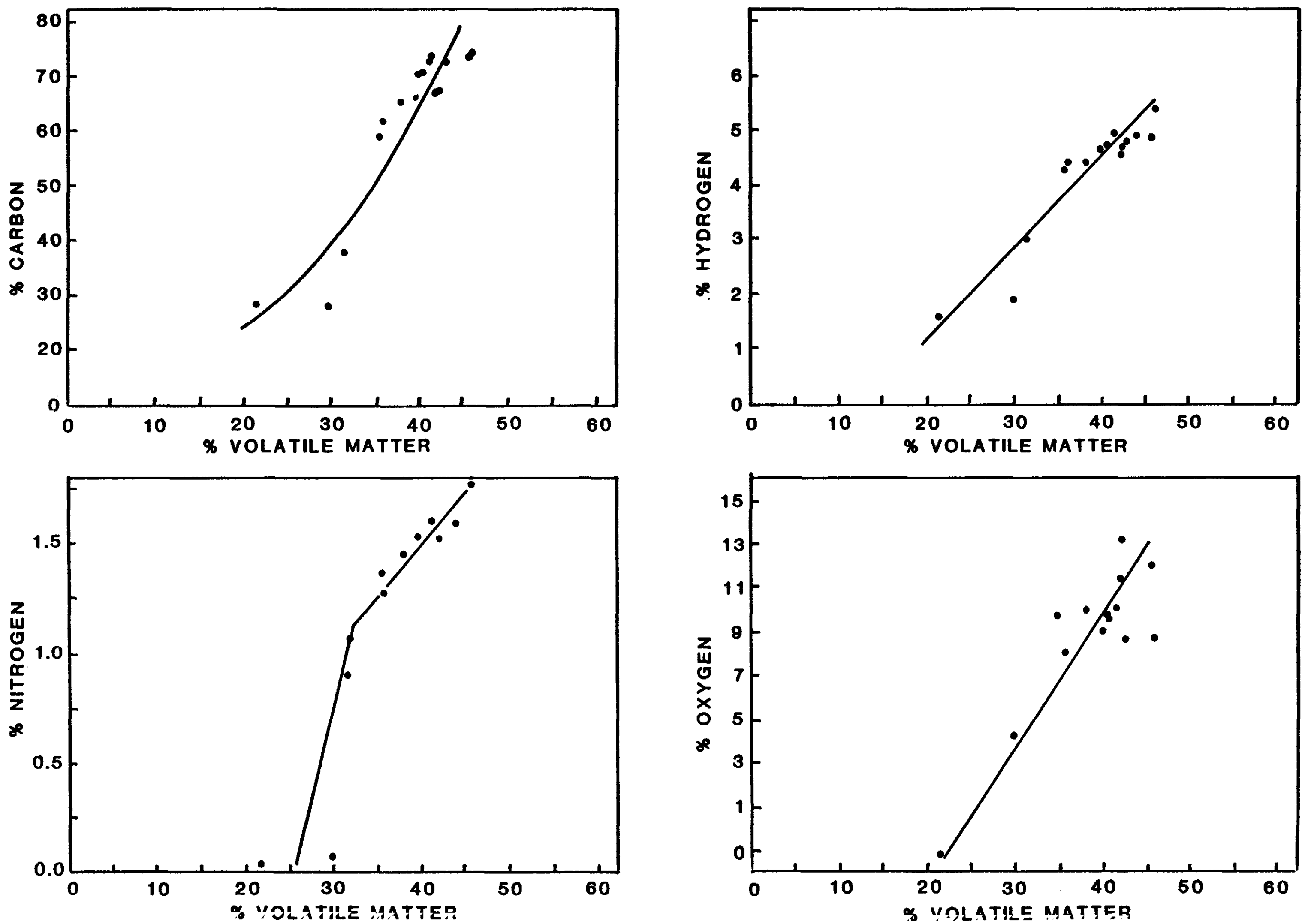


Figure 15. Correlation between volatile matter content and coal properties.

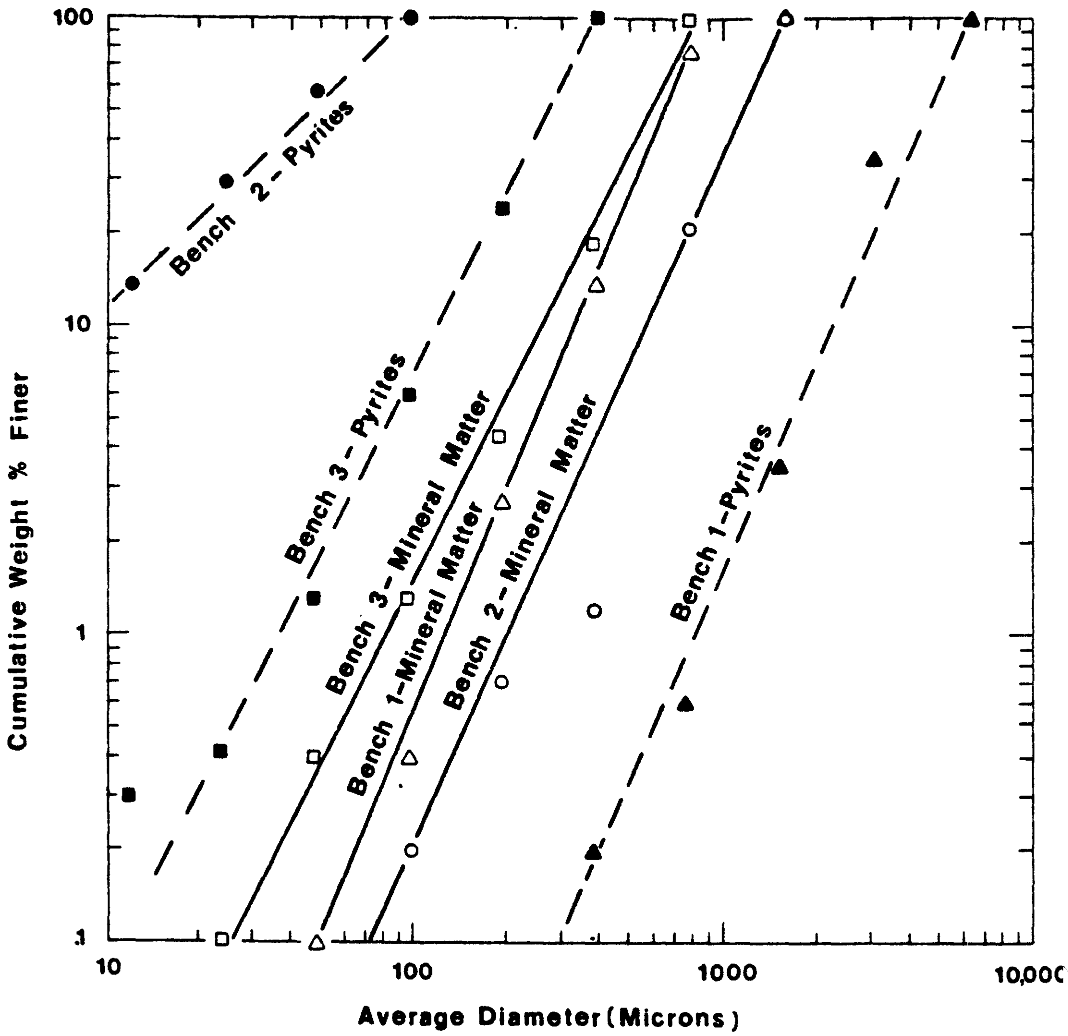


Figure 16. Pyrite and mineral-matter size distribution for three benches of a coal core.

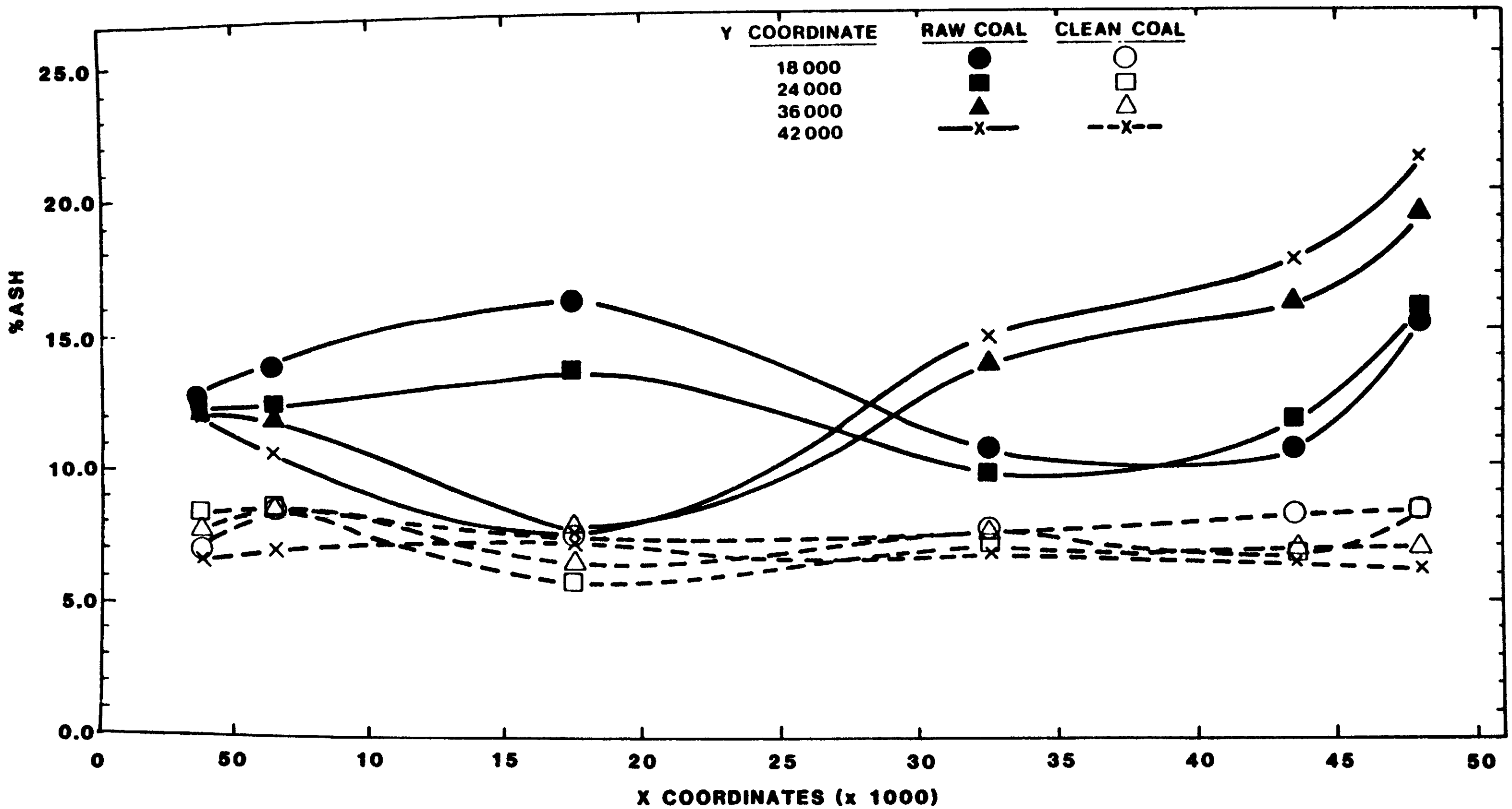


Figure 17. Ash variability in the raw and clean coal. (X and Y coordinates relate to an arbitrary map grid used during evaluation of a particular coal reserve.)

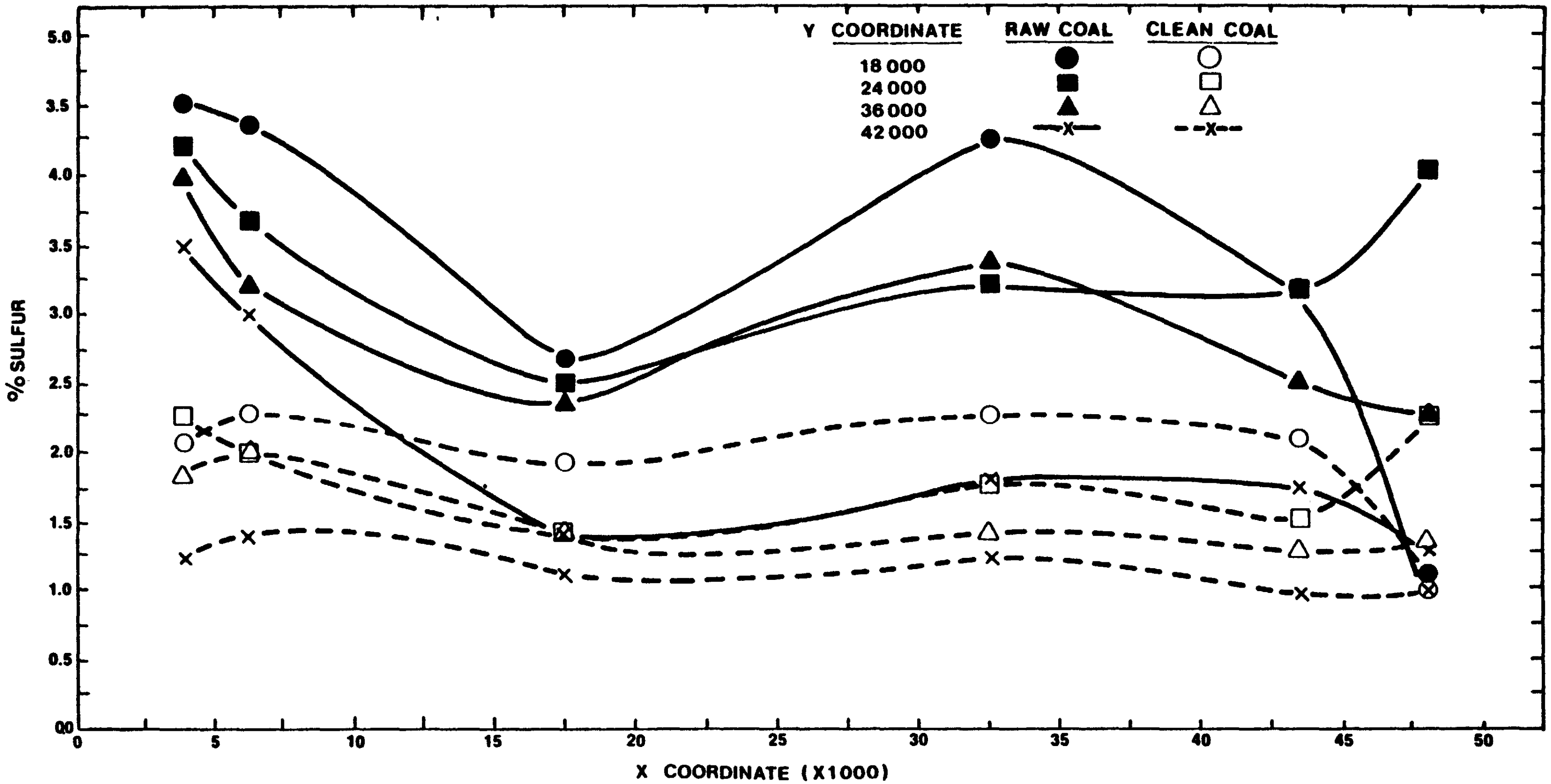


Figure 18. Sulfur variability in the raw and clean coal. (X and Y coordinates relate to an arbitrary map grid used during the evaluation of a particular coal reserve.)

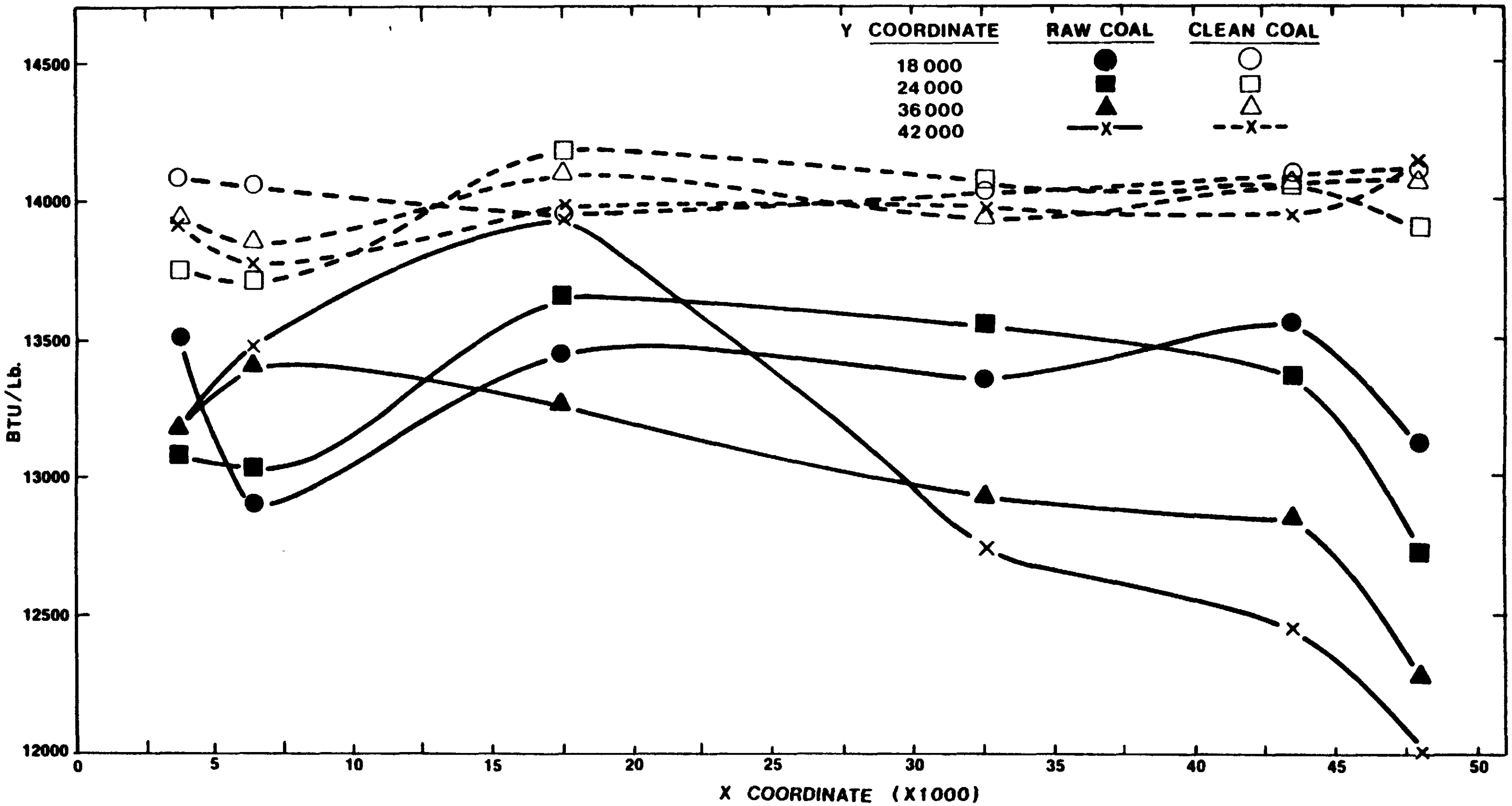


Figure 19. BTU variability in the raw and clean coal. (X and Y coordinates relate to an arbitrary map grid used during the evaluation of a particular coal reserve.)

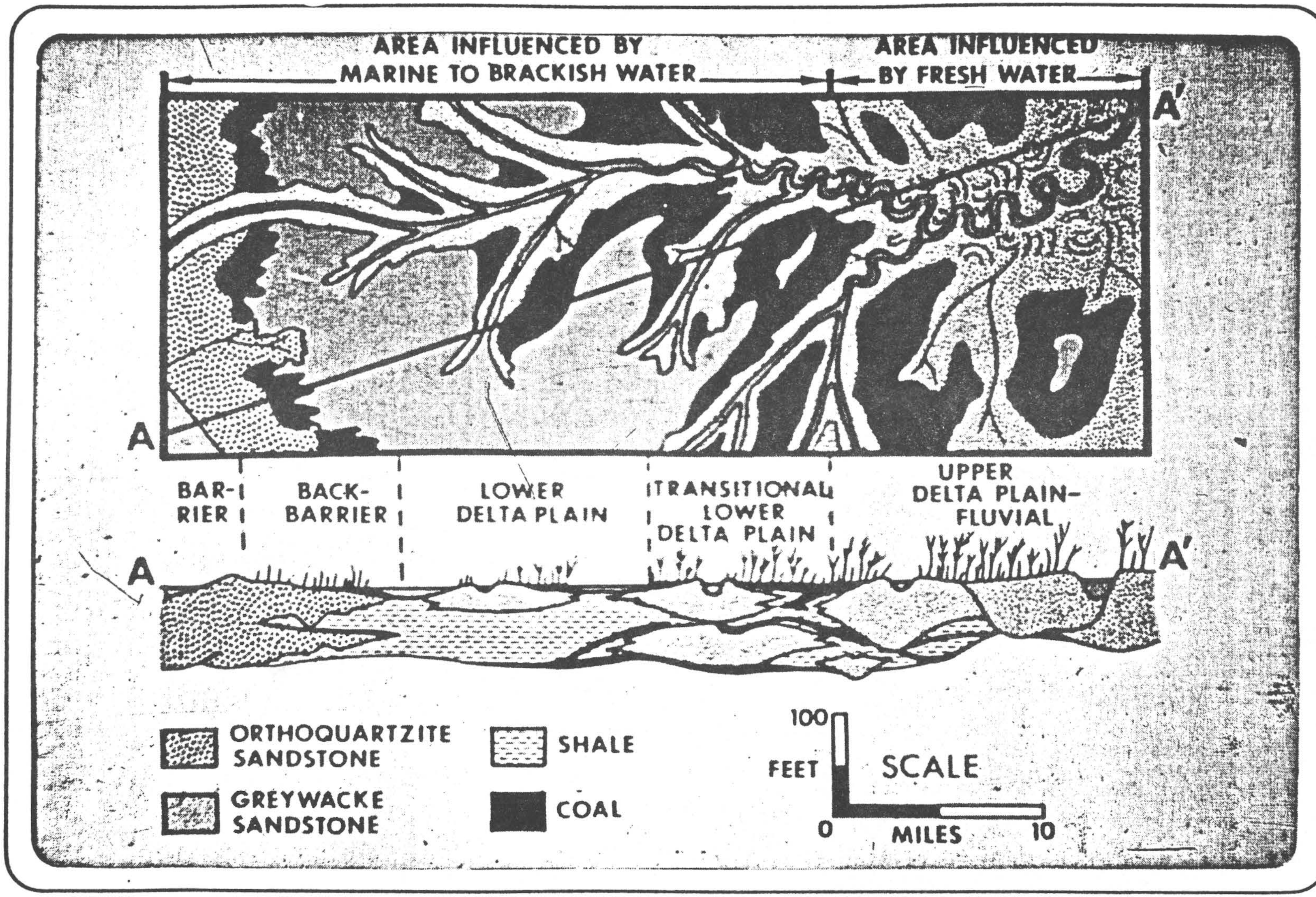


Figure 20. Idealized models for environments of deposition of coal deposits.

Roof Problems	Back-Barrier	Lower Delta Plain	Transitional Lower Delta Plain	Fluvial and Upper Delta Plain
Clay-rich Rooted Zones	3-2	2	2-1	1
Slump Blocks	1-2	3-2	2-1	1-2
Rider Coals within 20 ft. (6 meters) of Mined Coal (Intervening Material Fine-grained)	3-2	2-1	1-2	1
Kettles (Upright Stumps) in Fine-grained Rock	2	2	2-1	1-2
Sandstone Channels Enclosed in Shales	1	1-2	2	2-3
Jointed Orthoquartzitic Sandstones	2-1	3	3-4	4
Cube Rock (Non-bedded Black Claystones)	2	2-1	1	3-2
Conglomerate and Plant Debris Lags	3-2	2-3	2-1	1
Fine-grained Burrowed Zones	1-2	1-2	2-1	3-2

1. Abundant 2. Common 3. Rare 4. Not present

Figure 21. Abundance of potential roof problems related to depositional environments.

Environment	Thickness	Areal Extent	Sulfur	Roof Problems	Mini Deltas Crevasse Splays	Proximity to Marine Environment
Barrier Bar/ Lagoon	Thin	Discontinuous 3-15 Miles	High Framboidal	Severe		Closest
Lower Delta Plain	Thin	Widespread; 5-70 Miles Wide	Irregular	Few	40' Thick 100'-5 Mi. Wide Usually 3-4,000' in Dia.	
Transitional	Thick	Widespread; Continuous	Low	Some		
Upper Delta Plain	Thick Locally	Discontinuous; May Pinch Out in 500'	Low	Best		Farthest

Figure 22. Characteristics of coal quantity, quality, and mineability expected in coals deposited in selected environments.

variability anticipated. In this manner, a logical exploratory drilling program can be devised to obtain samples for coal-quality analyses to both test and refine the model and predict with some degree of certainty the range of mining conditions and coal quality anticipated (fig. 23).

Geostatistics is another powerful tool that can be used in reserve evaluation. The advantage of a geostatistical approach is that it permits you to place a confidence level on your estimates of quality, variability, and so on. However, when applied indiscriminately, geostatistics can lead the unwary astray. Figure 24 is an idealized example of an attempt to construct a semi-variogram from a set of coal-quality data from a hypothetical coal resource in northern Appalachia. Any interpretation of the data would be suspect. However, when the data is broken down into two separate sets, each consisting of data within an interpreted environment of deposition (based on geologic data), the semi-variograms become more meaningful (figs. 25 and 26). After a structural study (figs. 27 and 28), the semi-variograms indicate the variability expected in different directions within each environment of deposition found in the deposit. Thus, drilling patterns required to obtain additional samples can be logically established to maximize information at the minimum exploration cost.

MARKETABILITY

Once the resource has been evaluated in terms of mineability (that is, production cost) and range of coal-product qualities producible (that is, coal-preparation costs), a curve of product cost versus coal quality (fig. 29) can be generated. The Marketing Department must then gather information to permit generation of a curve showing anticipated market price versus coal quality (fig. 30). Combining these curves gives an indication of where coal-product qualities producible will be uneconomic to produce and market (fig. 31, Areas A, B, and C). This curve permits evaluation of the profitability anticipated when marketing particular coal-product qualities.

SUMMARY

Coal-resource assessment is a dynamic, phased process requiring input from geologists, mining engineers, preparation engineers, marketing departments, and corporate management. Early input from the marketplace is essential in identifying opportunities for coal-product penetration. Predicting the range of mining conditions expected to be found as well as the range of coal qualities found and coal-product qualities producible requires extrapolation of data on less than 10 tons of material to a reserve that may have over 100 million tons of recoverable coal. Because this sample is so small and the results of the exploration program and engineering evaluation affect a $100 million corporate decision on

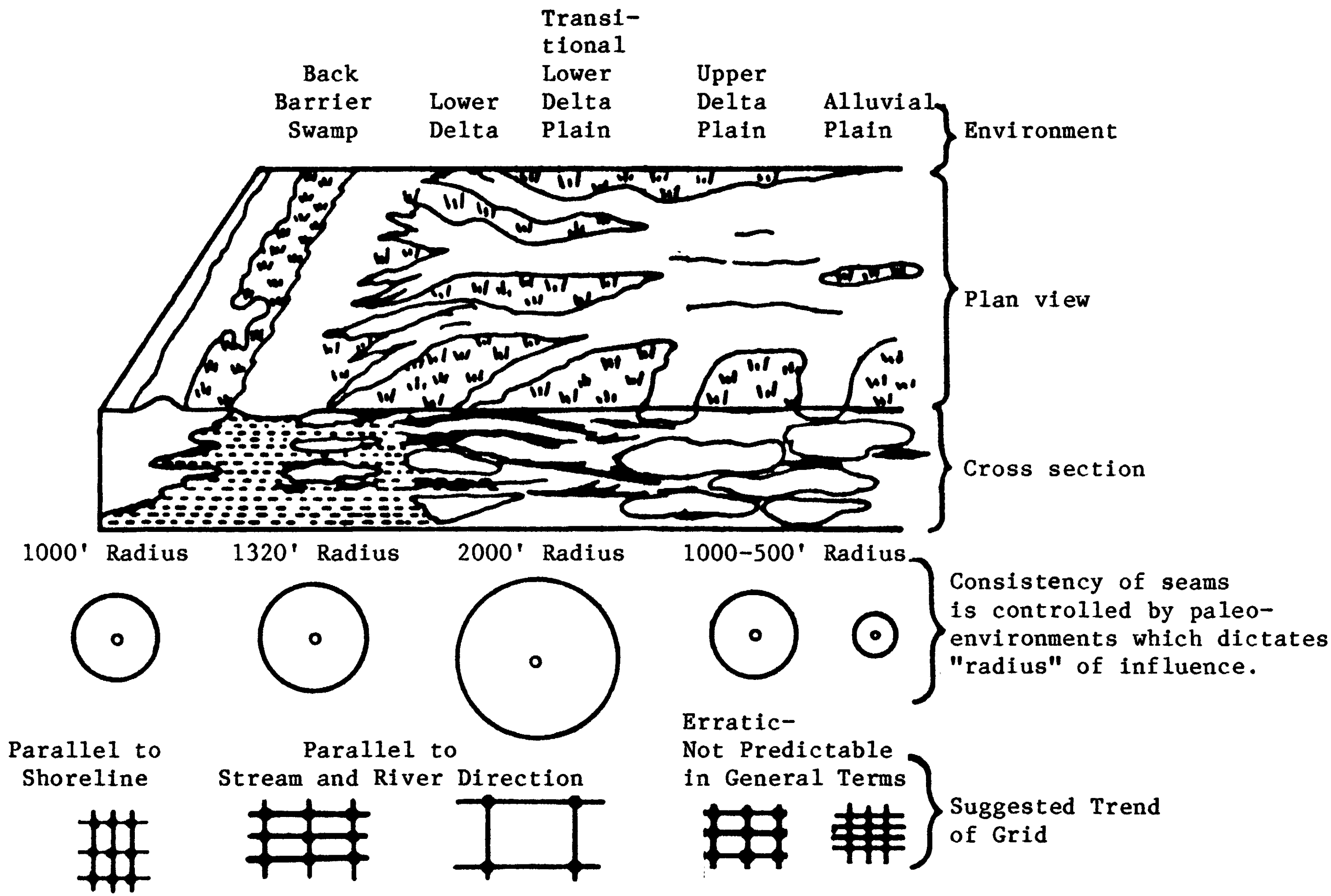


Figure 23. Use of depositional models to reduce costs of exploration drilling.

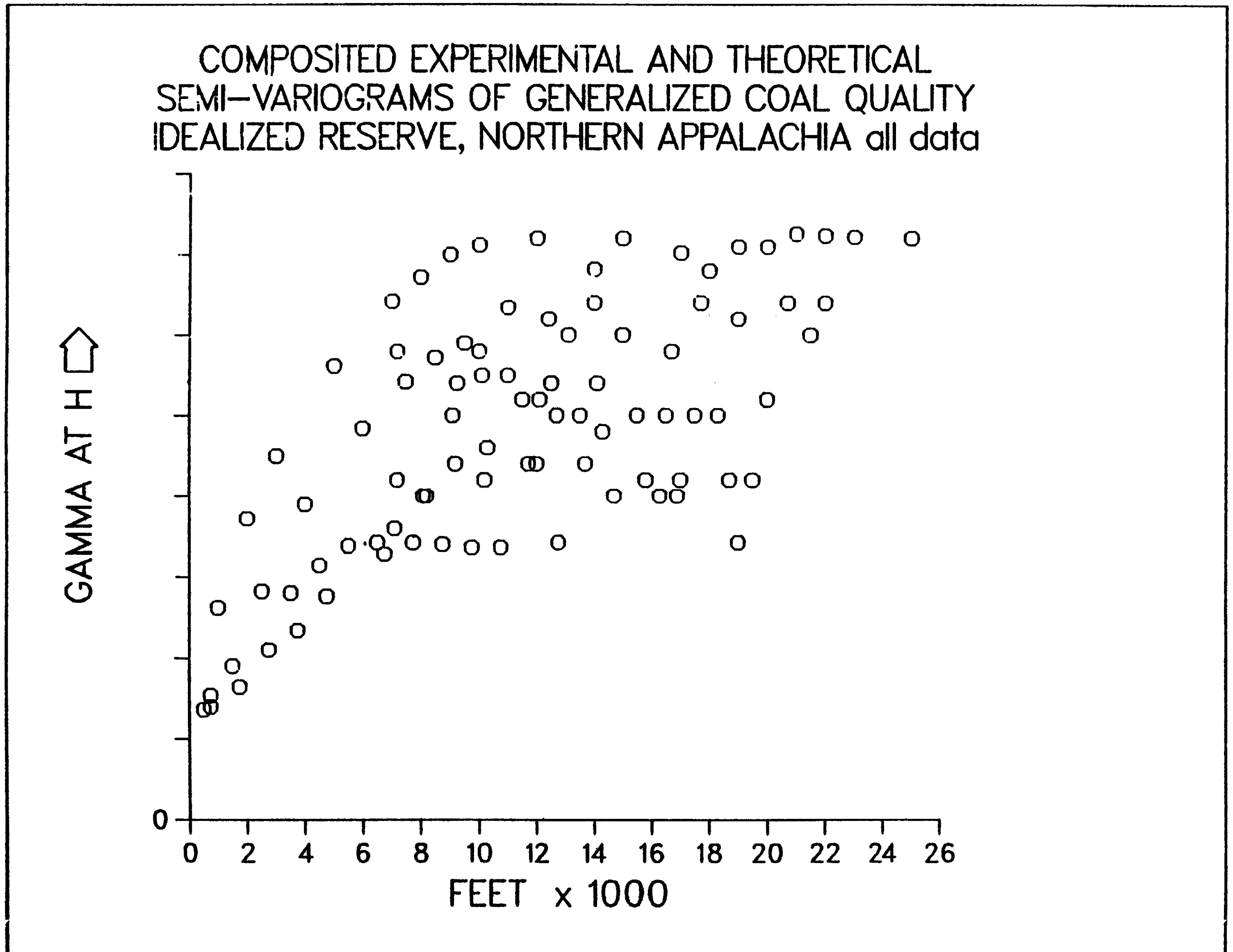

COMPOSITED EXPERIMENTAL AND THEORETICAL
SEMI-VARIOGRAMS OF GENERALIZED COAL QUALITY
IDEALIZED RESERVE, NORTHERN APPALACHIA all data
GAMMA AT H
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26
FEET x 1000

Figure 24.

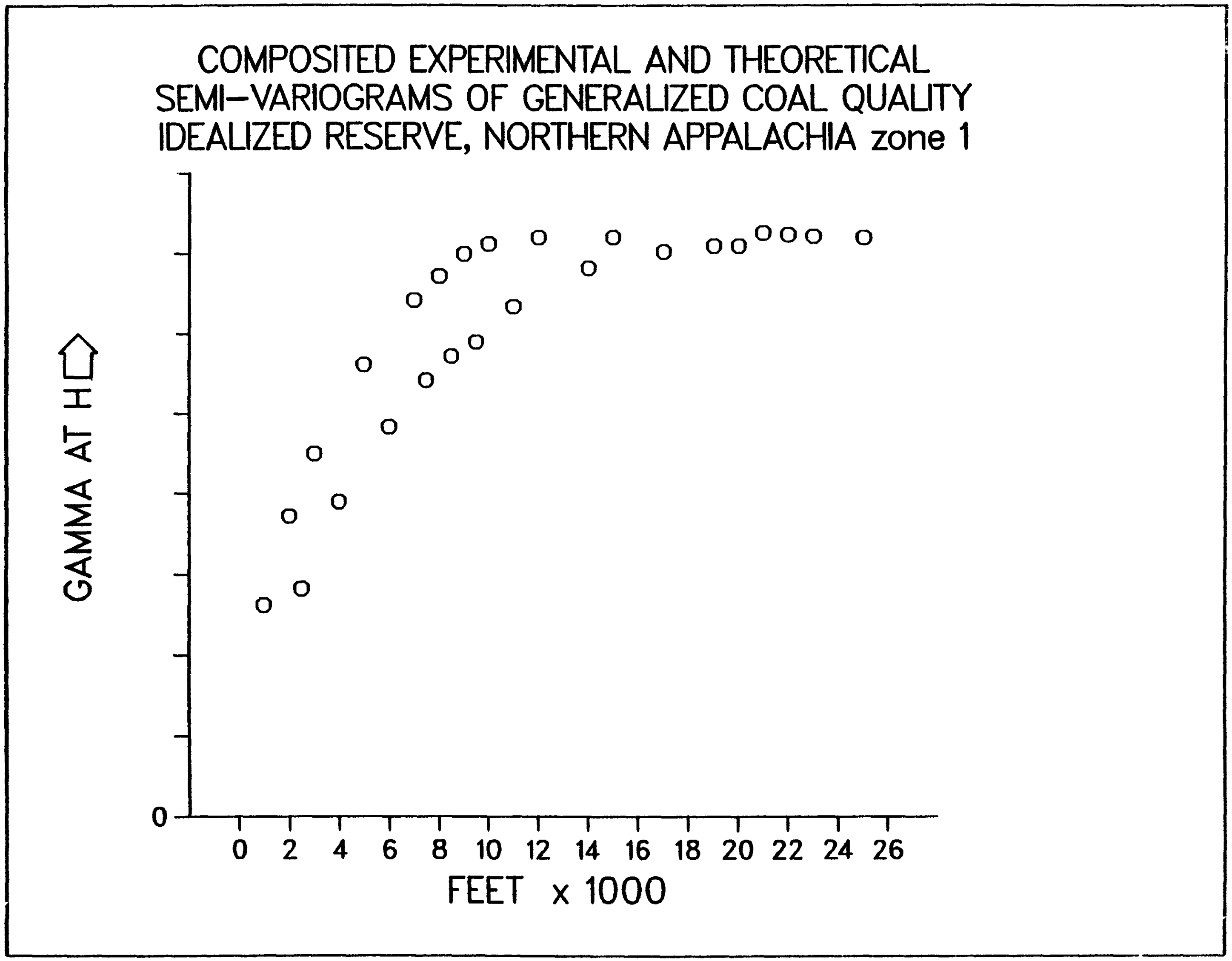

COMPOSITED EXPERIMENTAL AND THEORETICAL
SEMI-VARIOGRAMS OF GENERALIZED COAL QUALITY
IDEALIZED RESERVE, NORTHERN APPALACHIA zone 1
GAMMA AT H
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26
FEET x 1000

Figure 25.

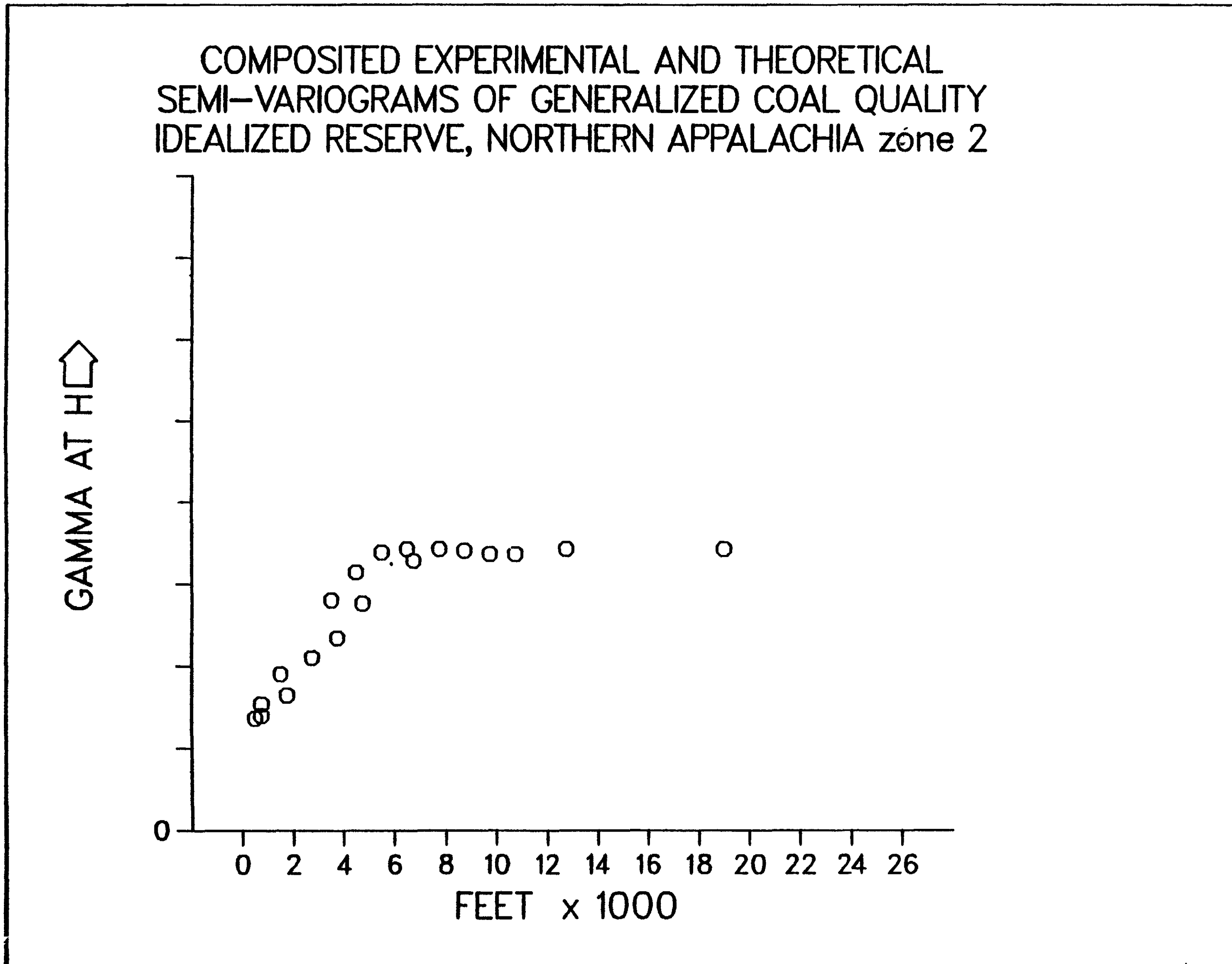

COMPOSITED EXPERIMENTAL AND THEORETICAL
SEMI-VARIOGRAMS OF GENERALIZED COAL QUALITY
IDEALIZED RESERVE, NORTHERN APPALACHIA zóne 2
GAMMA AT H
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26
FEET x 1000

Figure 26.

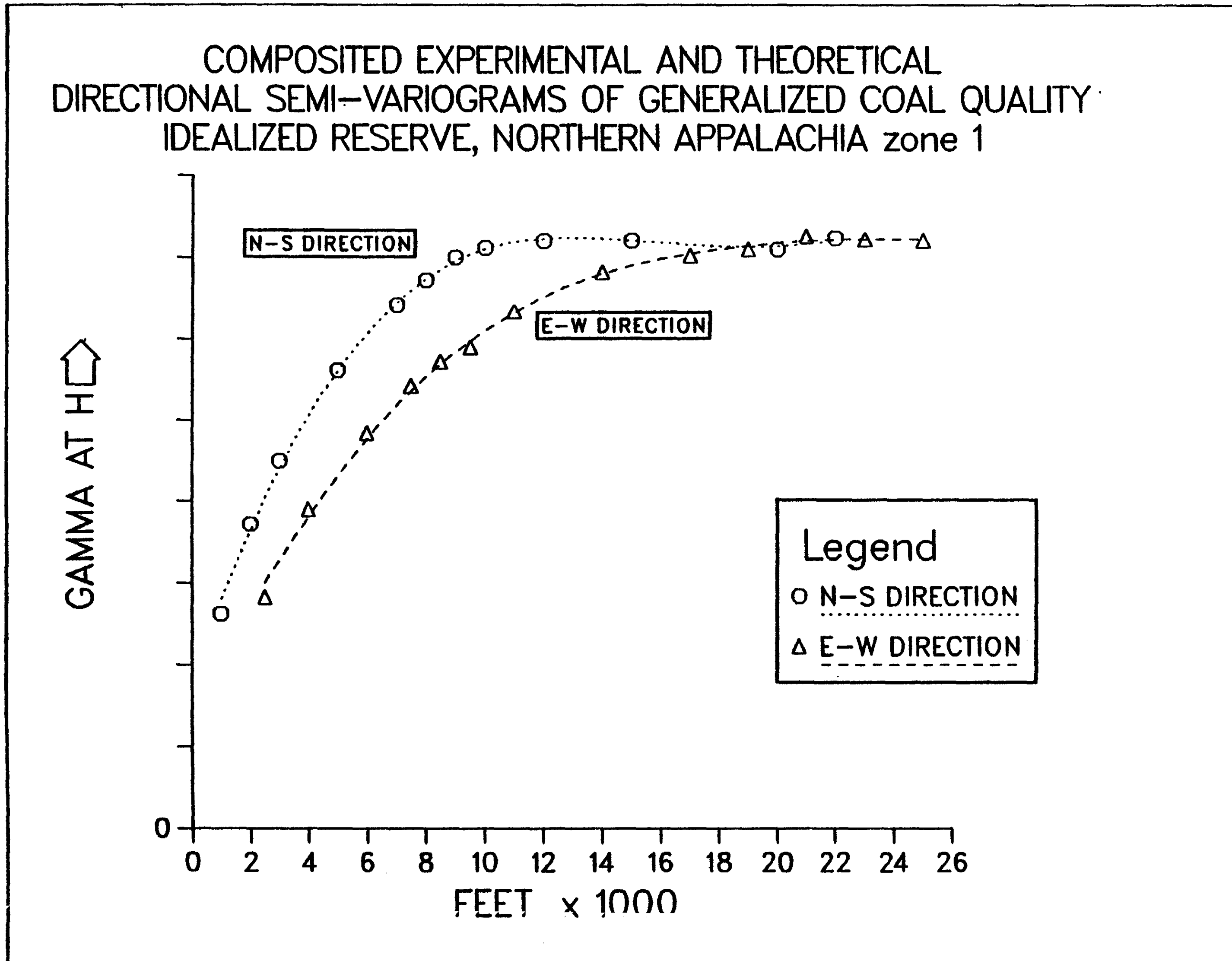

COMPOSITED EXPERIMENTAL AND THEORETICAL
DIRECTIONAL SEMI-VARIOGRAMS OF GENERALIZED COAL QUALITY
IDEALIZED RESERVE, NORTHERN APPALACHIA zone 1
N-S DIRECTION
E-W DIRECTION
GAMMA AT H
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26
FEET x 1000
Legend
N-S DIRECTION
E-W DIRECTION

Figure 27.

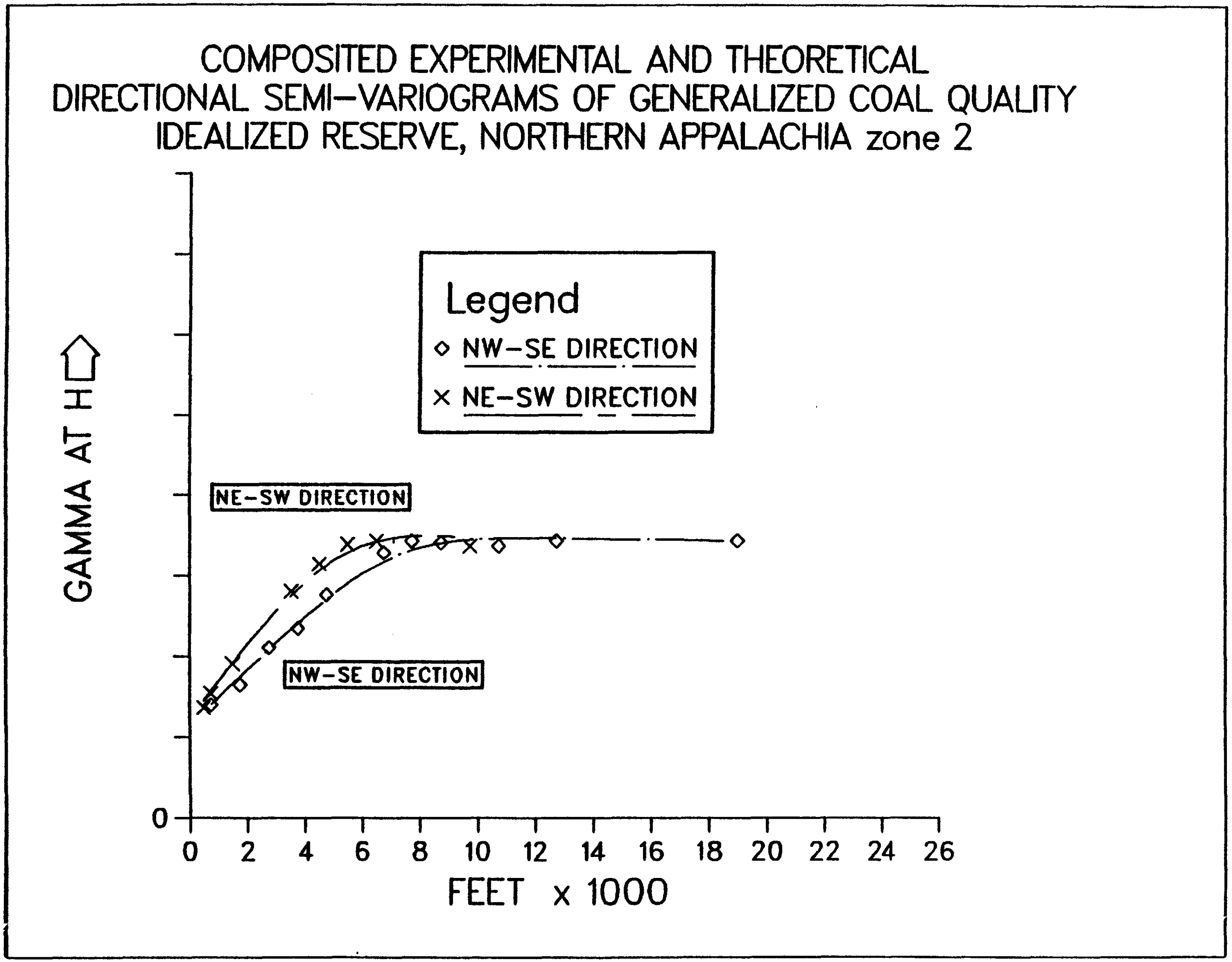

COMPOSITED EXPERIMENTAL AND THEORETICAL
DIRECTIONAL SEMI–VARIOGRAMS OF GENERALIZED COAL QUALITY
IDEALIZED RESERVE, NORTHERN APPALACHIA zone 2
GAMMA AT H
Legend
NW–SE DIRECTION
NE–SW DIRECTION
NE–SW DIRECTION
NW–SE DIRECTION
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26
FEET x 1000

Figure 28.

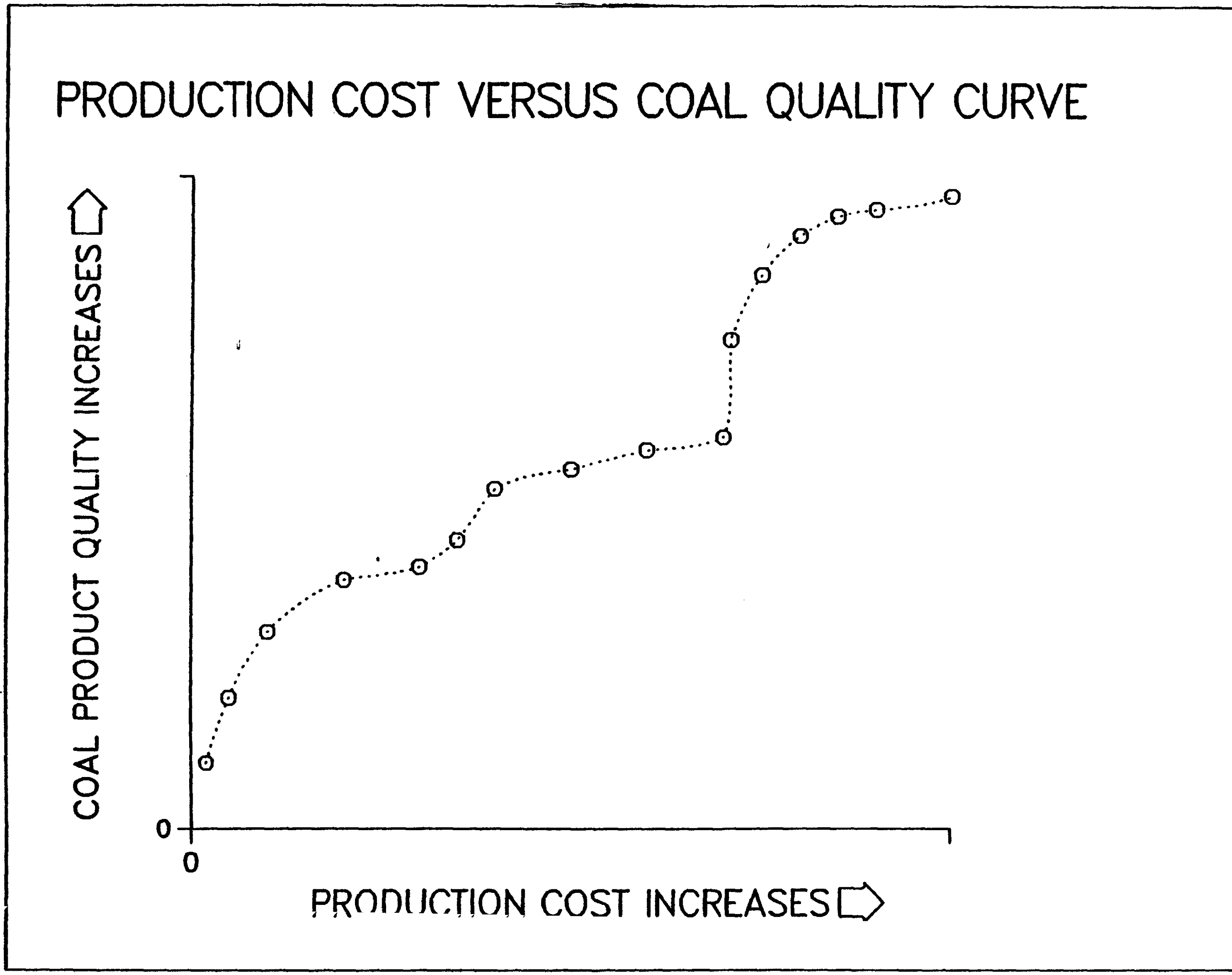

PRODUCTION COST VERSUS COAL QUALITY CURVE
COAL PRODUCT QUALITY INCREASES
0
0
PRODUCTION COST INCREASES

Figure 29.

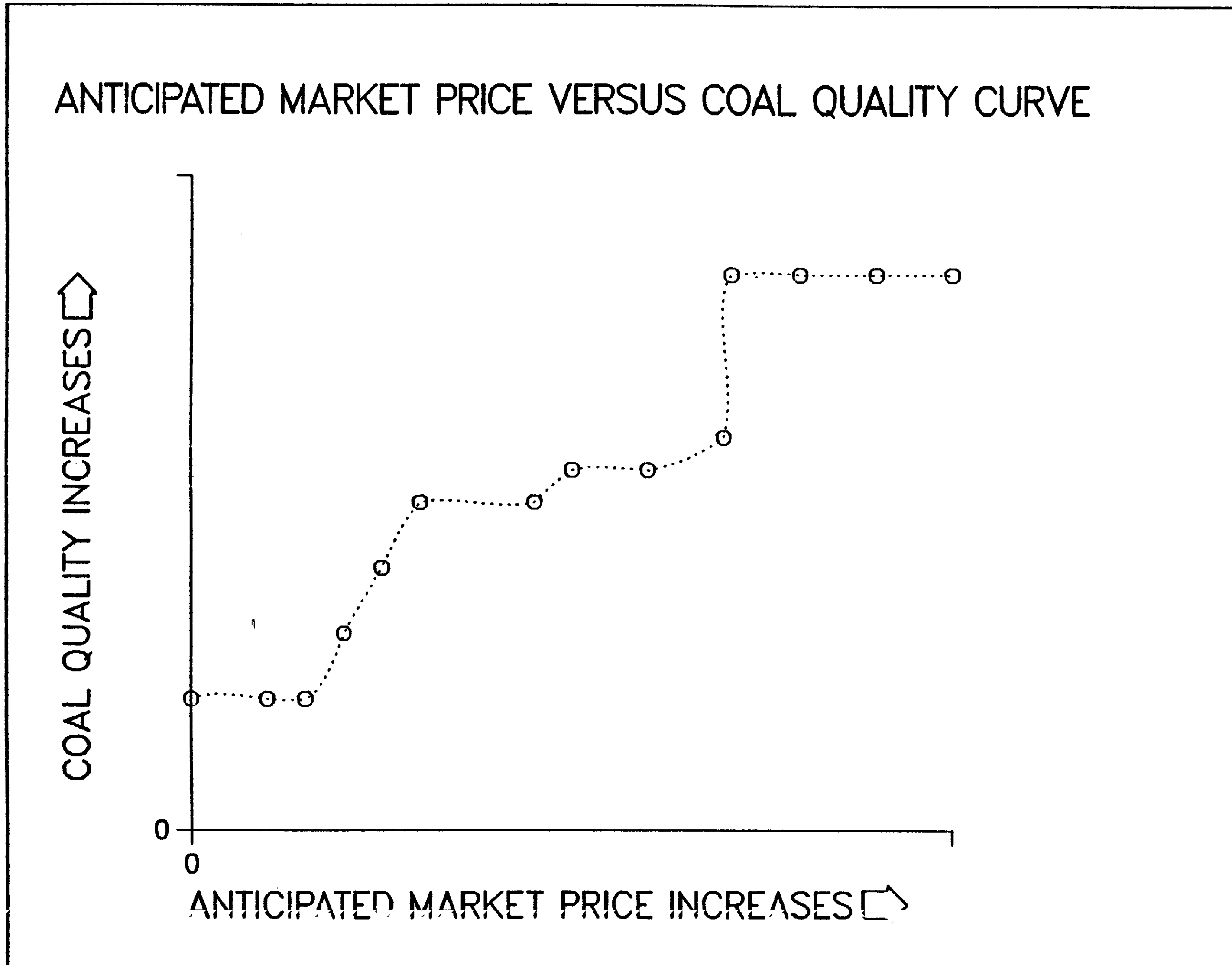

ANTICIPATED MARKET PRICE VERSUS COAL QUALITY CURVE
COAL QUALITY INCREASES
0
0
ANTICIPATED MARKET PRICE INCREASES

Figure 30.

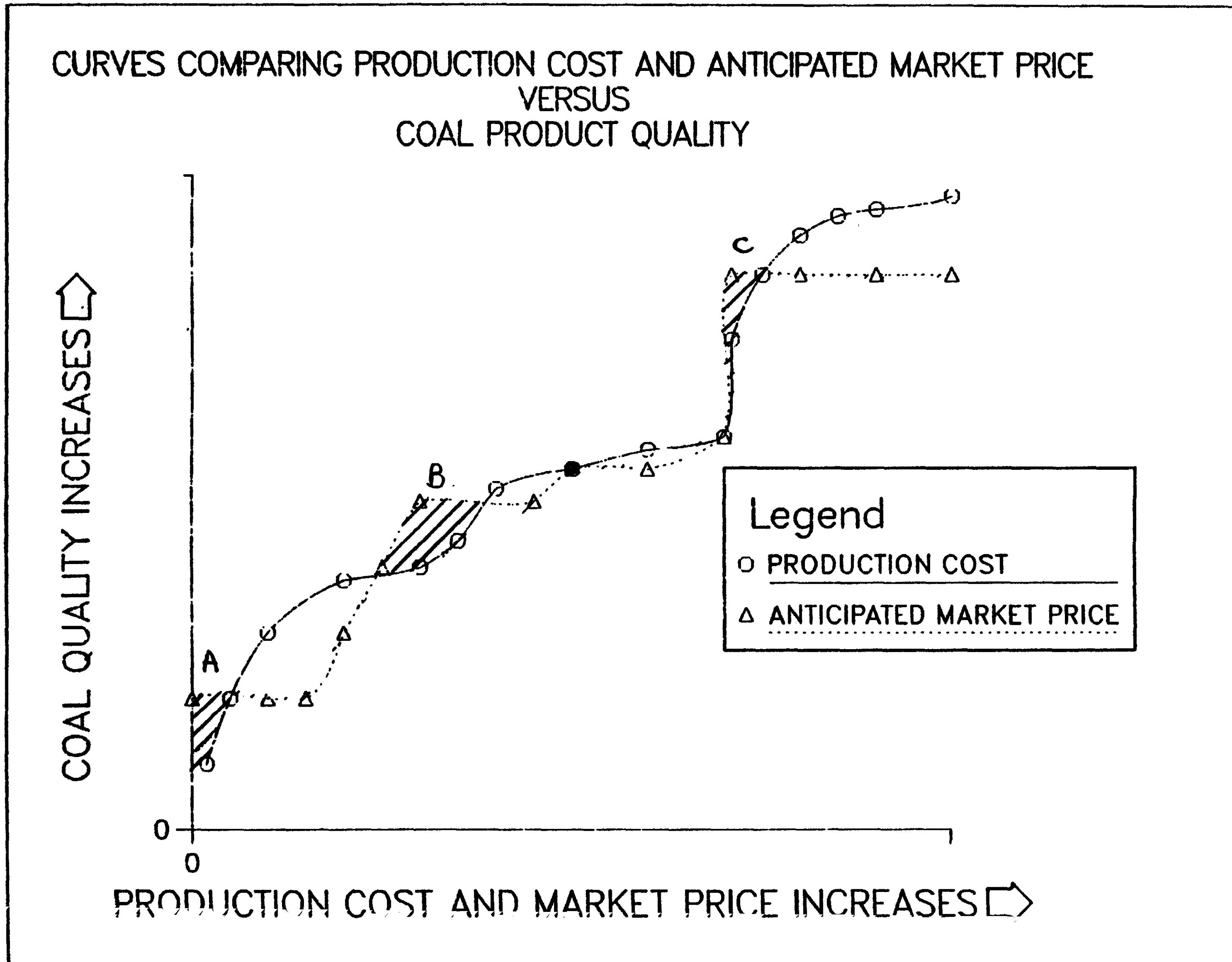

CURVES COMPARING PRODUCTION COST AND ANTICIPATED MARKET PRICE
VERSUS
COAL PRODUCT QUALITY
COAL QUALITY INCREASES
PRODUCTION COST AND MARKET PRICE INCREASES
0
0
A
B
C
Legend
PRODUCTION COST
ANTICIPATED MARKET PRICE

Figure 31.

mine development, it is important that resource assessment teams (a) interact at all levels, and (b) use all the "tools" (that is, depositional modeling, geostatistics, geologic interpretation, and so on) available, and use them properly.

Only when the resource has been characterized and the project engineered sufficiently to predict with reasonable confidence the cost of production, and when a buyer has committed to purchase the mine production at a price level that results in an attractive investment for the mine construction, will a company commit capital to open the mine.

A NATIONAL AGENDA FOR GEOLOGICALLY RELATED COAL RESEARCH

by

Donald C. Haney
Kentucky Geological Survey

Why do we need to know more about coal quality? This Nation has billions and billions of tons of coal, so why the concern? I truly wish it could be so simple.

Sometimes I think coal researchers and developers have a very narrow view of the subject about which they are supposed to be the experts. It may be caused by isolation or ignorance or apathy--who knows? So, for the next few minutes I am going to talk about coal in general, and then finish my presentation by mentioning research areas I consider important.

Even though I represent the coal-producing States of the Association of American State Geologists, what I say today reflects my own opinions, but not necessarily those of the entire group.

From coal, this Nation produces 55 percent of its electrical needs. In 1984, the United States produced nearly 800 million tons of coal valued at $26 per ton, and that alone contributed $22 billion to the national economy. Together with its related goods and services, coal is a very major contributor to our national economic well-being. Coal is as valuable to this Nation's economy as are all metallic and nonmetallic minerals combined. Coal constitutes 70 percent of the known fossil fuels on earth. But coal has a bad name. Who is interested in coal? I am, you are, and others should be.

Figure 1 demonstrates that our ability to produce oil at the pace of current world consumption and population growth is in jeopardy. For the near and possibly distant future, coal will be our principal source of electricity, and in time, coal will probably be our principal transportation fuel. We once had coal-fired steamships and trains, and we may see their return in the future.

Even though coal and the services it generates are very important to our national economy, very few dollars are earmarked for research on coal. The present administration is, through the

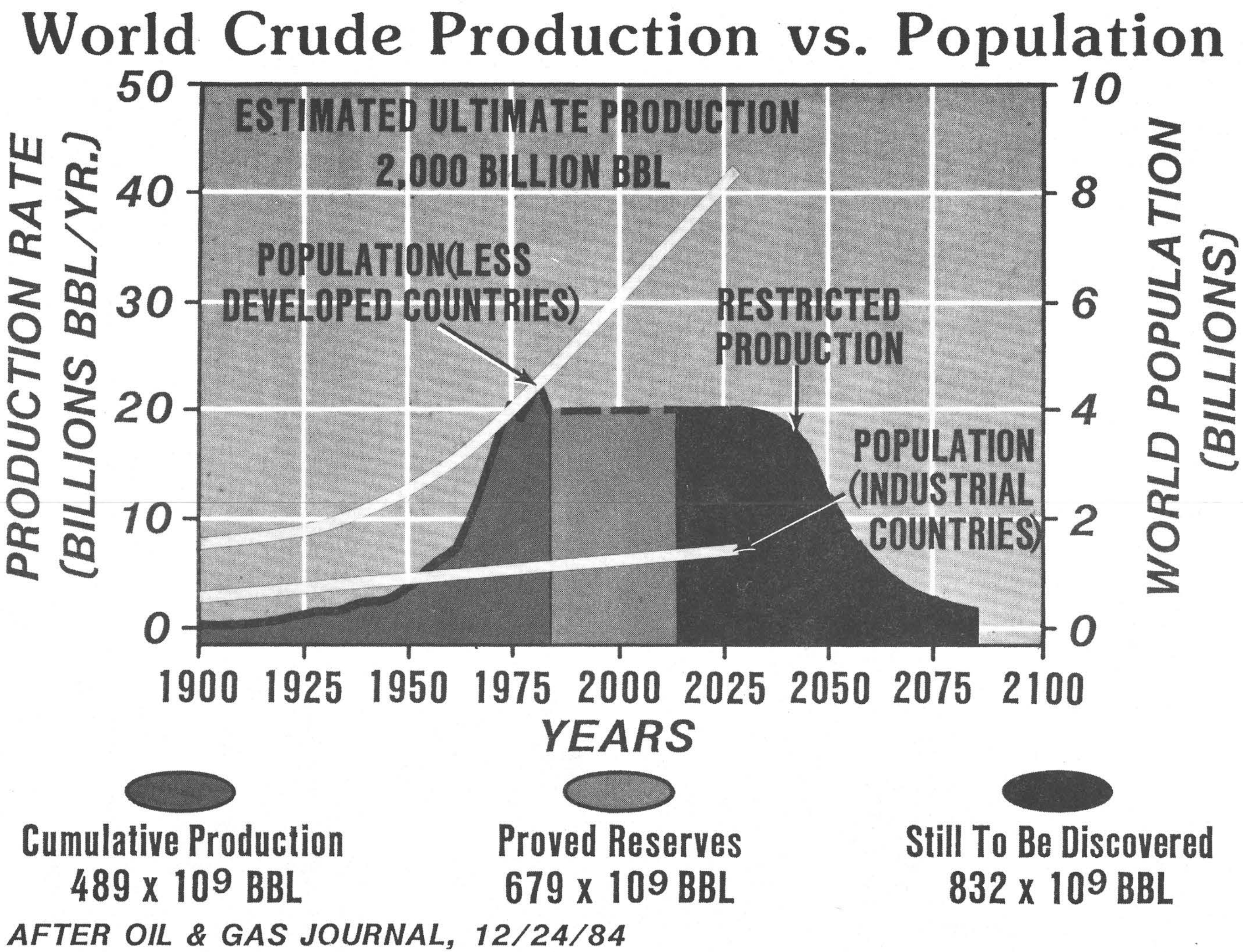

World Crude Production vs. Population
PRODUCTION RATE (BILLIONS BBL/YR.)
WORLD POPULATION (BILLIONS)
ESTIMATED ULTIMATE PRODUCTION
2,000 BILLION BBL
POPULATION(LESS DEVELOPED COUNTRIES)
RESTRICTED PRODUCTION
POPULATION (INDUSTRIAL COUNTRIES)
0
10
20
30
40
50
0
2
4
6
8
10
1900
1925
1950
1975
2000
2025
2050
2075
2100
YEARS
Cumulative Production
489 x 10⁹ BBL
Proved Reserves
679 x 10⁹ BBL
Still To Be Discovered
832 x 10⁹ BBL
AFTER OIL & GAS JOURNAL, 12/24/84

Figure 1.

Environmental Protection Agency (EPA), talking about putting several millions of dollars into acid-rain research, but I would like to point out to you that new money is not being appropriated. That money will come out of someone's budget, and it may be that of the U.S. Geological Survey.

Why has coal-related research fallen on such hard times? For example, at the Federal level why do we have to hide coal-related research by calling it something else such as Regional Geology or Evolution of Sedimentary Basins? Do we hide oil and gas research, uranium-thorium research, volcano research, or earthquake research? Why coal?

Why does the U.S. Office of Surface Mining spend millions of dollars on regulating mining, reclaiming abandoned mine lands, pumping grout into the bottomless pits of old underground coal mines, and allocate only pennies for research?

Whether it pleases us, the EPA, the Sierra Club, Common Cause or anyone else, coal will have to provide most of this Nation's and the world's near-future energy needs. By the year 2000, the portion of the world's energy supplied by coal will have grown from 19 percent to 32 percent.

So why are the press, public, special interest groups, and government putting so much pressure on coal? It's almost like shooting yourself in the foot. Why are we putting so little research effort into coal? Why is our government deserting coal?

I realize that the people in Alaska, California, Missouri, southern Illinois and Indiana and western Kentucky are concerned about earthquakes. I know the people in the Cascades of the Northwest and in Alaska are concerned about volcanoes. But, does that concern warrant or justify a particular research organization spending approximately six times as much money on those areas last year as on coal from which 55 percent of our electricity is generated?

In recent times, we've had only one volcanic eruption in the continental United States, and that was in a very remote area. If better judgment had been shown, possibly no lives would have been lost. I am not necessarily suggesting that we spend less on earthquake and volcano research, but I do declare an urgent need to increase spending for coal research.

Do the special interest groups and Congress realize what they are saying when they advocate raising clean air standards? Do people from noncoal-producing States which use electricity generated from coal realize what is happening? Do regulators who help set policy and advise Congress acknowledge or consider the impact of certain pieces of legislation on our population? By law they are supposed to.

It is easy to sit in an office in Washington and formulate rules and regulations for the coal industry and related industries if one is not held responsible for the impact of such rules and regulations on society, individuals, States or the Nation. If Congressmen, overzealous environmentalists or overbearing regulators could be held responsible for the adverse impact of poorly conceived, unreasonable, and unnecessary rules and regulations on people or the Nation, maybe they would be more objective. If these same people had to be responsible for providing adequate coal supplies at reasonable costs when the temperature is -20 degrees, then they might take a more objective approach in formulating rules and regulations for others to live by.

Let us consider one State, one with which I am very familiar--Kentucky. Kentucky produced approximately 150 million tons of coal last year, having a mine-mouth value of $4.5 billion. Twenty-seven percent of Kentucky's tax revenue comes from coal. The value of coal production in Kentucky is about twice that of agriculture and livestock combined, including tobacco.

What happens if Kentucky's coal production drops significantly? Who takes the responsibility for feeding displaced people? Who keeps the children in school? Who is responsible for the lost dignity of once-proud families? The Sierra Club? EPA? Congress? Who is responsible, or better yet, who will assume responsibility? If you think electricity is high now, just wait.

In Kentucky, we already have a public debate and a split between some western Kentucky coal operators and eastern Kentucky coal operators. The problem concerns low-sulfur coal. Eastern Kentucky has a significant amount of low-sulfur coal. Western Kentucky has very little (figs. 2 and 3).

It is obvious that most of Kentucky's compliance coal is in eastern Kentucky, but only 40 percent of it is in compliance at 1.2 pounds of sulfur dioxide per million Btu. In western Kentucky only 2.5 percent is in compliance at 1.2 pounds of sulfur dioxide per million Btu. Should the emission standard be changed to 0.8 pounds of sulfur dioxide per million Btu, only 5 percent of eastern Kentucky coal would be in compliance, and none of the western Kentucky coal would meet this standard.

It is unlikely that the utility companies will devise new or improved combustion technology to comply with clean-air standards if they can get low-sulfur coal. By high-grading, we can provide low-sulfur coal from eastern Kentucky, but at what cost, and for how long? In fact, most of the low-sulfur coal in eastern North America is within a 100-mile radius of Pikeville, Kentucky.

Histogram of Frequency Distribution For Potential SO_2 Emissions for Eastern Kentucky Coal Resources

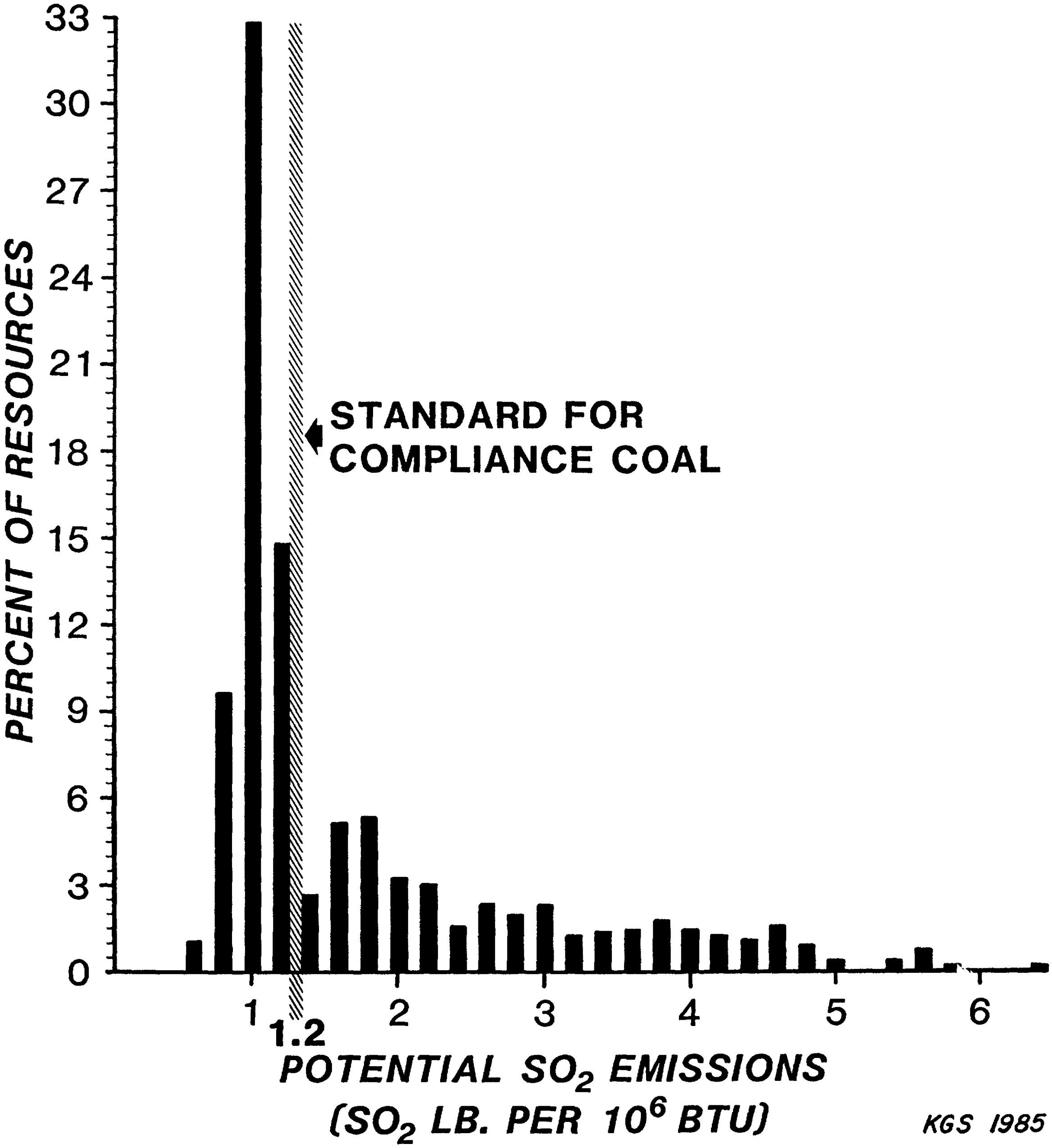


Figure 2.

Histogram of Frequency Distribution For Potential SO_2 Emissions for Western Kentucky Coal Resources

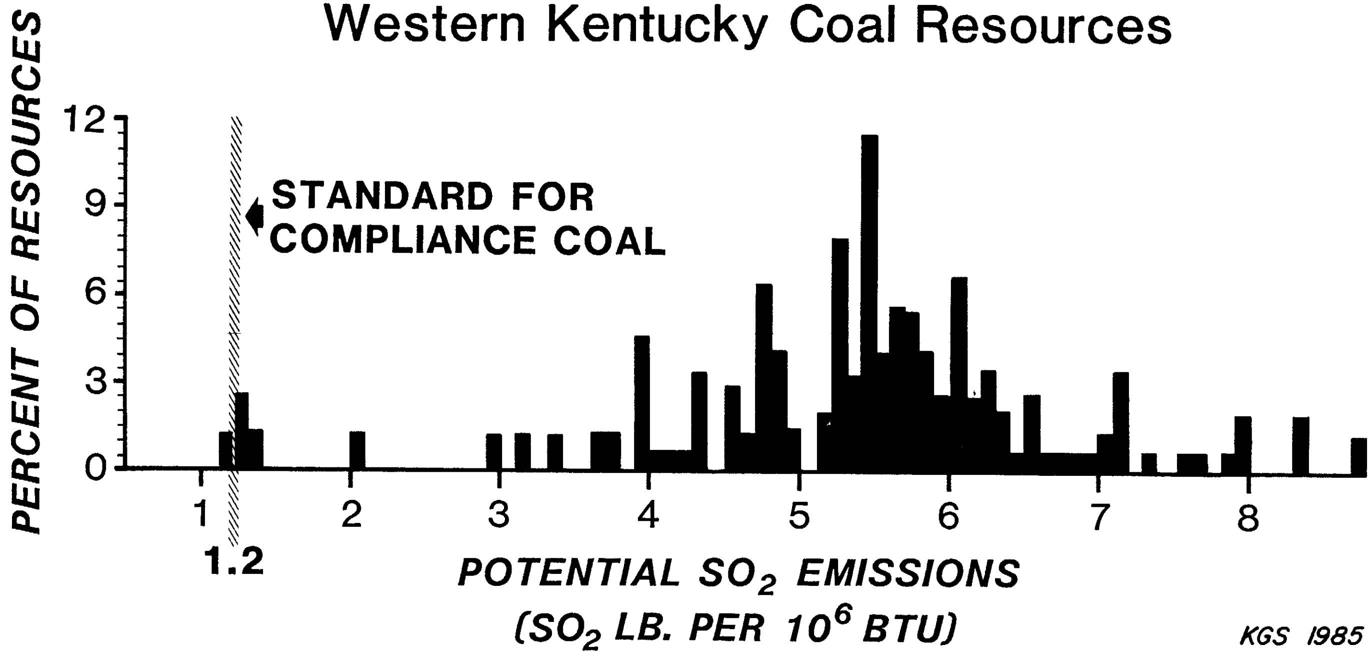


Figure 3.

What does all this have to do with a conference on coal quality? Everything. We must burn coal and we must do it responsibly; also, we must zealously preserve and protect our resources. We must find ways to do both.

If our coals are not clean enough to burn and at the same time protect our air quality, then we must clean them. If we cannot clean them using known technology, then we must improve known technology and devise new technology. To devise new technology for cleaning requires us to learn everything we can about coal. Its composition affects cleaning and combustion. Much research is needed in the area of combustion. We cannot expect our mining industry to bear all the burden of providing clean coal. The utilities are part of our system, and they too must accept a fair share of the burden.

Attitudes must change. Government must help. Industry must help. We do not have unlimited natural resources as we once thought we had. We can no longer afford to mine and use our mineral resources in a helter-skelter fashion as we have in the past. Our resources must be managed and used responsibly.

For example, how would high-grading affect marginal coals? It would render many unmineable. Already some of the higher sulfur coals are being put on spoil piles in order to meet competitive market demands. How would high-grading affect the energy supply of future generations? It would deprive them of a resource that I think we are obligated to share with them. What is our responsibility to future generations? Obviously some people think there is none, and others don't care. Still others are very concerned. Nonrenewable resources should be guarded with zeal and consumed with discretion. We are all responsible; the miner, the utility company, the consumer, the regulator--it's a responsibility that we all must assume.

I am not an expert on water chemistry or the physics and chemistry of air. However, I do know that lakes and other bodies of water are dynamic systems, and that the chemistry of these systems depends on many things such as rocks, development of both flora and fauna, and the age of the water body. They are very much a part of nature's evolutionary scheme. I also know that rainfall is not the only thing that determines the water chemistry of a body of water. Therefore, is sulfur from the combustion of coal the only contributor to acid rain or acid lakes, or is it just an obvious contributor and one that is easy to attack?

Are we sure? Are we willing to use our precious low-sulfur coal while at the same time we destroy millions of tons of marginal coals because of a possible misconception or mistake? We've done similar things before. What about other nations of the

Earth with which we share a common atmosphere? Are they willing to go to the necessary expense to meet the same high clean-air standards that are being proposed? The answer right now is no. If they are not, then what will be the impact of our efforts on the world's atmosphere? What impact does the added expense of mining coal in the United States have on the world coal market where we are already competing with subsidized mining? What is the impact on our balance of trade?

Colombia is shipping coal into the southeastern United States cheaper than Appalachian coal can be produced. There are many reasons why they can do this. One is that their industry is State owned and regulated.

The coal industry in the United States is one of the most regulated industries we have, and it is also a very essential one for our present and future welfare. I truly hope that we do not shackle the industry with regulations. It is indeed one of the industries that has helped make this Nation great and one that has helped us attain the highest standard of living in the world today.

If we assume that the government, industry, concerned citizens, and people in general acknowledge the need, we can achieve much toward our goals through research. In my opinion, the national agenda for geologically related coal research should include:

1. Characterization of major coal beds - All major coal beds should be characterized by representative sampling and analysis by chemical, physical, maceral, and mineral methods.

2. Geologic mapping - Geologic mapping is the foundation of all geologic and resource studies. Resource estimates are not possible without outcrop mapping. Nationally, we are not doing much in this research area.

3. Thickness mapping - Thickness mapping is also essential for resource estimates and for geologic modeling.

4. Coal-quality mapping - Coal-quality mapping is important for determining trends in coal quality and resource availability, and for geologic modeling.

5. Resource estimates - Resource estimates are important for public policy decision making, revenue predictions, utility-fuel projections, transportation projections, financial planning, and geologic studies.

6. Modeling of coal-forming environments - Modeling of coal-forming environments is vital for interpolations and extrapolations of coal thickness and quality data, and it is

also valuable for predicting mineability. Understanding of the modern analogues so often referred to, Mississippi River Delta, Okefenokee Swamp, and Everglades, is not sufficient; further research into modern swamp environments should be encouraged.

7. Characterization of sulfur - Characterization of sulfur is important because sulfur is the most notorious contaminant in coal; it is also important in geologic modeling and resource classifications. Sulfur occurs in a variety of forms in coal, and much of it has unknown origins. We must characterize these forms and study the sulfur isotopes to determine the sources of sulfur in coal.

8. Geostatistical methods for coal study - It is important that we improve our quantitative methods for studying coal; these include resource calculations, measure of variability and uncertainty, and coal-quality predictions and variability.

9. National Coal Resources Data System - This Nation needs a centralized and uniform coal resources data system. Currently, the U.S. Department of Energy, Energy Information Agency; U.S. Geological Survey, National Coal Resource Data System; and Bureau of Land Management all maintain separate coal-resource data bases. Efforts should be made to coordinate these separate, and sometimes conflicting, data bases.

Work is going on in these areas now, but not at levels equal to the need; therefore, the levels of funding must be raised. Overlap among various governmental agencies wastes research dollars through duplication. Overlap should be eliminated.

The major research agencies for coal are performing many tasks that might be better done by local agencies. Perhaps the efforts of major agencies would be more effective if directed toward more basic research which often involves highly specialized analytical tools.

Finally, we need cooperation between Federal, State, and private agencies before research is initiated and after it is underway. This doesn't always happen today. If we don't change this situation, then improvement in the effectiveness of coal research, which is so sorely needed, will be much slower in becoming reality.

U.S. GEOLOGICAL SURVEY COAL-QUALITY RESEARCH

by

Terry W. Offield, Susan Garbini, and Stanley P. Schweinfurth
U.S. Geological Survey

INTRODUCTION

The U.S. Geological Survey (USGS) coal program consists of three major parts:

1. Studies of the sedimentary rocks containing the Nation's coal resources and their environments of deposition. This involves geologic mapping and delineation of stratigraphic relationships and sedimentologic character, leading to interpretation of the original conditions of peat deposition, and the subsequent geologic history involved in coalification of the peat.

2. Characterization of peat, lignite, and coal according to the type and composition of their organic and inorganic materials. The nature and composition of the macerals, including their original botanical character, and the chemistry and mineralogy of the inorganic components define the quality of the fuel material and prefigure much of the utilization process. This work, together with the studies of the enclosing rocks, is intended as a basis for models that will be useful in assessing the Nation's coal resources and predicting the character of coals out across basins long in advance of actual exploration or mining.

3. The National Coal Resources Data System (NCRDS), a computerized bank of information on more than 100,000 drill holes and measured sections and 10,000 coal and rock samples. Coal-quality data consist of the usual data from proximate and ultimate analyses, ash-fusion temperature, and so on, and also comprehensive multielement chemical data. Data and samples are provided to NCRDS by 20 State organizations; analyses are performed by the USGS and by contract laboratories. Much of the analytical work has been supported by the Department of Energy and the Environmental Protection Agency.

Coal quality is a vital issue in the Nation's energy and future. This meeting was conceived and organized with the cosponsors in order to survey a broad array of Government, industry, and academic concerns and ideas having to do with coal quality. It is expected that the symposium results will be useful in planning USGS research efforts, especially in gauging new directions, and assigning priorities. Conversation among such a variety of coal experts as are gathered here can provide a whole field of coal knowledge and insights into its optimal utilization.

Background

There is no argument today about whether the United States has enough coal. In 1974, the USGS estimated the country's coal resources as about 4 trillion tons--a lot of coal by anyone's standards. It should be noted that much of the estimated resource is in the "hypothetical" category; that is, it has not been tested by the drill and is simply projected by geologic reasoning to be out there underlying sedimentary basins. Much of the stated resource will prove to be unavailable for recovery--overlain by roads or towns, too deep or too thin by today's economics, or perhaps of too poor or too variable quality to permit economic use. However, there is still a lot of coal, and developing new technologies of coal utilization might well expand the range of coals that can be used economically. The successful design and use of such technologies, however, will rest on better knowledge of coal quality and how it varies within coal beds, from bed to bed in the same sequence and from area to area. Such knowledge will also be the undergirding of an appropriate structure for regulation of coal use and determination of environmental standards.

Whether our vast coal resources will serve us in environmentally and socially acceptable ways will depend to a large extent on the physical nature or quality of that coal. Coal is a complex and heterogeneous mixture of organic and inorganic constituents whose composition may vary significantly between coal beds or even over short distances within a single bed, as shown by the real example of sulfur and ash contents in two coal beds illustrated in figure 1. Because of this kind of variability in coal quality, particularly with regard to constituents that affect the environment, much more basic and applied research is required to determine the most efficient and least environmentally harmful ways in which to utilize coal.

Horror stories abound concerning multimillion-dollar mistakes or problems that arise because of too little awareness of coal quality. In mining, a recent reported example showed a large western mine operation losing 4 million tons of production because of unacceptable sodium content in the coal--an unforeseen change in the reserve that might have been predicted with better understanding of the local geologic setting of the coal.

Plans and procedures for blending and cleaning coal to meet consumer standards often go awry because of unexpected variation

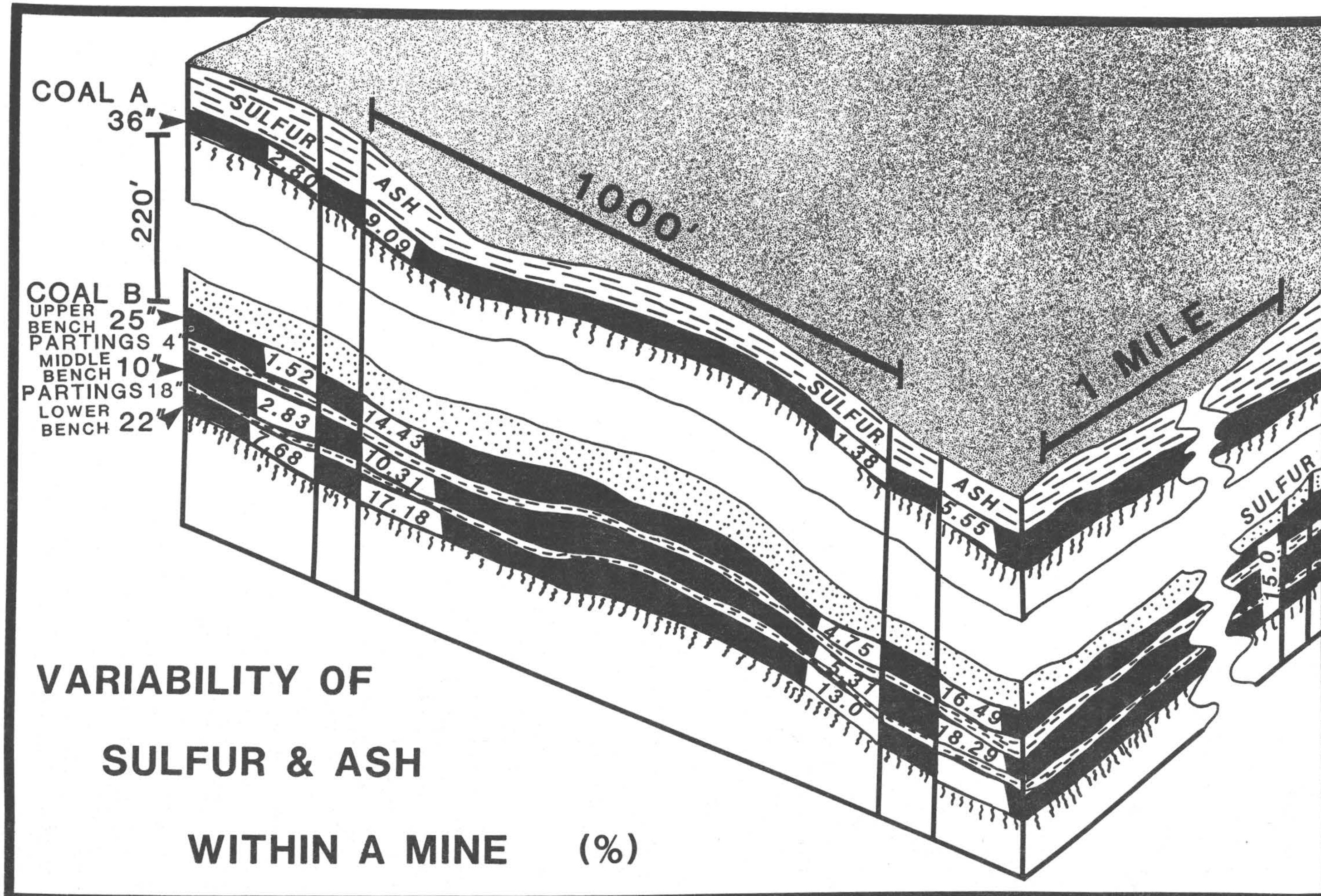


Figure 1. An example of the variability of coal quality as demonstrated by the variations in sulfur and ash within a single coal bed (bed B) and between coal beds (beds A and B), based on an actual situation. The vertical lines within the block diagram represent cored drill holes. (Source: P.C. Lyons, U.S. Geological Survey, written commun., 1984.)

in the delivered coal. Many such procedures focus on sulfur content in coal, but other chemical and physical components, commonly not even analyzed for, also cause problems in the utilization of coal. Mineral matter in coal is a major cause of slagging and fouling of equipment when coal is burned or gasified, and it causes myriad problems with filtration, catalysis, and abrasion when coal is converted as in liquefaction and solvent coal refining. Similar problems arise in the design of pollution-control equipment, where the interactions between pollutants and their effect on the operation of control equipment complicate design and make it difficult for operators of coal-fired boilers to select the optimum control method. (For instance, the properties of ash are a significant determinant of collector performance when an electrostatic precipitator is used for ash removal.) Attributes of coal that will be relevant to the fledgling synfuels industry are still poorly understood, but billions of dollars almost certainly will be spent on new technologies, and their effectiveness and success and breadth of applicability will be inextricably tied to the character of the coal put into the technological processes.

Efforts are being made to find solutions to the problems associated with coal use, but it is possible that the fixes designed for currently perceived problems may give rise to a host of new or previously unrecognized problems. For example, if a solution to the problems of SOx and NOx emissions were achieved, resulting in increased use of coal, other noxious materials in coal such as arsenic, lead, cobalt, chlorine, and fluorine might reach harmful levels of concentration in the environment. In order to avoid a pattern which might lead to the ramification rather than the mitigation of environmental damage, it is essential to establish a comprehensive understanding of the complex nature of coal as the foundation for wise and economic coal utilization.

Current knowledge about coal-quality parameters as they relate to coal resources is limited by a small number of samples, incomplete characterization of coal quality, and an unrepresentative distribution (fig. 2). Most data on coal quality refer to mined-out areas; there are very little data on the quality of deeper coals yet to be mined (fig. 3). As high-quality coal is depleted (we always mine the best of the most accessible coal first), it will be necessary to understand and predict in advance the nature of the deeper coals farther out in the basins. It cannot be assumed that those coals will be of poorer quality than coals along the outcrop--the original depositional environment controls on coal character may just as well have produced better coals downdip--but we won't know until we have enough information to make predictive models of coal regions and coal types.

DEMONSTRATED RESERVE BASE OF COAL ACCORDING TO TOTAL SULFUR CONTENT

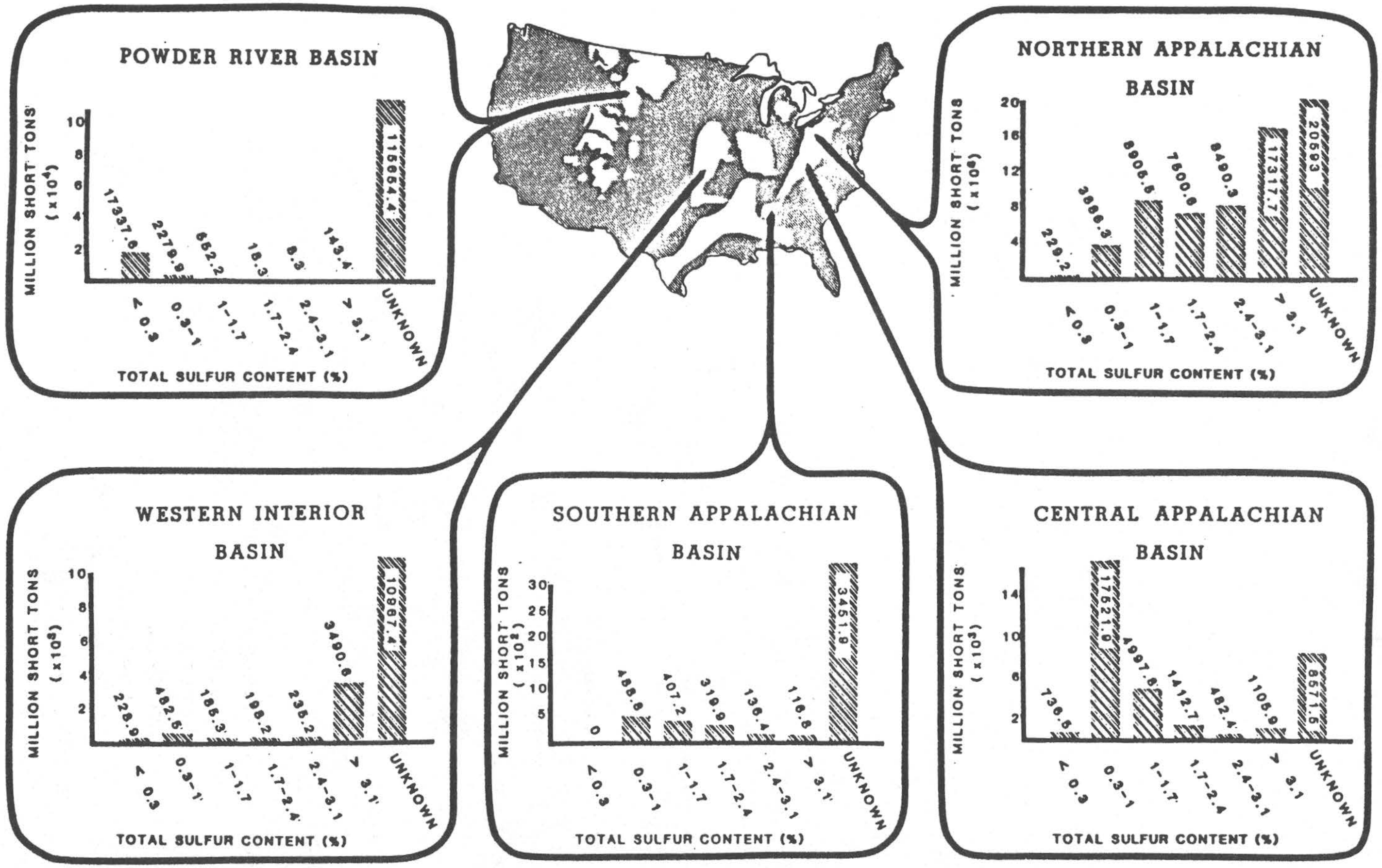


Figure 2. For most U.S. coal basins large amounts of coal resources have not been sampled and analyzed for total sulfur content. This is shown by the large amount of coal in the unknown category for each basin. The Central Appalachian Basin, where there is a much higher level of certainty about sulfur distribution, is an exception because of the long history of mining of high-quality, low-sulfur coal in that area. Sulfur data are on an as-received basis. (Source: J.H. Medlin and F.O. Simon, U.S. Geological Survey, written commun., 1984.)

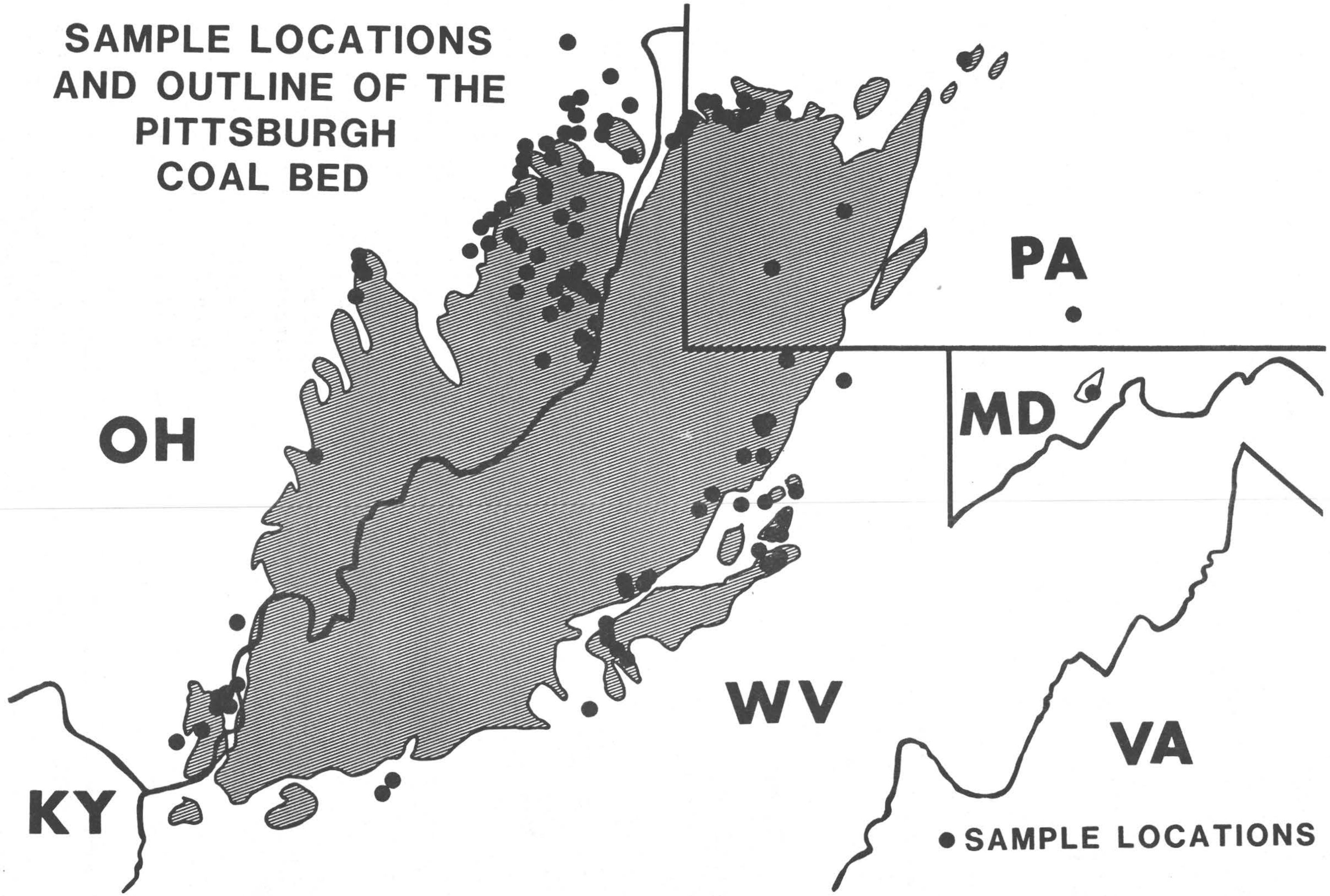


Figure 3. The Pittsburgh coal bed serves as a typical example of the distribution of coal samples from coal beds in the United States. Most samples for which data are available for public purposes are from the edges of the main deposit and from isolated pockets, or outliers, of the main deposit. These are areas that have been mined out or are being mined currently. Few or no samples are available from the more deeply buried parts of deposits. (Source: J.H. Medlin and F.O. Simon, U.S. Geological Survey, written commun., 1984.)

Because of the general paucity of up-to-date coal-quality information, one frequently hears such statements as: Appalachian coal is medium-sulfur; midcontinent coal is high-sulfur; western coal is low-sulfur. These generalizations are misleading and oversimplified and do not provide a correct basis for decisionmaking concerning coal utilization.

For example, such discussion of the pollution-control issue revolves around the misperception that a switch to low-sulfur western coal would solve the problem of acid precipitation related to stationary sources. However, most low-sulfur western coal is also much lower in Btu content than midwestern and eastern coal, so in order to obtain equivalent heat value more coal would have to be mined and burned. Thus, a lot of sulfur would be released into the environment as the overall amount of coal burning increased, and other important environmental disruptions and economic side effects of the switch to western coal would come into play as well.

Figure 4 shows the average sulfur content of coals by major coal basins with respect to existing and suggested limits on pounds of SO_2 per million Btu. Although the dots on the graph represent basin-wide averages of available data on sulfur, this figure suggests that there are few areas that could maintain sustained production of coal to meet current new-source performance standards, and none that could meet a suggested lower level of allowable sulfur input of 0.6 lb of SO_2 per million Btu. Pre- or post-use cleaning could change this, but only at increased costs.

There also are difficulties in the presumption of an easy fix to the SO_2 emission problem by using eastern low-sulfur coals (locally available but not regionally abundant) because: (1) these coals are nearing depletion along the outcrop belt, which means that future mining must be at increasing depths and expense; (2) reliable identification and characterization of large remaining quantities of this type of coal are lacking; and (3) there is competition for this type of coal for domestic metallurgical uses and for export. Careful and systematic characterization of all U.S. coal resources may reveal more low-sulfur, high-Btu coal that can directly meet the requirements for SO_2 reduction or that can be cleaned or blended to meet proposed tightened standards, but it will require substantial additional work to either prove or disprove this possibility.

A further point of concern is secondary pollution associated with the burning of coal. Removing pollutants by pre-use cleaning or from smokestack emissions may simply transfer them to the solid wastes and water emerging from the coal-use processes. For example, if sulfur is removed during coal conversion and disposed of with the ash or waste pile, water percolating through the waste

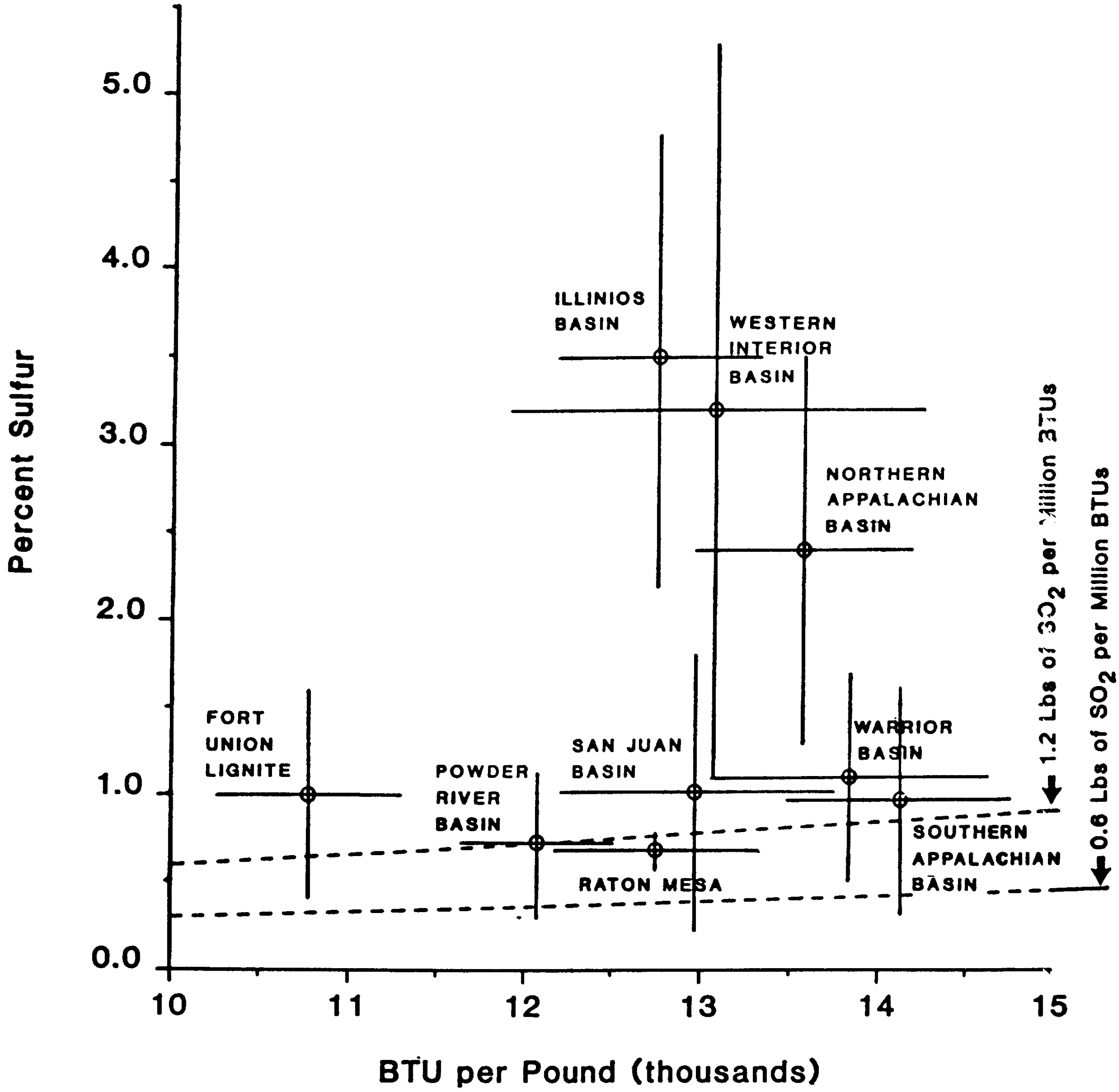


Figure 4: On the basis of the data in the U.S. Bureau of Mines Demonstrated Reserve Base of Coal, very few areas can be expected to contain large quantities of coal that will meet current new-source performance standards (NSPS) for SO_2. Even fewer areas can be expected to contain large amounts of coal that will meet the stricter level of SO_2 input that has been suggested by some groups without some kind of pre-, syn-, or post-utilization modification. (Major coal basins are shown in figure 2.) The dots on the chart represent the means and the bars represent one standard deviation about those means for Btu and total elemental sulfur content from the data available for the coals of each area. Analytical data are on an as-received basis. (Source: F.T. Dulong, U.S. Geological Survey, written commun., 1985.)

material may be acidified, mobilizing and transporting a variety of polluting chemical elements into the local environment. Coal cleaning does not eliminate any elements. The trace-element content of the cleaning water is tremendously enriched, which can cause serious pollution problems. The chemical composition of fly ash is influenced by the composition of source coal and by plant operating conditions. If scrubbers are used, a proportion of the contaminants will end up in the scrubber sludge, causing disposal and potential ground-water problems. Little information is available on the potential emissions of trace pollutants from coal combustion or conversion processes. More data on coal quality are needed to evaluate and improve control options.

If we are to rely on increased use of coal to meet our future energy needs, without allowing the quality of the environment to deteriorate, we must conduct research that will provide us with an adequate information base for predicting and controlling the effects of emissions and effluents from coal, and for optimizing the development of technology for coal cleaning, burning, and use in synfuels production. In the long run, and perhaps even in the near term, research focused in these directions will be much less costly than mistakes in design of processes or equipment or in setting policies and regulations.

Coal Research Activities

For decades, the USGS has had at least a few individual researchers working on coal-quality topics. Prominent among these were David White, who wrote classic papers on the origin of coal; Reinhart Thiessen, founder of coal petrography in the United States; Taisia Stadnichenko and Peter Zubovic, who developed the concept of elemental affinities in coal and began defining the distribution of minor and trace elements in coals of the United States; James Schopf, continuing the basic research on the origin of coal; and Irving Breger, with advances on a broad front in organic geochemistry of fossil fuels. An irony of some of this forefront research is that it was not done for the sake of coal, but rather because of short-term major interest in trace elements like uranium and germanium.

Today coal-quality research is well recognized as a critically important aspect of the overall coal program, and the research is expanding to serve the needs described in the preceding section. Coal-quality work at the USGS comprises:

- Basic and applied research into the physical and chemical nature and cycling of the organic and inorganic constituents of coal, focusing on the rapid identification and quantification of sulfur-bearing components and other noxious and deleterious components.

- o Basic research into the geologic aspects of deposition and formation of coal that also control the petrographic and chemical variability of coal beds.

- o Investigations of the nature and modes of occurrence of chemical contaminants in the rocks that surround and are interbedded with coal.

- o Studies of the occurrence, distribution, and accessibility of coal deposits that have specific chemical and physical properties.

- o Development of field and laboratory methods, instruments, and techniques to analyze, examine, interpret, and predict coal-quality parameters that can be related to coal cleaning or feedstock characteristics, and to determine the distribution of these parameters in coal deposits in relation to geologic and geochemical factors.

- o Routine, reliable, and credible analyses of coal samples for calorific value, ash, moisture, and sulfur, and 70 major, minor, and trace elements.

- o Maintenance of a computer-based system for the storage, retrieval, and manipulation of data on coal quality and quantity.

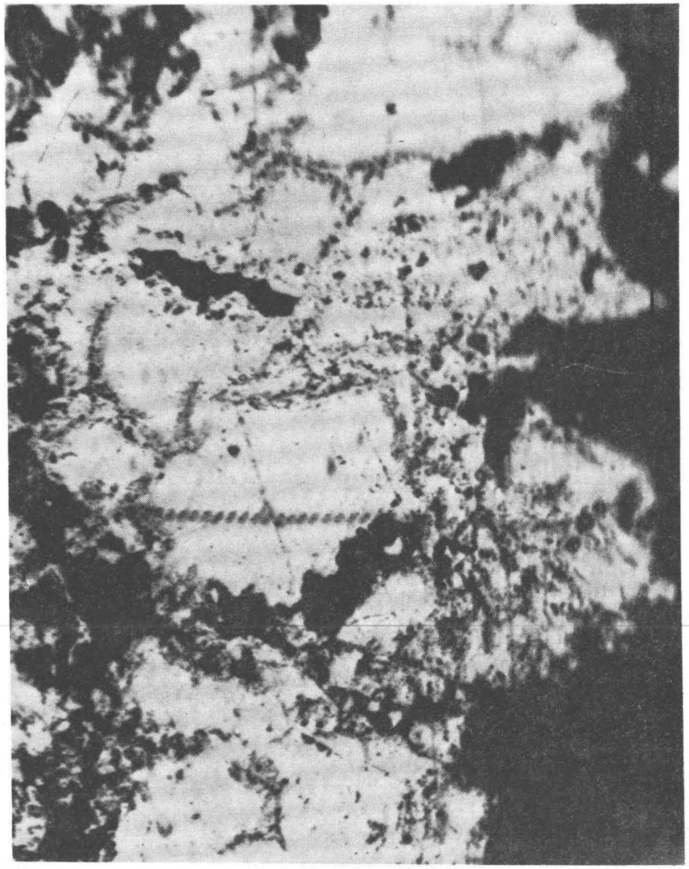
Because coal typically is such complex material, the key to understanding it is in petrographic and chemical analysis using an array of increasingly sophisticated techniques. It is necessary to characterize the macerals as telinite, fusinite, cutinite, sporinite, and other such components, and to determine their paleobotanical origins, in order to establish the origins of coal. It is necessary to identify inorganic components of coal beds, to ascertain their depositional or diagenetic origins, and to determine the partitioning of significant trace elements between the inorganic and organic materials of the coal. It also is necessary to decipher the effects of coalification on the starting materials, and the nature of the coalification process. Further, it is important to relate the coal to its enclosing rocks in order to understand the precise geologic environment in which peat-swamp deposition, coalification, and diagenetic changes took place. This requires an understanding of the nature of the swamps, their vegetation, and paleoclimates.

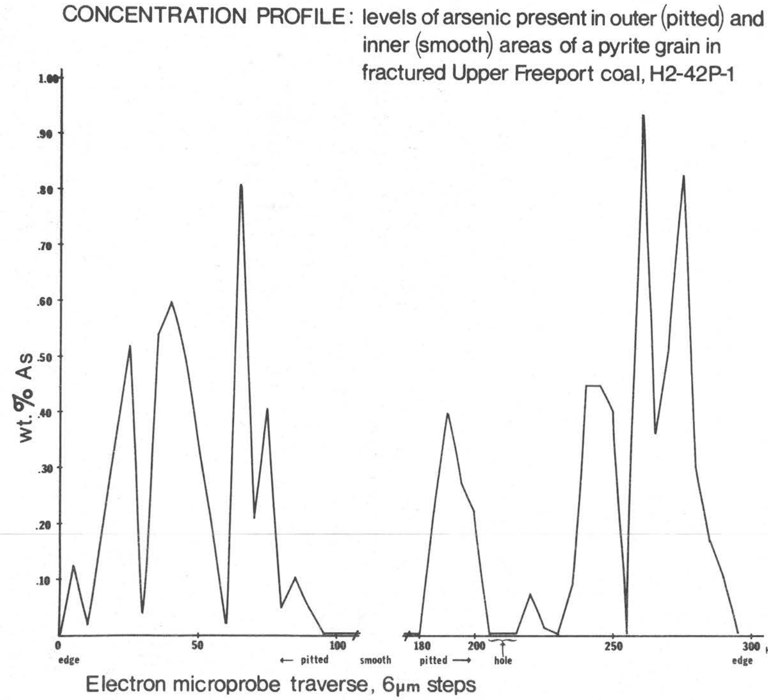
Selected examples of current USGS research results may serve to illustrate some of the avenues being followed:

- o In addition to standard megascopic field descriptions and conventional microscopic petrographic analysis of pellet mounts to describe the average compositions of coals, quantitative descriptions of coal beds from top to bottom are produced by means of modal analyses of continuous columnar or core samples utilizing an automated image analysis system. Lithologic units determined by microscopic analysis with this system are in turn described in terms of microscopically determined percentages of vitrinite, exinite, inertinite, and optically resolvable mineral content to give a quantitative quality profile of the given coal bed (Chao and others, 1980). This provides a partial basis for interpretation of coal origin (for instance, peat materials deposited in place or transported), depositional environment, diagenetic changes, burial history, and so on, and identified points for more detailed studies by other techniques.

- To define the distribution of mineral matter, determine its origins (depositional or diagenetic), and identify actual residence of important chemical elements, microscopic petrography commonly is followed by scanning electron microscopy (SEM) and microanalytic techniques. When mineral grains are identified, they are examined by electron microprobe to establish chemical contents. Thus, the presence of zinc known from multielement chemical analysis can be shown to be precisely related to the presence of sphalerite, and the character of the sphalerite may reveal diagenetic origin. In one recent study, pyrite grains were found to have smooth areas and pitted areas: microprobe traverses across the grains showed arsenic in the pyrite to be confined to the pitted portions (figs. 5a, b). As these portions also were characterized by fractures, the arsenic is interpreted as having been made available from epigenetic solutions moving through the coal after it originally formed.

- Routine electron microprobe analysis of chemical contents of individual maceral grains has the capability of detection of elements of atomic number 11 and greater and a minimum detection limit of 0.01-0.05 percent for most elements. Important extensions of microprobe capability now are available with PIXE, (proton-induced X-ray emission) and LAMMA (laser microprobe mass analysis) instruments. With PIXE, quantitative analysis is carried out for elements of atomic number 11 or higher at concentrations as low as 1 to 10 ppm (Minkin and others, 1982), while LAMMA can be used for qualitative analysis of all elements from H to U at sensitivities as low as 1 ppm. Although not yet quantitative, LAMMA "fingerprints" both





a. Photomicrograph in reflected light, showing both smooth and fractured massive pyrite. Center areas of the pyrite are smooth whereas areas adjoining fractures are pitted. The series of spots across the center of the field mark the sequence of electron microprobe analyses of arsenic concentration at 6 μm intervals. Bar scale = 0.25 mm.

b. Profile of arsenic concentration along the path of the electron microprobe traverse shown in a.

Figure 5. Photomicrograph and arsenic concentration profile of a pyrite grain from the Upper Freeport coal bed, Indiana County, Pennsylvania (modified from Minkin and others, 1984).

the mineral and maceral components of coal, and is especially powerful for detection and characterization of certain organic fragments that may vary with maceral variety as well as rank of coal (Lyons, P.C., written commun., 1985).

- Studies of concretions found in coal ("coal balls") show that coalification is identical inside and outside the concretions, even though the woody-material cell structure inside the concretion shows none of the compaction undergone by the material of the surrounding coal. The nature of the chemical changes in the process of coalification of woody tissue is studied using NMR (Nuclear Magnetic Resonance). This shows that, initially, wood is diagenetically altered, primarily with loss of cellulose and other carbohydrates and with concomitant selective preservation of lignin-like components. These are also altered but with retention of some structural character of lignin, as evidenced by NMR spectral peak. From these observations, a new hypothesis has been derived for the loss of oxygen during coalification (Hatcher and others, 1982): humic acids, soluble and readily mobilized components rich in oxygen-containing chemical structures, are mostly oxidation products of the chemical alteration from peat to lignite. Loss of humic acids during compaction and expulsion of water explains the observed loss of oxygen content during coalification to higher rank. As rank increases up to high-volatile bituminous coal, changes in the spectra imply significant loss of oxygen-rich functional groups. With additional increase in rank, the primary change is loss of aliphatic peaks, as is expected from pyrolitic breakdown of the chemical structure. High-rank coal is essentially entirely aromatic in structure.

- Quartz grains in upper Freeport coal have been studied using the electron microprobe and cathodoluminescence (Ruppert and others, 1985). Nonluminescence of quartz connotes that it is authigenic (formed in place by diagenetic process). Quartz grains in this coal bed are 83 percent authigenic; 17 percent of the quartz is detrital. In the roof shale, 7 percent of the quartz is authigenic.

- Calcite deposited in cleat in the upper Freeport coal has been characterized by means of carbon-oxygen-isotope analysis (Dulong and others, 1985). Its isotope content is very different from that of calcite from freshwater limestone a short distance below the coal. It may be said that the cleat calcite is not derived from solution of the underlying limestone, but rather was produced in a process of isotopic fractionation caused by methanogenic bacteria. Calcite in macerals was produced by both biotic and abiotic processes. A practical benefit is the knowledge that the two kinds of calcite have different specific gravities and respond differently in sink-float treatment during coal beneficiation.

- Studies of modern swamps as early-stage analogs of coal beds are revealing details of plant-community distribution and associated chemical processes that appear directly applicable in interpreting the nature of coal facies. Peat swamps show directly the variations in plant materials, admixing of in-place and transported materials (both organic and inorganic), and changes resulting from natural events such as alternating wet and dry periods or fires. Observation of differing peat-accumulation morphologies and the associated differences in water supply and the chemistry of the peats has led to an important distinction that may be made between two fundamental types of peat deposits (fig. 6): ombrogenous or rainfall-dependent peats and topogenous or ground-water fed peats (Cecil and others, 1985). As a general rule, ombrogenous peat deposits tend to be domed and can be expected to produce low-ash, low-sulfur coal deposits, whereas topogenous peats tend to be planar and can be expected to produce relatively high-ash and high-sulfur coal deposits. Because each type of peat has a different type of water supply, each would be very different in chemistry. This distinction results in different chemical make-up of the original peats and the resulting coals.

- In related studies of the coals of the Pennsylvanian sequence in the central Appalachian basin, ash and sulfur variations are linked to type of coal deposit. This in turn relates to both local settings and to interpreted paleoclimate (fig. 7). It is construed that lower to middle Pennsylvanian coals were derived from ombrogenous peats that formed in wet climates, and upper Pennsylvanian coals were derived from topogenous peats that formed in more seasonally dry conditions (Cecil and others, 1985).

- In other swamp studies, the primary distribution of coal's sulfur and its forms and the genesis of its pyrite have been documented in Everglades peats in a regional study of peat stratigraphy and chemistry. A prominent finding is that pyrite forms at the expense of organic sulfur in the

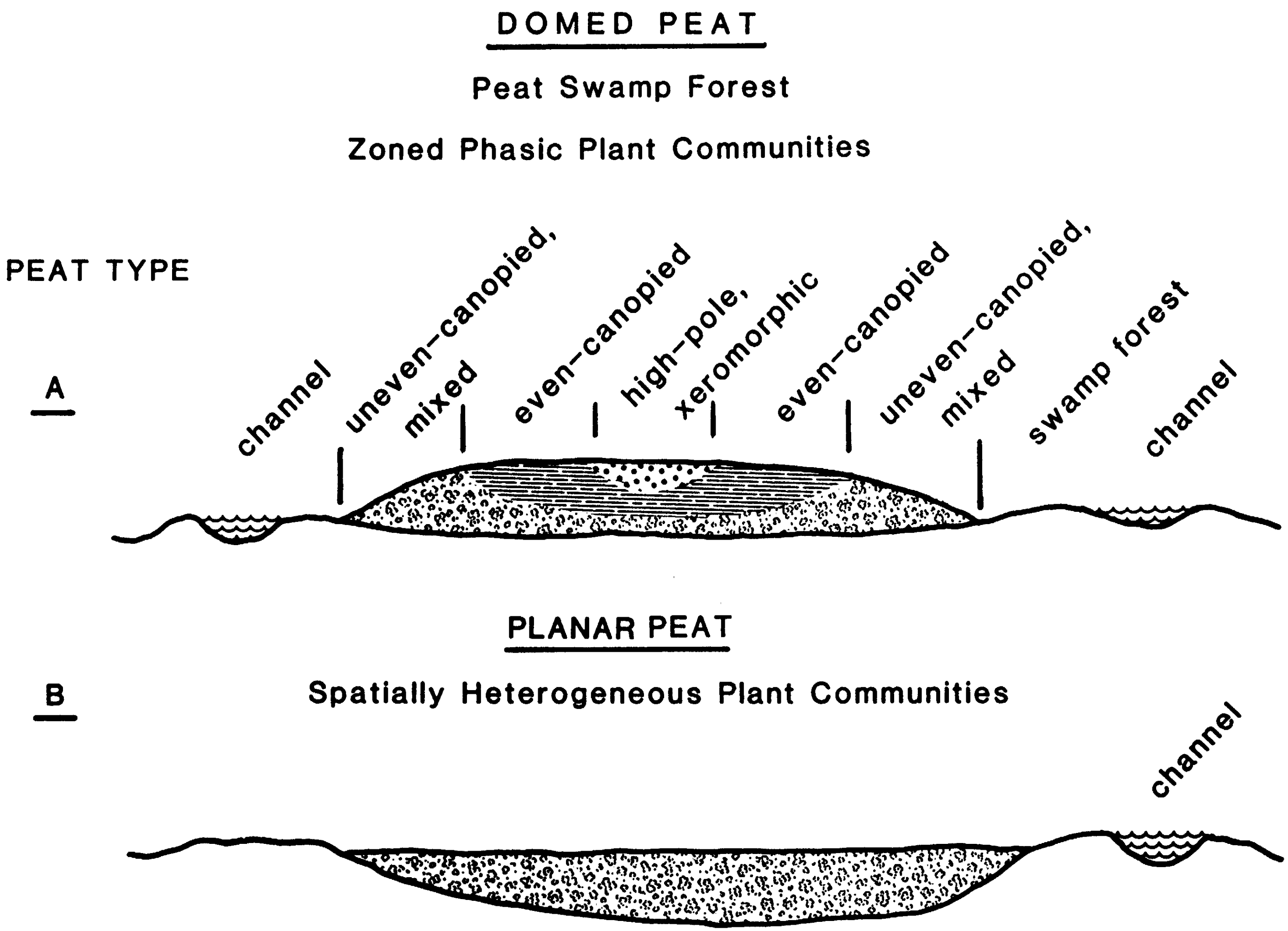


Figure 6. Generalized cross-sections of domed and planar peat deposits. Domed peat deposits are ombrogeneous and generally have zoned plant communities (A). Planar peat deposits are topogeneous and contain spatially heterogeneous plant commmunities (B) (modified from Cecil and others, 1985).

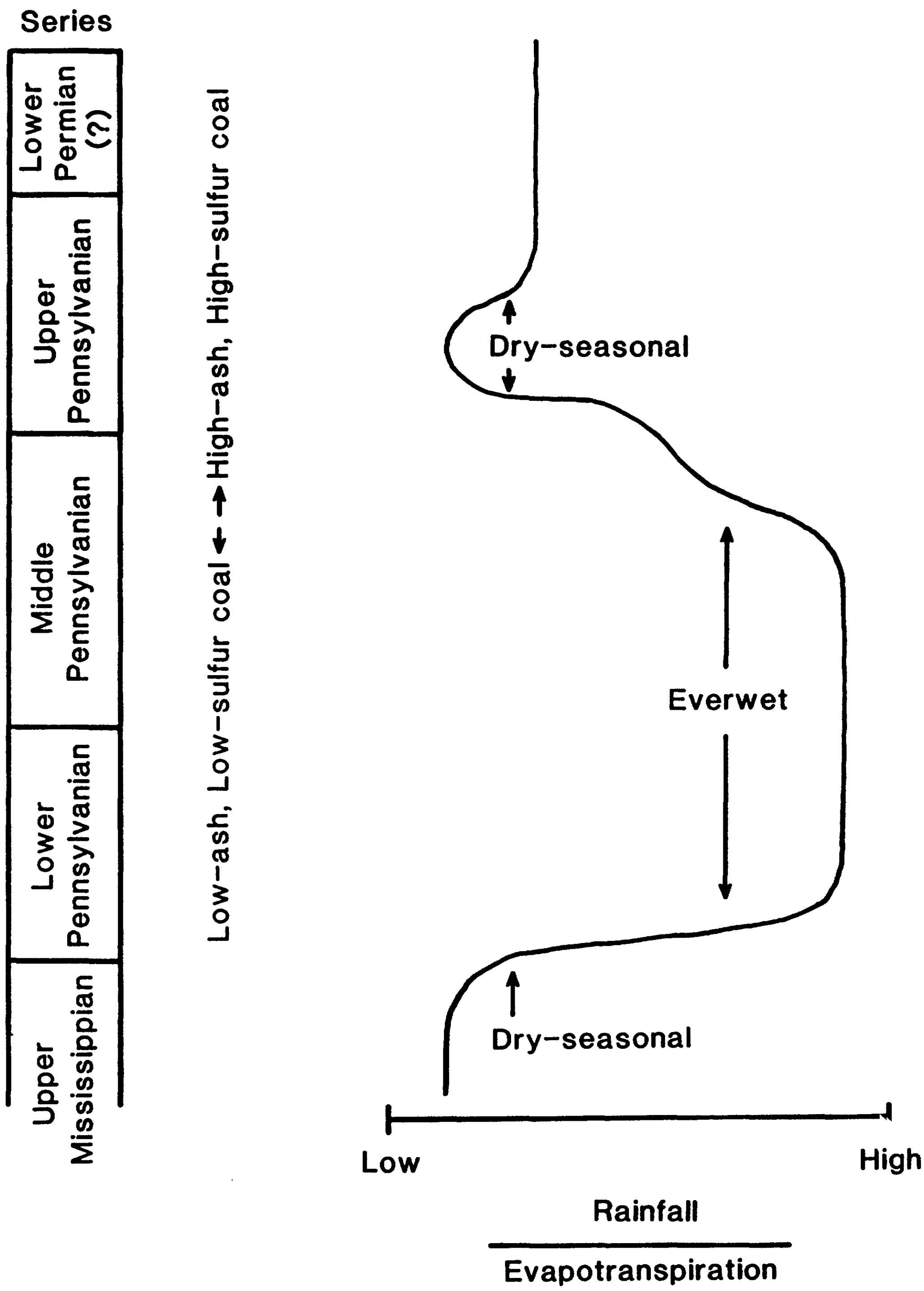


Figure 7. The ratios of rainfall to evapotranspiration interpreted from stratigraphic changes in lithologies and coal quality in the Mississippian and Pennsylvanian Series in the central Appalachian basin (modified from Cecil and others, 1985).

lower part of the peat column across the Everglades. This is a significant diagenetic change occurring early in the coal-forming process. It involves the bacterial reduction of organic oxy-sulfur compounds to sulfides that react with ferrous iron to form pyrite. These findings explain the tissue- and cell-bound status of the framboidal and microglobular pyrite in coal, and the basal accumulation of pyrite that is noted in many coal beds. (See figs. 8 and 9 from Altschuler, Schnepfe, Silber, and Simon, 1983.)

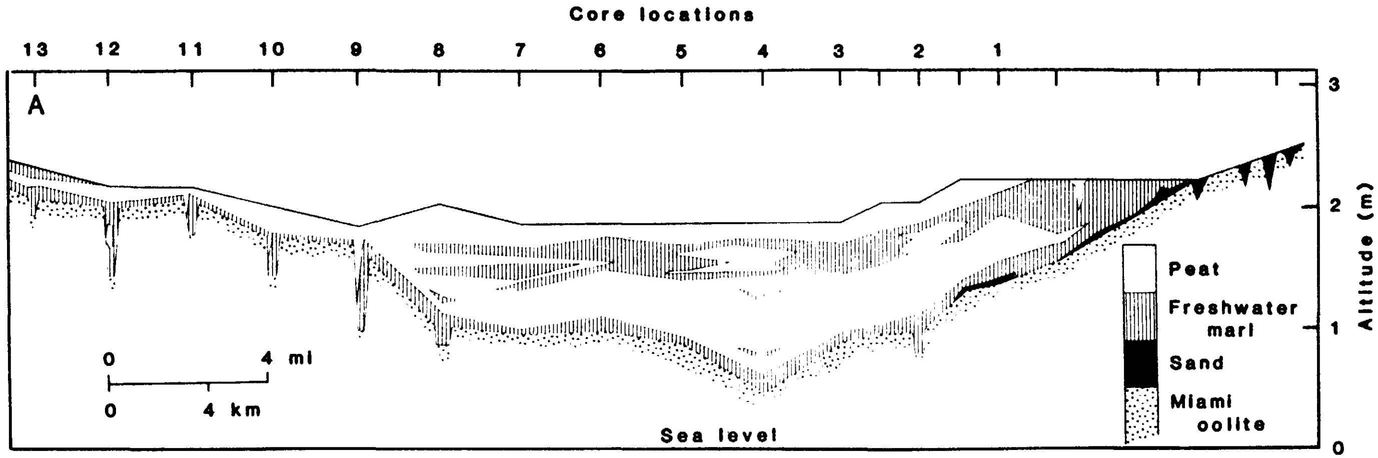
o The detailed character of the coals and their enclosing rocks are brought together in models of the coal-forming environments in order to interpret the precise geologic settings and/or subsequent diagenetic processes associated with coal facies. Examples of this modeling include: central Appalachian Pennsylvanian coals (particularly the Freeport); coals from the barrier-beach swamp settings along the margin of the western seaway of Cretaceous time; and a 200-foot-thick coal bed, known as "Big George," in Tertiary rocks of the Powder River Basin.

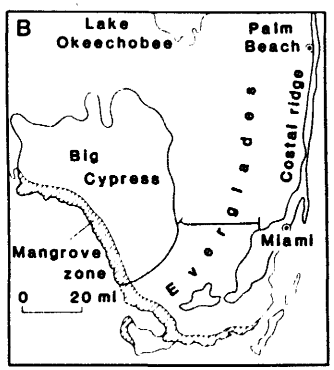
Conclusions

All this work needs to be intensified and expanded, preferably through the development of consortia of government (Federal and State), academic, and industry researchers of diverse talents and interests. In this way, studies can span the necessary range of concerns from understanding the field setting of the raw material through insights into the mineralogy and chemistry that affect coal cleaning, combustion, and pollution potential. In addition, an ultimate goal of the USGS is to accumulate enough data-bank information along with modeling insights so that coal resources throughout the Nation can be estimated and characterized in terms of coal quality and optimal-use potential.

ACKNOWLEDGMENTS

The ideas and activities described here involve many USGS researchers and have been clarified for the authors in many diverse conversations and presentations. Thanks are particularly due to Blaine Cecil, Jack Medlin, Edward Chao, Ron Stanton, Patrick Hatcher, Paul Lyons, Sam Altschuler, and their coworkers.





(A) Core lithology and stratigraphic profile of Holocene deposits across the southern Everglades along the Tamiami Trail. Average depth to Pleistocene Miami oolite basement is shown by the general profile where cores penetrate solution pits in the basement. Thus the actual basin extends from cores 1 to 9, and major peat deposition from 1 to 8. (B) The profile in (A) follows the horizontal line through the Everglades in the area map.

Figure 8. Stratigraphic profile of peat basin, southern Everglades, Florida (from Altschuler and others, 1983).

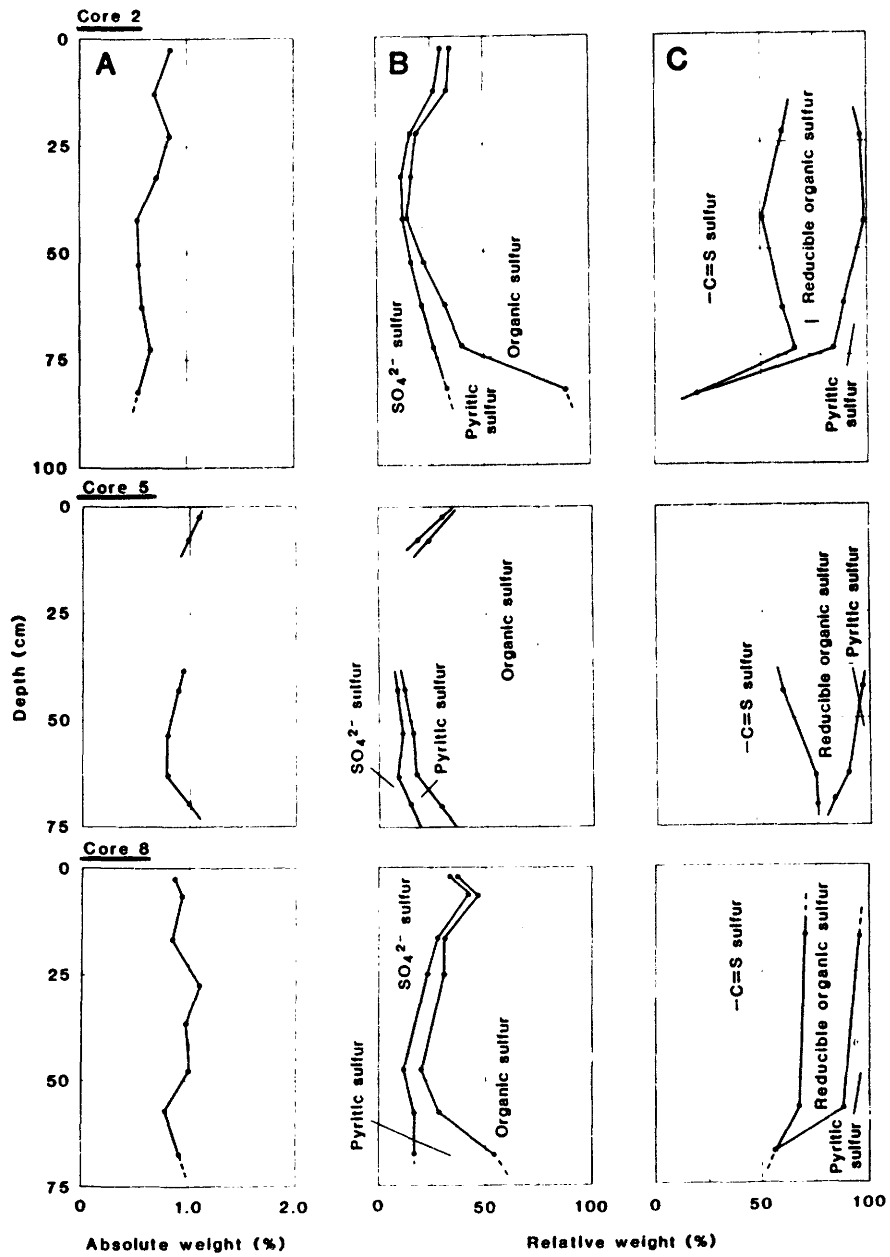


Figure 9. Sulfur and its forms in representative cores across the Everglades peat basin showing the vertical distribution of (A) total sulfur, (B) its mineral and organic forms, and (c) the relation of pyritic sulfur to forms of organic sulfur. Note the decline in organic S (B) and particularly of reducible organic S (C) as pyrite increases. (From Altschuler and others, 1983.)

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PART II. WORKSHOPS

AN ANALYSIS OF THE PROCEEDINGS OF THE SYMPOSIUM WORKSHOPS

by

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Background

The five workshops described in the Introduction met concurrently on the second day of the symposium and then presented their findings and recommendations to a plenary session of the meeting on the morning of the third day. Panel coleaders and panelists had done much advance work in preparation for their workshop sessions.

The discussions of each workshop were recorded by participating scientists whose notes form the basis for the analysis presented in this chapter. The recorders' notes were reviewed by the panelists for general agreement as to the substance, form, and content of the workshop's deliberations before they were included as part of the final record of the symposium.* The formal recommendations of each workshop are presented following this paper.

The purpose of this analysis is to provide a substantive summary of the detailed discussions of the individual workshops. Discussion in each workshop was devoted to a variety of subjects that cut across all of the workshop topics and that were universally viewed as major problem areas. Each workshop recommended that priority attention should be given to one or another of these problem areas in their formal recommendations. This paper summarizes the workshop proceedings as they relate to major problem areas and only briefly touches on other, less well-covered topics.

The major problem areas as inferred from the discussion of the five workshops on coal-quality research are discussed below.

*The names of the recorders are included with the names of the panelists for each workshop in Part V. Workshop notes will be available for inspection by appointment, for 1 year from the date of publication of these proceedings at the U.S. Geological Survey, Reston, Virginia.

The topic of each major problem area and the sequence for discussion of each of these topics were selected as the best reading of the intent of the workshop participants.

Major Problem Areas in Coal Quality Research and Related Activities

Analysis of the workshop proceedings indicates that the discussions, suggestions, and recommendations of the participants with regard to major problems in coal quality and related topics can be grouped into seven major areas. Analysis and discussion of these major problem areas, which require either research or institutional attention or both to provide needed answers and results, is presented in approximate order of priority.

The priority assigned to each of the major problem areas is based on the amount of discussion recorded for that topic in each workshop, averaged across all five workshops. In some cases the differences in the amount of discussions between these major problem areas are very slight and the rankings of several of the topics might easily be reversed if ranked by another analyst. For example, sulfur was identified as a separate topic because of its perceived relation to major environmental problems, with the result that it received a lower priority relative to some other topics. If, however, sulfur had been included with the general problem area that seemed to hold the highest priority in the workshop discussions--the need for new analytical procedures and more data on coal composition in general--it would have been included in a topic that appears to rate a much higher priority in the views of the symposium participants.

Analytical procedures and results. Specific interest was registered in certain kinds of analyses that are not now available as the direct result of an existing analytical procedure. Interest was also expressed in obtaining more and better analytical data on a variety of specific inorganic elements, other than sulfur, that affect coal use or that may cause environmental problems. Among the elements and properties for which there are no direct methods of analysis, oxygen and inherent moisture were identified (organic sulfur is included under sulfur in coal below); whereas among those elements for which more analytical data are needed, silicon, aluminum, iron, calcium, sodium, potassium, arsenic, chlorine, boron, fluorine, lead, magnesium, mercury, titanium, and certain other trace elements such as selenium, that may cause environmental concerns, were identified. Several participants questioned whether enough is known about the fate of some of these potentially harmful elements when they are released from mines, preparation plants, and scrubber sludges. Additional research on the occurrence, pathways, and ultimate resting places of potentially harmful trace elements was recommended.

Participants explained that better data on oxygen, oxidation of coal surfaces, and moisture are needed with regard to advanced uses of coal, especially gasification and coal-water slurries or mixtures. Research into ways to prevent or slow surface oxidation was recommended. Calcium, iron, silicon, and aluminum primarily control slag viscosity. A large amount of iron causes wall corrosion in boilers. Sodium is useful in small quantities, but too much causes fouling (although this apparently depends to some extent on how the sodium is bound in the coal). Halides cause corrosion, and lead, mercury, and selenium may cause environmental problems.

There was a general call for research into methods to improve predictability of the slagging and fouling properties of coal and coal blends. Several participants suggested that detailed analyses should be made of washed and/or pulverized coal because that is what is fed into boilers. In both of these cases, the inorganic chemistry may be expected to be different from the chemistry of either run-of-mine (ROM) coal or face or core samples. Others advised that analyses should be performed on both low- and high-temperature ashes of the same sample. One participant reported good results for some elements with electron-probe microanalysis of raw coal. Development of better analytical techniques for ultrafine coal was singled out as an important area for additional research.

With respect to the organic constituents and structures of coal, concern was expressed that although much is known, opportunities still exist for research because of inadequacies in ultimate analyses (C, H, N, O, S) as currently performed, and because a better understanding of organic functionalities and the structure of coal is needed. This was reported to be especially true with regard to advanced uses of coal such as coal-water mixtures, advanced combustion, and liquefaction.

Participants who deal with coal handling, coal beneficiation, and advanced uses of coal indicated that there is a need to devise better methods to study the surface chemistry of coal and to better understand the electrical properties of coal. The surface properties and effects of different coals apparently have significant impacts on such things as the beneficiation potential of coals, reactivities of coal with the various media used in beneficiation, how well different coals can be made into coal-water slurries or coal-water fuels, and how well they can withstand long periods of storage. A general appeal was made to devise better methods for nondestructive testing, automated testing equipment, and especially cost-effective equipment that could continuously analyze wet coal streams because so much of coal gets wet during transportation, storage, and preparation.

It was also generally concluded that more attention should be given to the chemistry and physical properties of the rocks adjacent to coal beds because they frequently contribute to the mineral matter mixed with the ROM coal. A better understanding of the geochemistry of these rocks may also contribute to a better understanding of the geochemistry of coal.

In summary, the participants requested more chemical data on coal. As one participant stated: "With policy decisions, there is so much to gain if there are good data. With a poor data base one makes bad decisions." Another participant recommended that the chemical data called for would be much more generally useful if it were reported by mole percent rather than by weight percent as is current practice.

Standards and samples. The consensus on standards seems to be that although there are standards (ASTM, institutional), they do not cover the full range of needs of coal users and they are inconsistently applied. Greater care in the application of existing standards was urged so that the results of analytical work on one body of samples will be comparable with work on any other. Recommendations were made that new kinds of analyses and standards need to be developed. However, it is necessary to be sure that new data will be comparable to old data.

Because in most cases only limited funds are available to obtain samples and because samples are the basis for coal-quality research at all steps in the process of characterizing and using coal, the following actions were recommended with regard to standards:

1. Devise new ASTM standards for particle sizes, ash and washability analyses, and for slagging and fouling indices for ultrafine coals (UFC) because existing standards are only useful for coal greater than 30 microns (38 mesh) in particle size (separate standards need to be developed for both eastern and western coals), and also for chemically cleaned coals.

2. Devise new ASTM standards for mineral forms in coal and for describing coal quality versus coal rank.

3. Devise ASTM standards for the analysis of sulfur forms that do not result in errors for organic sulfur.

4. Devise ASTM standards for coal products that contain very small amounts of sulfur and ash.

5. Devise standards for analytical procedures for coal ash released under reducing conditions.

6. Devise uniform standards for geophysical methods being used to estimate coal-quality data.

7. Prepare standardized samples and make available.

8. Devise standards for ROM coal sizes.

9. Devise standards for use in blending coals.

Considerable debate was focused on where and how coal samples should be taken. For example, it was pointed out that tests on core samples do not accurately predict the washability of ROM coal. One attendee from a major energy company remarked that there are significant problems in writing specifications. For instance, even weighing a ton of coal produces disagreement. The coal company takes measurements at the loading of the car and the utility company takes measurements at arrival, and the numbers don't mesh. Even when numbers and sampling procedures are specified, the numbers for coal Btu, sulfur, and ash content differ. The need is for more information on the natural variability of a given coal in the ground and for acceptable limits over which a given coal may be expected to vary (with reasonable care in handling) after it is mined. If these limits are generally understood and accepted, then some variation within the limitsought to be acceptable to all concerned.

The consensus on sampling seems to be that:

1. Samples should be taken at each point where coal undergoes a major change, beginning with prospecting cores, or wherever a major decision about its use needs to be made, such as after long periods of storage.

2. Coal in the ground should be sampled by bench or natural break, letting the user composite the results if so desired.

3. Only coal of "mineable" thickness should be sampled.

Other recommendations for sampling procedures and standards and other concerns expressed were:

1. Greater attention should be given to describing why a sample was taken and what the sample represents.

2. Larger samples should be collected at individual sampling points to improve the representativeness of each sample.

3. Partings are part of coal beds and should be included in a sample, no matter how thick, if they are going to be mined along with the coal.

4. Those who sample coal should receive adequate training.

5. Mechanical sampling is preferable to manual sampling.

6. The entire issue of sampling and sampling standards should be reviewed at a special workshop.

7. "Top-of-car" sampling should be avoided because it is not representative.

8. Samples for which data are stored in any data system should be especially carefully documented.

One indication of the size of the problem of reliable samples and analyses is that some utilities reportedly drill for their own coal samples on suppliers' properties. This is a kind of insurance, no doubt, but expensive. Should it be necessary? One attendee commented that "coal preparation plants are operated, not controlled," implying that little attention is given to sampling and analytical standards at many coal preparation facilities.

Specific recommendations on sampling and analytical standards were made by all of the workshops.

Communications. Every workshop indicated large and continuing problems with the level, and sometimes with the very existence, of communications among the various members of the coal community. It was recognized that there are numerous meetings where coal-research results are presented, but a general complaint was that too few opportunities exist for specialists to discuss problems in a workshop/roundtable atmosphere. Another general complaint was that communication and coordination are lacking among Federal agencies and between Federal and State agencies with regard to coal research and coal research needs. Private industry was faulted for being too proprietary with the results of work that is of a general nature and that could be shared without harmful impact on profits. It was recognized that some competition in research activities is healthy and productive, but that poor communication can result in needless duplication of effort, wasted money, and missed opportunities.

Other problems and suggested solutions with regard to communications and data bases that were voiced by a large number of attendees were:

1. It is often unknown, or at best unclear, to researchers and coal suppliers just what the coal-quality data needs

of utilities and other coal users are, so that a greater effort should be made to communicate those needs throughout the coal community.

2. Some attendees commented that coal-quality research and characterization should be done only on problems of immediate concern, whereas others suggested that it should be the responsibility of public agencies to try to determine what might materialize in terms of future problems and begin working on them and including the results in a "national" data system. It appears that this issue requires further discussion and clarification.

3. More communications and "technology transfer" need to be carried out with coal researchers and users in foreign countries. It was recommended that an official U.S. delegation to the International Standards Organization (ISO) should be sponsored.

4. In the coal-quality data systems community it was recommended that a thorough review of the content, direction, and addressability of computer data bases be conducted and that a single publication be prepared which describes each system so that a single reference would be available for coal researchers and users. One major consulting firm reported that it uses only publicly available data in its coal demand/supply analyses, but that it encounters great difficulties in trying to integrate data on coal quality, quantity, and accessibility into complete coal-demand/coal-supply scenarios because these data are not adequately related or integrated within their source data systems.

A general recommendation on communications and data systems was that user groups should be organized and should meet on a regular basis to compare and exchange information on coal quality and related issues.

Ash properties, coal cleaning, slagging, and fouling. Much of the discussion on these topics relates in some way to coal-ash mineral forms and inorganic chemistry. However, there was also discussion of ash as a separate, complete entity in coal in terms of amounts, kinds (that is, alkaline versus acid), and properties as they relate to coal use, cleaning, blending, and slagging and fouling. It seemed appropriate, therefore, to discuss "ash" under its own heading. For example, the eutectics of ash fusion are important, especially with coals of different grindabilities, because mills process softer coal before harder coal and, therefore, ash can become concentrated in some parts of the feed stream resulting in "flameouts." It was pointed out that the ash-fusion eutectics of blends are different than the averages for the individual coals making up the blend and that the same is true for the swelling indices of blended coals. Furthermore, the slagging and fouling behavior of blends cannot now be predicted from the properties of the separate coals.

Participants expressed considerable dissatisfaction with current methods and standards for predicting ash fusion, viscosity, slagging and fouling, and these areas were identified as requiring more research. One panelist indicated that much of this research would have to be done in boilers rather than laboratories. In the case of slagging gasifiers, it was reported that the amount of ash is not very important but that the chemistry is. The gasifier requires ash that will fuse at relatively low temperatures. At least one firm is conducting research on methods to lower ash-fusion temperatures and on the relation between ash-fusion temperatures and viscosity. One attendee stated that the problem of ash-fusion is not conducive to solution by modeling. In response to this, several suggested that ash-fusion problems may well be addressed through knowledge gained from ceramics, metallurgy, and igneous petrology. Another attendee requested research to identify the temperatures of formation of slags, sinters, and calcines from coal mineral matter.

Another problem area is that coal washing changes the chemistry of the ash in the washed coal, but there is little data on what the resultant changes might be. Research to perfect the predictability of techniques for cleaning coal that are not based on specific gravity was identified as an important need in advanced uses of coal: more float/sink data for small particle-sized coal was also requested.

Fly-ash resistivity was identified in the workshops as another problem needing research.

Petrography is a technique for sample analysis that may be required to accomplish other recommended research objectives outlined above, but this technique was discussed in a unique perspective which could lead to some productive research in coal cleaning and coke production. It was reported that there has been promising petrographic research indicating the relationship between coal macerals and the response of a coal to grinding and washing, as some macerals are more friable and lighter than others. It was also reported that no petrographic work is being done on coke in the United States, although research on coke and coking coal is necessary to improve the worldwide marketability of U.S. coals suitable for making coke.

<u>Modeling, geostatistics, and prediction of coal quality</u>. These topics received much discussion in the workshops at the symposium and especially in Workshops I, II, and III. It was generally agreed that we need the capability to predict what will

happen under a given set of circumstances, but how to get there? It was suggested that the proper approach is to develop models, test them against the real world, and then, if they survive, to apply them. One way to test the performance of models against the real world is through the use of geostatistics.

Some participants expressed the opinion that geostatistics is a mature subject and available for use for any purpose, whereas others thought that additional research is required before geostatistical methods could become universally applicable. Most participants seemed to agree that most existing models for predicting coal quality and quality variations at all stages of the coal business--from characterizing the quality and quantity of coal resources to predicting ash composition and ash behavior--leave much to be desired. The consensus seemed to be, however, that good models will save time and money and deserve a reasonable amount of research effort. Nevertheless, statistical process control is currently used by only a very few coal producers and users.

Specific areas identified as needing additional research and related activities were: (1) methods for locating minimum-variance samples; (2) inclusion of post-depositional history in developing coal-deposit models; (3) methods to relate coal-washability data from large and small diameter cores; (4) more education and training on the use of geostatistics; and (5) publication of more modeling and geostatistical "case histories" in a timely manner.

Sulfur in coal. Sulfur in coal continues to be a problem. Whether there is too much or too little sulfur, whether it occurs as pyrite, organic sulfur, or sulphate, and how entrained, were all subjects of discussion at the symposium. Additional research needs were identified as:

1. Methods to identify the forms of sulfur in coal, especially organic sulfur.

2. Methods to extract organic sulfur before using coal.

3. Methods to predict where and in what form sulfur will occur in coal in the ground.

4. Determination of the "true" size of pyrite grains in coal.

5. Development of models to predict the formation of acid mine waters.

6. Development of selective mining methods to reduce the level of pyrite in ROM coal.

Several attendees commented that it would be very beneficial if the agencies that prepare coal-resource maps would include data on sulfur content and forms on their coal maps.

Minerals in coal. This topic took up much discussion time in most of the workshops and especially in Workshop V with regard to UFC (ultrafine coal). Apparently, it is as important to know what the mineral forms are that are present in coal as it is to know what the inorganic chemical composition is. The consensus was that too little is currently known about minerals in coal. Minerals such as quartz and pyrite cause erosion in coal handling and utilization equipment, whereas clay affects coal handling; if feldspar is present, it may be of the sodium variety. There was agreement that much more research needs to be done on mineral forms in coal. Some attendees suggested that data on mineral forms in coal would be far more valuable for steam coals than a maceral analysis would be because bottom and fly-ash characteristics will depend, to some extent, on the minerals present in the feed coal.

It was reported that there is evidence that mineral grain sizes tend to be smaller in coals of lower rank, but that this tendency requires more research for corroboration. If true, this tendency has important implications for coal beneficiation.

Opportunities for research on mineral forms appear to be in devising rapid, improved, and inexpensive analytical methods for determining mineral forms; determining origin, sizes, and distribution of mineral forms in coal and how the mineral matter interfaces with coal; determining the relationships of different mixes of minerals to ash-fusion and fouling characteristics; and making minerals liberation measurements (separation of coal from mineral matter) for finely ground coals.

Additional Recommendations

Some of the workshops at the symposium provided recommendations for research on coal quality and related activities that were unique to that group. These recommendations are presented by workshop:

Workshop I - Complete geologic mapping in all coal basins and expand research on the geology and geochemistry of low-rank coals--most research is being done on bituminous coals; change the manner in which coal resources are characterized to meet the needs of the mining and utilizing industries within the next decades; and study the physical characteristics of overburden for use in mine planning.

Workshop II - Make a greater effort to extend the classification of resource data into reserves data with associated production costs. The focus of this effort should be to provide better data on coal reserves by sulfur categories, and perhaps other quality criteria, for use in strategic planning by government and industry. Study the chemical reactions of coal blends during combustion. Initiate research to simplify the evaluation of the coal-handling factor (HF); HF is mainly a function of moisture, particle size, and clay content. Provide data on coal accessibility as well as on total resources.

Workshop III - Devise new technology for reserve characterization such as the following: a borehole miner, thickness of seam using radar, and directional underground drilling. Devise new technologies for mine operation such as coal preparation at the face, underground disposal of preparation waste, ash analyzers to detect partings, methods to reduce ROM sulfur, and methods to minimize contamination and variability of ROM coal. Devise a relative spontaneous-combustion potential index. Determine the fate of various pollutants in typical disposal situations from mines and preparation plants. Study methods to provide analyses of geologic hazards and risks involved with coal mining.

Workshop IV - Do research on biological and combined biological physical methods to clean coal and on methods to recover coal fines (fines may include as much as 10 percent of the combustibles) from preparation-plant waste streams. Study the effects of toxic substances derived from coal mining on ground water.

Workshop V - Initiate or expand research on atomization characteristics of coal-water fuels, particle-size distribution in ultrafine coals and standardization of these particle sizes, and comminution properties to aid in ultrafine grinding of coal: the Hardgrove test is not representative for other high-moisture coals or for ultrafine grinding. Study the details of the coal-water fuel-combustion process. Initiate research on collection of the very fine dust resulting from coal burning. Perform long-term research on coals that do not liquefy well and be able to correlate the variables important in various liquefaction processes.

Afterward

The five workshops at the Symposium on Coal Quality have provided a massive amount of material on the kinds of research and related activities that are needed in the field of coal quality in order to facilitate expansion in the use of coal in an environmentally sound and cost-effective manner. These workshops provided what is truly a "national agenda" for research on coal. In general, the participants called for a systematic, multidisciplinary approach to coal research which they indicated should consist of all parts of the coal community, including geologists, chemists, engineers, and economists, from Federal and State agencies, industry and academia in order to be most effective and incorporate the special abilities of each in the research program. The U.S. Geological Survey (USGS) is in agreement with this approach and is presently analyzing what its role can be in this national agenda for coal-quality research; it will describe its proposed program in the near future. In part, the planning process in the USGS will depend on the response of industry to the recommendations of these workshops. The USGS must depend heavily on the willingness of the coal industry to share information with the USGS on coal occurrence and quality. The general concepts that the USGS formulates will be more credible if industry data are available and these concepts will be of greater benefit in return to the entire coal community: details of shared data can be kept confidential by USGS. Industry has shared data with the USGS in the past on an ad hoc basis to the mutual benefit of both sides. If this relationship could be broadened and institutionalized, the mutual benefits could be even greater. As steps toward this end, the USGS may enter into cooperative research with industry if the results may be made publicly available. Industrial Research Associateships are also available at the USGS whereby someone from industry may conduct research with Survey equipment at Survey facilities under the same conditions as for USGS/industry cooperative research.

The challenge has been made. Will we rise to it? We have in the past; we can in the future.

WORKSHOP AND PANEL I
CHARACTERIZATION OF THE QUALITY OF COAL RESOURCES AND RESERVES

The more significant issues considered by this workshop were (1) characterization of coal in place, (2) assessment of coal resources by quality, (3) methodologies and uses of predictive models, (4) uses and availability of data in the public domain, and (5) information dissemination and technology transfer.

Recommendations:

- Develop and quantify geologic models. Rates of change and interdependence of variables must be expressed in quantitative and probabilistic terms to have the greatest utility to the coal industry.

- Promote the use of statistical and geostatistical methods for coal-quality characterization. Nonparametric statistics are recommended and Kriging is a useful technique but other methods may be useful if properly applied.

- Standard procedures for coal analyses should be followed "without deviation." New analyses must be comparable with older analyses. If new techniques are developed, they must produce results that are comparable with older techniques.

- Give special attention to sampling of low-rank coals, standardize sampling practices not currently covered by standards, and develop statistical methods for determining the variabilities in quality parameters caused by sampling practices.

- Develop geophysical methods for coal-quality analysis.

- Improve communications between Government agencies, and provide inventories of increased access to Federal data bases.

- Convene workshops to consider each of the items listed in more detail.

Panel I recommended that the following topics should receive special attention for research:

- Studies of modern swamps as analogs of coal deposits should be expanded to understand process relationships in time and space and the relationships between dependent and independent variables to aid in the development of predictive models.

- Geologic mapping should be completed in all coal basins.

- Studies of the geology and geochemistry of low-rank coals should be expanded. Most research is being done on bituminous coals.
- Forms of sulfur should be investigated by modern techniques and the sources and mobility of sulfur compounds should be investigated.
- The variability of important coal-quality characteristics should be documented and reported by statistical parameters.

WORKSHOP AND PANEL II
COAL UTILIZATION AND PROCUREMENT

The objective of the panel was to identify the technical information needs of coal producers and consumers for developing effective procurement relationships, for producing the lowest electric generating costs at the bus bar with reliable system operations, and for strategic planning. Once the needs were identified, a set of research recommendations was derived to satisfy the objective of the symposium.

Output of the panel is a set of recommendations for coal-quality research and improved communication. Four broad categories identified are (1) a set of target topics, (2) assessment of existing data bases, (3) improved identification of economic reserves, and (4) better communication.

Target topics include:

A. Sampling - Assess current techniques and their representativeness.

B. Blending - Conduct research on the ash fusion, grindability, and handling characteristics of various coal blends in order to develop criteria for blending;

C. Coal petrography/petrology

   1. Identify petrographic relationships associated with coal utilization/combustion parameters.

   2. Determine the usefulness of data from experimental petrology, combined with coal analyses, in predicting ash fusion and other combustion characteristics.

   3. Assess the predictability of combustion characteristics of coal blends and coals mixed with other compounds in order to modify those characteristics.

D. Applied Coal Geology/Geostatistics - Conduct additional research on the use of these tools in evaluating in-place resources, recoverability, and quality variations and in developing exploration and mining plans.

E. Develop data relating drill-core coal quality to run-of-mine and cleaned coal quality, including an assessment of the impact of coal cleaning processes on how coal should be characterized.

We recommend that existing data bases be reevaluated. Available data should be assessed for their reliability based on sampling and measurement techniques employed. We support the concept of the National Coal Resources Data System and consolidation of the various coal quality data bases.

It is suggested that a greater effort be extended to the classification of resource data into reserves data with associated production costs. The focus of this effort should be to provide better data on coal reserves by sulfur categories, and perhaps other quality criteria, for use in strategic planning considerations of Government and industry.

Finally, we propose that some resources be expended in improving communication among coal quality researchers and the users of their product. Some possible approaches might include:

A. Topic-user groups composed of data development and user personnel in target subjects;

B. Online newsletter identifying who is doing what in specific areas (emphasis should be on who to contact for information); and

C. Regional technical meetings on subjects of interest.

WORKSHOP AND PANEL III
COAL MINING AND COAL CLEANING (BENEFICIATION)

The consensus of the Panel discussions is as follows:

I. Mine Planning

A. Develop predictive techniques to provide better definition of individual coal reserves with regard to the following aspects:
   1. Minor anomalies (utilizing high-resolution seismic methods)
   2. Geological features
   3. Selected coal constituents
   4. Mineability
   5. Adjacent rock properties (natural radiation levels, sparking tendencies)

B. Minerals in Coal
   1. Investigate the amounts, particle sizes, and types of minerals as they exist in coal and correlate these variables with the performance of the coal in various utilization unit operations. New or modified analytical techniques may be required
   2. Predict distribution of utilization "bad-actors"

C. Core and Channel-Sample Treatment
   1. Develop a method for treatment of core and channel samples to improve estimates of plant yield and permit an optimum plant design.
   2. Determine target-size distribution for ROM (run-of-mine) coal
   3. Determine the relationship between coal properties and particle-size distribution
   4. Develop a method to simulate a particle-size distribution of preparation-plant feed and ROP (run-of-plant) material

D. New Technology Development
   1. Develop new technology for reserve characterization
      a. Bore-hole miner
      b. Bore-hole elemental analyzer
      c. Thickness of seam using radar
      d. Directional underground drilling

II. Mine Operation

A. Develop New Technology
   1. Coal preparation at the face
   2. Underground disposal of preparation waste
   3. Ash analyzers to detect partings

4. Control ROM coal sizing
    a. Investigate bit spacing and design
    b. New fragmentation methods
5. Run-of-mine sulfur reduction
    a. Improved cutting
    b. Mining strategies
    c. Improved control by automation
6. Minimize contamination and variability of ROM coal

III. Coal Cleaning (Beneficiation) - Above Ground

A. General
1. Develop an improved data base of coal-preparation-plant performance
2. Develop an on-line coal-slurry analyzer
    a. Moisture and other pertinent parameters
3. Determine the separation capacity relative to trace elements and mineral species, such as quartz
    a. Determine environmental concern of trace elements at utilization level, and removal strategy at preparation plant
4. Fate of chemicals used in coal-preparation processing
5. Develop off-line control of preparation plants using ROM quality estimates based on geostatistics
    a. Compare with on-line control based on elemental analysis

B. Ultrafine Coal
1. Develop new test methods to replace washability tests presently used on +28 mesh material
2. Develop new ASTM analytical methods where existing methods are either inapplicable or inaccurate, such as for ash and sulfur
3. Develop new measures of beneficiation potential, as maceral/mineral liberation

C. Chemical Cleaning
1. Quantitatively and qualitatively identify organic sulfur-containing molecules
2. Develop measurement of physico-chemical surface properties to control surface-chemistry-based processes

IV. Coal Marketing

A. Develop relationships to quantify differences in coal quality as they affect the value of <u>steam</u> coal
1. Constituents that cause abrasion and erosion
2. Ash properties correlated with combustion behavior

B. Develop relationship to quantify differences in coal quality as they affect the value of metallurgical coal

C. Develop relationships to quantify differences in coal quality as they affect the value of coal used in cement kilns

D. Develop blending techniques to produce desirable coal characteristics
   1. Steam coal
   2. Metallurgical coal
   3. Cement-kiln coal

V. Ancillary Operations

A. Develop a relative spontaneous-combustion potential index
B. Fate of various pollutants in typical disposal situations from mines and preparation plants

VI. Technology Transfer

A. Foreign Information
   1. Greater involvement in international organizations such as ISO (Standards)
B. Domestic Information
   1. Collected by U.S. Government from foreign sources
   2. Collected by Federal and State agencies
      a. Central data base
C. Domestic Industry
   1. Workshops and seminars
      a. Further the application of existing, powerful tools, such as geostatistics and geographical logging

In summary, the following four issues among those delineated were considered most significant for future research and development investigations.

- o Characterization of minerals
- o Estimation method for plant performance from core/channel data
- o National coal-mining/preparation-plant performance data base
- o Coal properties as they relate to value of coal for specific utilization purposes

WORKSHOP AND PANEL IV
ENVIRONMENTAL ISSUES AND THE ROLE OF COAL-QUALITY RESEARCH

Workshop IV concluded that:

- Additional research is needed to establish important coal-quality parameters that are related to major environmental issues and to establish the limits over which certain coal-quality parameters vary in nature.

- Coal-industry technology needs to be upgraded and the methodologies used by the industry need to be reexamined.

Panel IV recommended that additional research be conducted on:

- Sulfur and its forms

- Particulate matter with regard to the fusion tendency of fly ash, mineral species in coal, and ash resistivity

- Physical properties of coal such as grindability, washability, and the viscosity of slag

- Properties of the organic constituents of coal and ranges of moisture content

- Specific trace elements--arsenic, selenium, mercury, boron, fluorine, and chlorine

- Nitrogen in whole coal and in the volatiles produced during coal use

WORKSHOP AND PANEL V
ADVANCED TECHNOLOGIES FOR COAL UTILIZATION

Summary of the conclusion and recommendations were:

1. Initiate or expand research on:

   - o Understanding the mineral species present in coal and the reactivities and size distribution of mineral-matter grains in coal.
   - o Develop a direct method to determine the oxygen content of coal
   - o Improvements in coke petrography (very little is currently being done in the United States)
   - o Atomization characteristics of coal-water mixtures (CWM)
   - o A high-shear viscosity test related to coal quality and to atomization of CWM
   - o The properties of coal-ash slags under both reducing and oxidizing conditions
   - o The chemistry of organic-sulfur compounds in coals
   - o Particle-size distributions in ultra-fine coal (UFC) and standardization of particle sizes in UFC
   - o New techniques to measure the chemistry of surface oxidation of coal and of specific chemical groups in coal.
   - o Understanding of trace-metal associations in coal and trace-metal release patterns
   - o Comminution properties to aid in ultra-fine grinding of coal

2. Improve coordination and cooperation among Federal agencies engaged in coal-quality research and in dissimination of research results by:

   - o Providing better access to coal-quality data in the National Coal Resources Data System (NCRDS) of the USGS, holding workshops on NCRDS, and publishing a brochure(s) describing NCRDS
   - o Provide computerized lists of coal-research projects and findings and mailing lists of appropriate personnel to

receive notice of relevant reports on research results. Greater interaction is needed between the various subdisciplines working on coal quality

- o USGS should publish an annual report on projects and results of its coal-quality research

- o Establishing an intergovernmental task force to coordinate coal-quality research objectives

Panel V recommended that priority should be given to research on mineral species and mineral-grain size distribution in coal, on coal grindability, and on improving communications among coal-quality researchers and between them and the general community of coal users.

PART III: POSTER SESSION ABSTRACTS

LIST OF ABSTRACTS

Friedman, S.A., A geochemical study of bituminous coal resources of Middle Pennsylvanian age in eastern Oklahoma: Part 1: maps showing distribution of fixed carbon and sulfur, and lead, zinc, and manganese.

Golightly, D.W., and others, Current analytical methods for determining the inorganic composition of coals.

Grady, W.C., and others, Relationships of palynology, petrography, and coal quality in some Upper Kanawa Formation coal beds of West Virginia.

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Windolph, John, Jr., and others, Comparative geochemistry of two coal beds from contrasting depositional environments of Late Cretaceous age in the western part of the Wind River Basin, Wyoming.

GEOCHEMISTRY OF SOME TERTIARY ALLUVIAL LOWLAND COALS FROM THE CAPPS AND CHUITNA COAL FIELDS, COOK INLET REGION, ALASKA

by

R.H. Affolter and G.D. Stricker
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The Capps and Chuitna coal fields, Beluga coal-resource area, are located approximately 90 km west of Anchorage in the upper Cook Inlet Region of south-central Alaska. Forty-three core samples from these fields, representing eight coal beds (Capps, Waterfall, M, O, Q, and three unnamed beds), were collected from the lower Oligocene to middle Miocene Tyonek Formation. The coal-bearing section of the Tyonek Formation is believed to have accumulated in poorly drained alluvial lowlands adjacent to tectonically active highlands.

Statistical summaries of proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, and contents of 40 major-, minor-, and trace-elements were compiled and evaluated along with the low-temperature-ash mineralogy for each sample. Analyses show an apparent rank that ranges from subbituminous B to subbituminous C, with a variable ash content of 4.7 to 46.5 percent and one of the lowest reported sulfur ranges for any United States coal of 0.08 to 0.33 percent.

Nearly half of the elements analyzed (Si, Al, K, Ti, Be, Cr, Cu, F, Ga, La, Sc, Th, U, V, Y, Yb, and Zr) show a variation in concentration that is directly related to the ash content of the coal (linear correlation coefficients >0.8). Mineral composition of the low-temperature ash is predominantly kaolinite and mica-type clays with varying amounts of quartz. These data suggest that many of the elements that vary with ash content may also be associated with the clay minerals. The M bed has the lowest ash content and the lowest concentration of ash-correlated elements, whereas the Capps bed has the highest ash content and therefore, the highest concentration of these elements. The variability of ash content is probably a direct result of the proximity of the original peat swamp to nearby tectonically active highlands. The peat is thought to have accumulated in non-marine swamps as indicated by the low average forms-of-sulfur for all eight coal beds (0.13 percent organic sulfur, 0.02 percent sulfate sulfur, and only 0.01 percent pyritic sulfur). Trace elements that normally show positive correlation with sulfur in most U.S. coals, such as As, Cd, Co, Fe, Mo, Ni, Pb, and Zn, are low in concentration for coal from the Tyonek Formation.

AN INTERDISCIPLINARY GEOSCIENTIFIC APPROACH TO MODELING COAL-QUALITY VARIATIONS IN A TEXAS LIGNITE DEPOSIT: IMPLICATIONS FOR MINE PLANNING AND USE

by

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Phillips Research Center

Geologists, mining engineers, geophysicists and geochemists from Phillips Coal Company and Phillips Petroleum Company are working together to determine the best way to mine a lignite seam to meet quality standards for a potential client. The program combines existing whole-seam quality data from more than 60 cored holes and geophysical logs from more than 600 uncored holes with analyses and logs from three cores that were sampled in 0.2-0.5-foot intervals and analyzed in detail. Standard analyses were done by an independent laboratory and mineralogical, petrographic, infra-red and pyrolysis studies were done by Phillips and the University of Utah. We used this information to interpret the earlier data and develop an environment of deposition model.

The seam, as much as 5.5-feet thick and covering an area about 5 miles by 7 miles, formed in lower Wilcox (Eocene) times in an upper-delta-plain, freshwater hardwood swamp between two regional distributary channels. Sulfur content is <0.8 percent (dry basis) except in the extreme southwest of the prospect. Sediment supply was mostly from the north, so the overall ash content decreases southwards, although it increases near smaller channels. The overall energy level increased through time (upwards) with four recognizable higher energy pulses.

These pulses were traced by density logs to predict ash distribution when designing a selective mine plan for part of the prospect. The plan increases as-mined calorific value by 350-600 Btu/lb and reduces ash content by 3-5 percent while losing only 8 percent of the original tonnage and increasing the strip ratio from 12.4 to 13.4.

Groundwater-driven redistribution of organically bound calcium has increased the Ca:S ratio, and thus the potential natural sulfur retention, in the proposed mine area.

Vertical maceral zoning, partly correlatable with the sedimentary cycles, can be traced by resistivity log signatures. The zones have different pyrolysis yields and the relationship could be used to evaluate synfuel potential of lignite seams.

ASH-FUSION STUDY OF WEST VIRGINIA COALS

by

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As more industries and utilities convert to coal, ash-fusion information becomes more important for boiler design (waste-disposal systems). For example, burning a low-fusion-temperature coal can cause slagging--the buildup of molten ash on boiler waterwall tubes. This not only lowers boiler efficiency but also can increase downtime.

Recently, potential buyers of West Virginia coal have frequently inquired about ash-fusion. However, the amount of information in the West Virginia Geological and Economic Survey's database is limited to data from about 800 samples, 50 percent of which are collected in five counties. Thus, the Survey is conducting a study of ash-fusion temperatures for the State's coals, to increase available data and its geographic coverage.

A Leco AF-500 automated ash-fusion analyzer[1] is used in this study. This presentation addresses:

(1) operation of an automated ash-fusion analyzer;

(2) repeatability of results from an automated analyzer;

(3) comparison of automated with conventional data;

(4) preliminary research developments.

The goal of this project is to do research on ash fusion of West Virginia coals. The research seeks to develop for West Virginia coal a statistical-correlation model relating ash-elemental data with fusion data, and to investigate the relationship between ash color and fusion temperature. (Light-colored ashes tend to have higher fusion temperatures than darker ashes.)

The ash-fusion project adds vital user-needed information to our computer database. With this addition, the Survey can offer a more complete, unbiased source of information about West Virginia seams to prospective buyers of West Virginia coal.

OCCURRENCE OF SULFATES DISCRIMINATES OXIDIZED FROM UNOXIDIZED COALS IN WESTERN NEW MEXICO

by

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Knowledge of the depth and distribution of oxidized coals can allow for better development of the coal resource of an area, as well as increased accuracy in prediction of trends in coal quality.

Sulfates, usually in the form of gypsum, tend to be found in near surface coals whereas organic and sulfide sulfur are found in coals at all depths. The formation of sulfates is a product of oxygen-bearing surface water, which percolates through a coal bed converting sulfides to sulfates. Thus the presence of sulfates can be useful in identifying oxidized coals.

Twenty-two commonly run combustion analyses including nine major oxides (Si, Al, Fe, Ti, Ca, Mg, Na, K, P) were run on 50 coal samples from western New Mexico; the coals were from the Upper Cretaceous Moreno Hill and Fruitland Formations. Both proximate and ultimate analyses show significant differences when separation is based on whether or not sulfates are present in the sample. Parameters, such as Btu, carbon and hydrogen, in the sulfate-bearing samples have a lower average value and a higher standard deviation in range of values and lower means. In those samples containing sulfates both moisture and oxygen are increased, along with their standard deviations. Downhole profiles show these changes in combustion parameters with depth at a single location. Of the nine major oxides, four, (Ca, Na, Mg, K) showed change in oxidized coals. Ca and Na are decreased in both the mean value, as well as their standard deviations. An increase in mean and standard deviation are found for Mg and K. This results in a slight reduction in the silica ratio for unoxidized coals. The depth at which the sulfates form, indicating an oxidized coal, is reasonably uniform throughout an area, but differs in areas of different climatic and geologic conditions.

The accuracy of some calculated values, such as rank and relation of hydrogen to volatile matter are affected. The calculated rank will vary depending on whether or not sulfates are present. In the case of the Moreno Hill coals, the rank ranges from subbituminous A to high-volatile bituminous C for coal from the same area coal bed. Hydrogen has a direct relationship to volatile matter in non-sulfate-bearing coals making estimates of volatile matter from hydrogen content more accurate.

IMAGE ANALYSIS OF PYRITE IN OHIO COAL: RELATION BETWEEN PYRITE GRAIN-SIZE DISTRIBUTION AND PYRITE SULFUR REDUCTION

by

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The size characteristics of pyrite in coal have long been known to influence the amount of pyrite sulfur reduction that will occur when a coal is washed by float-sink methods. However, manual microscopic methods of determining the size characteristics of pyrite embedded in coal are tedious and time consuming, and, as a result, practical application of this knowledge has been very limited. Modern automated image analysis offers a potentially rapid, nontiring method of determining the size distribution of pyrite associated with coal.

Linear-regression analysis of data collected on 14 X 28-mesh coal indicates a strong correlation between the cumulative percent pyrite in certain pyrite size ranges determined by image analysis and pyritic sulfur reduction of washed coal. Using two different magnifications and slightly different operating conditions for the image analyzer, correlation coefficients of $r = -0.95$ (high magnification), and $r = -0.90$ (low magnification) were obtained between pyritic sulfur reduction and cumulative percent pyrite in the less than 24 micron and less than 66 micron size range, respectively. Two factors which appear to work against these strong relationships in this study are poor precision of the pyrite-size-distribution data and the unpredictable clustering of pyrite grains in some coal particles. The equations defining the sulfur reduction/size distribution correlation should be applied only under the conditions in effect when the relationship was established.

PETROGRAPHIC DOCUMENTATION AND INTERPRETATION OF PRINCIPAL MINERAL OCCURRENCES IN COAL

by

E.C.T Chao, J.A. Minkin, J.M. Back, and S.S. Crowley
U.S. Geological Survey

In order to understand and interpret the sulfur and ash contents and variations in coal, it is necessary to document the crystal habit, modes of occurrence, distribution, and abundances of the principal minerals in coal. These minerals include iron sulfides (pyrite and marcasite), quartz, clays (illite, kaolinites, smectites, and chlorites), carbonates (calcite, siderite, ankerite, and so on) and other accessory minerals such as feldspars, rutile, and zircon. Some of these minerals, whether of primary (syngenetic), secondary (epigenetic), or diagenetic origin, may be important indicators of the paleogeochemical and paleodepositional environment of the precursors of the coal in which they occur.

The modes of occurrence, distribution, and abundance of types of minerals in coal seem to have close association and correlation with the relative abundance of either vitrinite, or exinite and inertinite groups of macerals in coal. High mineral contents generally correlate with high exinite- and/or inertinite-bearing coals and low mineral contents generally correlate with high vitrinite coals. These observations are important to our understanding of coals of allochthonous versus autochthonous origin.

Principal minerals in coal, and their occurrences in partings associated with coal bed, may also be correlated with the trace-element characteristics of particular coals. Hence, the minerals may be key indicators of the source of the organic and inorganic detritus that may contribute to the high or low sodium, chlorine, or fluorine contents of particular coals.

UPGRADED QUANTITATIVE PETROLOGIC AND FACIES CHARACTERIZATION OF COAL BASED ON MODERN METHODOLOGY

by

E.C.T. Chao, J.A. Minkin, J.M. Back, and S.S Crowley
U.S. Geological Survey

Our principal research objectives are the development and application of modern techniques and procedures for the establishment of an upgraded, quantitative coal-quality and description data base with emphasis on petrologic and facies characterization of autochthonous and allochthonous coals. (Autochthonous coals develop from plants which after death form peat in place. Allochthonous coals form from plant remains which were transported considerable distances from their original site to site of deposition and peat formation).

Coals of autochthonous origin generally have a uniform thickness (commonly less that 15 feet). Coals of allochthonous origin are generally very thick (more than 50 feet) and show pronounced coal-bed thickness variations. They may be distinguished petrologically on the basis of structural and textural characteristics of the coal. Autochthonous coals are usually well banded or finely laminated and layered. Allochthonous coals are typically poorly to irregularly banded or lenticular. The bands may be steeply dipping and contain rounded to irregular-shaped chunks of vitrite or vitrain.

The data obtained with the modern techniques we use include:

1. Macroscopic and microscopic quantitative characterization of coal-bed profiles in terms of coal lithotypes and total VEIM (V-vitrinite group, E-exinite group, I-Inertinite group, M-mineral group), using high-resolution binocular microscopes, research petrographic microscopes and an automated image-analysis system.

2. Characterization of the modes of occurence, assemblages, distribution, and abundance of the principal minerals in coal that contribute to the ash content in a coal bed. These minerals include pyrite-marcasite, quartz, clay minerals, carbonate, and accessory minerals. Such specific mineral data require the combined use of optical petrographic microscopy, interference microscopy, X-ray diffraction, automated image analysis, scanning electron microscopy, electron-probe microanalysis, and scanning transmission electron microscopy. The mineral distribution and abundance data so obtained are also essential for establishing a coal-bed formation curve.

3. Direct determination of trace-element content in coal macerals and minerals by electron-probe microanalysis and by proton-induced X-ray emission microprobe methods. The trace-element data may be used to establish a geochemical profile of the coal bed as a basis for interpreting the paleogeochemical environment of deposition of the coal precursor.

The new and upgraded quantitative coal-quality data base is essential and vital to both the characterization of the coal quality and to the interpretation of coal facies with respect to a particular depositional environment.

THE USE OF STABLE ISOTOPE RATIOS FOR MONITORING THE BEHAVIOR OF ORGANIC AND PYRITIC SULFUR DURING DESULFURIZATION OF ILLINOIS COALS

by

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Naturally occurring differences in the sulfur isotopic compositions of organic and pyritic sulfur in some coals make it possible to monitor the fate of these two different species during desulfurization. Once the isotopic compositions of the individual species are established, one can analyze the sulfur removed during desulfurization (or the residual sulfur remaining in the treated coal) and calculate the proportion of each species removed.

Previous research at the ISGS has shown that a significant amount of sulfur can be removed from coal by low-temperature charring (pyrolysis). Furthermore, the sulfur which remains in the char is rendered more subject to chemical attack than that in the feed coal. Pyrolysis experiments have been conducted on three different samples of Illinois No. 6 coal at temperatures ranging from 350° to 750°C under a nitrogen atmosphere. The sulfur released with the volatile products and the sulfur remaining in the char were quantitatively collected and their respective isotopic compositions measured. The isotopic data showed that for all three samples tested, the sulfur released with the volatiles was predominantly organic in origin; pyritic sulfur was not volatilized until the temperature exceeded 450° to 500°C. This is in agreement with thermogravimetric analysis (TGA) and differential thermogravimetric analysis (DTG) which suggests that organic sulfur and pyritic sulfur are liberated at different temperatures. Further testing has shown that during charring at 650°C, some of the pyritic sulfur becomes incorporated into the organic structure. There does not, however, appear to be any migration of sulfur in the reverse direction (from the organic phase to the pyritic phase).

Low-temperature pyrolysis coupled with other processes shows technical and economic promise as a method for producing a compliance fuel from high-sulfur Illinois coal. Stable isotope monitoring has proven to be very helpful in understanding the reactions which are involved during desulfurization of Illinois coal--a requirement if process efficiency is to be improved. The method is unique in that it uses an inherent characteristic of the coal as a "tracer"; no additives or chemical treatments of the coal are necessary prior to desulfurization.

APPLICATIONS OF A COAL-QUALITY DATA BASE: GEOLOGY AND QUALITY OF THE FIRE CLAY COAL IN EASTERN KENTUCKY

by

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The Fire Clay coal is one of the leading compliance coals in the eastern United States. This coal has been mapped on more than 120 7.5-minute quadrangles in eastern Kentucky. Resource estimates show 5.9 billion tons of original coal resources and 5.2 billion tons of remaining resources. The Fire Clay occurs in a terrigenous clastic wedge between two marine units in the Breathitt Formation of Middle Pennsylvanian age. An extensive data base for this coal consisting of 1,569 measured sections and 200 analyses of channel samples has been developed by the Kentucky Geological Survey. Applications of this data base include geologic and coal-quality modeling.

Geologic investigations of Fire Clay include mapping the coal thickness and various quality characteristics such as sulfur, ash, moisture, and calorific content. Analysis of the overlying strata provides information about potential influences on the coal from fresh, brackish, and marine depositional systems. Coal-resource maps serve as the foundation for geologic and coal-quality modeling. The geometry of coal-thickness contours gives information about paleoslope and drainage patterns, and the isopach maps serve as an appropriate base for plotting sulfur and ash values. Patterns and trends in geology and coal quality which arise from these constructions are useful for predicting coal-quality characteristics in areas of less data.

The use of cluster analysis has been attempted on an experimental basis to classify areas of the coal bed according to similar geologic parameters such as coal thickness, parting thickness, number of partings, sulfur content, and ash content. A principal-component analysis gives a ranking of the importance of each parameter in influencing the clustering. As more information becomes available and statistical relationships are better understood, the ability to extrapolate coal-quality characteristics will improve.

The abundance of compliance-quality coal in the Fire Clay has been estimated using probability modeling based upon the frequency of results of paired sulfur and Btu analyses. A cumulative frequency distribution was constructed to show the potential sulfur dioxide emissions per million Btu. This cumulative frequency distribution yields the percent of coal resources that satisfy any given sulfur dioxide standard. In the case of the Fire Clay coal, 68 percent of resources are in compliance at a standard of 1.2 pounds of sulfur dioxide per million Btu, 54 percent are in compliance at 1.0 pound of sulfur dioxide per million Btu, and only 3 percent are in compliance at 0.8 pound of sulfur dioxide per million Btu.

ELEMENTAL VARIABILITY AND CHARACTERIZATION BY PHYSICAL COAL CLEANING: ARSENIC, A CASE STUDY

by

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U.S. Geological Survey

J.D. Kilgroe
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Six hundred thirteen complete channel samples representing 34 coal beds of the Pennsylvanian and Permian (?) periods in the central Appalachian basin were analyzed for major, minor, and trace elements. The average arsenic concentration on a whole-coal basis is 14.0 ppm (standard deviation = 14.9). The ranking of the average arsenic concentration by formation is: Kanawha (mean = 5.04 ppm), is less than New River (mean = 10.1 ppm), which is equal to Pocahontas (mean = 10.9 ppm), which is equal to Monongahela (mean = 12.4 ppm), and all are less than Allegheny (mean = 18.1 ppm).

An analysis of the Upper Freeport coal bed of the Allegheny formation was undertaken to evaluate the regional (western Pennsylvania) versus local (within mine) arsenic variation. The arsenic concentration and variation are greater on the regional scale (mean = 40.8 ppm with a standard deviation = 30.6 for n = 21) than within mine (mean = 23.8 ppm with a standard deviation = 18.7 for n = 19).

Nine samples of the Upper Freeport coal bed were subjected to a 21-part washability study. This float-sink testing verified an inorganic affinity of arsenic and indicated an associative relationship between arsenic and pyritic sulfur for the Upper Freeport coal bed. There is an average 47 percent reduction in the arsenic concentration in utilizing the coal floated at a specific gravity of 1.6, which represents approximately 86 weight percent of the coal. The remaining 14 weight percent of the coal shows a seven-fold increase in the arsenic concentration relative to the original sample. On the basis of these results, arsenic in the Upper Freeport coal bed seems to be associated with large-sized, removable pyrite. High concentrations of both arsenic (>19 ppm) and pyritic sulfur (>1.3 percent) indicate a strong potential for their reduction by physical coal-cleaning methods. However, samples containing comparably high pyritic sulfur but moderate arsenic contents (<9 ppm) show very little potential for removal by physical processing. This is attributed to the small size (<30 um and dispersed) of the pyrite.

STABLE ISOTOPE GEOCHEMISTRY OF CALCITE IN THE UPPER FREEPORT COAL BED

by

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U.S. Geological Survey

At least two, and possibly three, stages of calcite formation are indicated by the isotopic composition of calcite samples from the Upper Freeport coal bed. Samples of calcite from cleat were compared to sink 1.8 gravity fractions and -100 mesh size fractions from size-gravity separates. All are enriched in ^{13}C relative to the PDB standard for carbon. The relatively constant ^{18}O values for these samples may indicate a constant temperature of formation. The positive enrichment in ^{13}C is indicative of CO_2 derived from fermentation processes. In contrast, calcite in float 1.275 gravity fractions tends to be depleted in ^{13}C. The ^{18}O values in the float 1.275 samples have a wide range, indicating possible variation in the temperature of formation.

Comparison of calcite from coal samples with samples of associated limestone suggests that calcite in coal resulted from biotic and abiotic processes within the peat/coal. Some of the calcite in the float 1.275 fraction from the Upper Freeport coal bed may have been formed very early as the result of bacterial sulfate reduction. The cleat calcite, sink 1.8 calcite, and -100 mesh calcite formed during a second stage, apparently as a result of fermentation and methanogenesis. Part of the calcite in float 1.275 samples may have formed in a third and still higher temperature stage which was probably abiotic and the result of thermally generated CO_2 during coalification. The origin of calcite in the coal controls its segregation during grinding, sizing, and float-sink testing.

COMPOSITION AND ENERGY CONTENT OF COAL WASTES AND WATER CHEMISTRY OF GREEN VALLEY-WABASH MINE AREA, VIGO COUNTY, INDIANA

by

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The site of the abandoned Green Valley-Wabash Mine, Vigo County, Indiana, contains an estimated 5 million tons of wastes distributed over about 60 acres to depths of as much as 55 feet. The wastes, from a coal-preparation plant, are composed of silicate and sulfide minerals and coal in gob piles and tailings ponds.

Analyses of coal tailings were as follows: ash (750°C), 13.1 - 35.5 percent; total sulfur, 3.5 - 9.3 percent; and heat content, 8,000 - 11,750 Btu/lb. Analyses of gob ranged, respectively, from 38.8 to 79.4 percent; 4.9 to 23.8 percent; and 1,360 to 5,470 Btu/lb. Washability tests on gob samples indicated that some beneficiation might permit recovery of about 1 million tons of coal.

Five water samples were taken and analyzed: (1) West Little Sugar Creek above the site; (2) West Little Sugar Creek downstream from the mine-waste area; (3) a small stream that drains the site; (4) a well in a waste pile; (5) a tailings pond. The pH of West Little Sugar Creek decreased from 7.8 above the site to 4.2 below. Concentrations of 10 of the 16 elements determined in samples from West Little Sugar Creek increased significantly below the mine-drainage area: iron, 0.2 mg/L above and 380 mg/L below (86 percent was ferrous iron); sulfate, 66 mg/L above and 1,600 mg/L below; aluminum, 0.06 mg/L above and 74 mg/L below. The highest total dissolved solids (118,000 mg/L), predominantly as ferrous sulfate, was in the ground water from the well in the waste pile.

Mine wastes at this site are a source of contaminants that adversely affect the quality of water in West Little Sugar Creek. Reclamation of this site would mitigate a significant source of acid mine drainage and provide coal for energy use.

GEOLOGIC SETTING OF THICK, LOW-SULFUR COAL IN THE LOWER PENNSYLVANIAN POCAHONTAS FORMATION, VIRGINIA AND WEST VIRGINIA

by

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U.S. Geological Survey

Economically important deposits of thick, low-sulfur coal are intercalated with a sequence of stacked delta lobes in the Pocahontas Formation of southwestern Virginia and southern West Virginia. The ancestral peat beds and associated clastic sediments were part of a northwestward - prograding terrestrial wedge that began to encroach on the southeastern shoreline of a regressive Carboniferous seaway in Late Mississippian time.

During Early Pennsylvanian time, the northwestward progradation of delta lobes was interrupted by periodic stillstands and, along the delta front, sand was reworked and segregated by coastal currents and waves to form a system of curvilinear barrier-bars. Extensive swamps developed behind these protective barriers and vegetation flourished on platforms created by the abandoned delta lobes. Plant growth and plant debris accumulated on the inactive, sand-dominated delta lobes and formed domed deposits of ombrogenous peat that were low in ash and sulfur. In contrast, high-ash mucks consisting of organic-rich clay and silt were deposited in the interlobe areas. As in modern analogous peat-forming environments on the north coast of Borneo, the accumulation of thick deposits of low-ash and low-sulfur peat on the slightly elevated platform areas was dependent on high rainfall which contributed little, if any, mineral matter to the peat. The ombrogenous nature of the Pocahontas coal beds is demonstrated by the occurrence of thick, low-sulfur and low-ash coal over the central part of the sandstone lobes whereas, thin, impure, and discontinuous coal beds occur in the shale-dominated interlobe areas. This analysis demonstrates that the geometry, thickness, and orientation of delta lobes correlate strongly with coal quality and thickness--a relationship that can be a useful exploration tool.

A GEOCHEMICAL STUDY OF BITUMINOUS COAL RESOURCES OF MIDDLE PENNSYLVANIAN AGE IN EASTERN OKLAHOMA: PART 1: MAPS SHOWING DISTRIBUTION OF FIXED CARBON AND SULFUR, AND LEAD, ZINC, AND MANGANESE

by

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More than 600 chemical analyses of channel and core samples of coal resources of Middle Pennsylvanian age from eastern Oklahoma, performed by The University of Oklahoma, the Oklahoma Geological Survey, the U.S. Geological Survey, and the U.S. Bureau of Mines since 1928 were tabulated and evaluated. These analyses provided 450 selected data points showing dry, ash-free (daf) fixed carbon and total sulfur and zinc, manganese, and lead in trace amounts that were plotted on four preliminary maps. The maps represent data from a combination of 17 coal beds. Some results and tentative conclusions follow.

Although the typical coal is high-volatile B bituminous in rank, an area in northeastern Le Flore County contains coal of semi-anthracite rank, and an area in Coal County contains coal of high-volatile C bituminous rank. Daf fixed carbon (coal rank) decreases from east (≥85 percent) to west (≤45 percent). "Hot spots" (>60 percent daf fixed carbon) are present northeastward from Tulsa to within a few miles of Kansas. These areas are not related to present depth of burial of coals but may be related to a heat source in shallow basement rocks.

The 7.8 million short tons of identified resources of bituminous coal in Oklahoma contains a weighted average sulfur content of 2.3 percent. Sulfur within individual coal beds ranges from <1 percent to >6 percent. Four of the 17 coal beds constituting the identified resources contain most of the low-sulfur (≤1 percent) coal. Most medium- to low-volatile bituminous coal contains ≤ 3 percent sulfur. In most areas near the Ouachita Mountains and south of Tulsa near the Ozark Plateau, coals contain <3 percent sulfur.

Whole-coal analyses indicate that positive anomalies exist for lead, zinc, and manganese near the Ozarks lead-zinc mining district, near the southern Ozarks, and near the Ouachita Mountains in the eastern part of the Arkoma Basin in Oklahoma. The lead anomaly in the southeastern area is small in areal extent and in quantity.

Coal rank shows no correlation with the proximity of the Ozark Plateau, the Ouachita Mountains, or the Arbuckle Mountains.

Low-and medium-volatile bituminous coals are believed to have been affected by a deep-seated heat source associated with the Mississippi Embayment. Most sulfur in coals was deposited during their peat-swamp stage, and the quantity of sulfur was due to depositional environments in and adjacent to paleo-swamps. The origin of trace elements is believed to be related to late Paleozoic emplacement of lead-zinc ores in the Ozark and Ouachita regions.

CURRENT ANALYTICAL METHODS FOR DETERMINING THE INORGANIC COMPOSITION OF COALS

by

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U.S. Geological Survey

Information on the concentrations of inorganic elements in coals is essential to a complete description of coal quality. Concentrations of more than 70 elements important to an assessment of coal quality are determined by methods established in U.S. Geological Survey laboratories for the chemical and instrumental analysis of whole coal and of coal ash. This group of diverse methods results from the application of generally complementary measurement approaches that account for the capabilities of individual techniques, the quality of information sought, and the cost of this information. Methods are described for the determination of major-, minor-, and trace-elements in coal and coal ash. The principal measurement techniques used include atomic emission spectography (AES), atomic absorption spectrometry (AAS), x-ray fluorescence spectrometry (XRF), instrumental neutron activation analysis (INAA), and specific ion electrode (SIE).

For the routine quantitative analysis of whole coal: Hg is determined by cold-vapor AAS; P is measured by XRF; and As, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, Hg, K, La, Lu, Na, Nd, Rb, Sb, Sc, Se, Sm, Sr, Ta, Tb, Th, U, W, Yb, and Zn are determined by INAA. Recently developed direct-current arc AES methods enable the determination of 28 elements in whole coals.

For the routine quantitative analysis of coal ash (500 degrees Celsius ashing temperature): Cd, Cu, Li, Pb, and Zn are determined by flame AAS; Al, Ca, Fe, K, Mg, Mn, Na, P, S, Si, and Ti are determined by XRF. After a special ashing procedure and fusion of the resulting ash with NaOH, F concentrations are measured by SIE. An automated, semiquantitative direct-current arc AES method is applied to the analysis of all coal ashed for the determination of 64 elements.

RELATIONSHIPS OF PALYNOLOGY, PETROGRAPHY, AND COAL QUALITY IN SOME UPPER KANAWHA FORMATION COAL BEDS OF WEST VIRGINIA

by

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Twenty-nine samples from three Upper Kanawha Formation coal beds (Stockton-Lewiston, Coalburg, and Winifrede) may be divided into two groups, based upon their coal-quality, petrographic, and palynologic characteristics. The first group contained 11 high-ash samples (average 17.5 percent) with moderate vitrinite abundances (V=61.6 volume percent), moderate exinite (E=7.4 percent) and moderate inertinite contents (I=13.1 percent). The second group of 18 samples contained moderate ash (8.7 percent), moderate vitrinite (V=57.4 percent), high exinite (E=9.2 percent), and high inertinite (22.6 percent) abundances. The first group of high-ash samples contained high percentages (average, 61.8 percent) of spores assignable to arborescent lycopods (Lycospora spp.). The second group contained high percentages (average 56.2 percent) of marrattiaceous tree fern spores (Laevigarosporites globosus, Punctatosporites minutus, and Punctatisporites minutus).

Petrographic results suggest that the tree ferns occupied raised, well-drained portions of the swamps in areas of high-peat oxidation, minor detrital influx, and minor early syngenetic mineral formation, which resulted in a lower ash content. The arborescent lycopods appear to have been the dominant vegetation in areas of more-or-less standing water, which were less susceptible to peat oxidation. These areas were more susceptible to early syngenetic mineral formation and detrital influx, resulting in a higher ash content.

These petrographic, palynologic, and coal-quality differences were observed between full-thickness channel samples (19 included in this study) and within a single coal bed sampled in 10 6-inch increments.

SIZE AND MACERAL ASSOCIATIONS OF PYRITES IN SOME ILLINOIS COALS AND THEIR FLOAT-SINK FRACTIONS

by

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Density-based processes are commonly applied to coal preparation and the amount of pyrite and other sulfides removed from coal varies considerably from one deposit to another. Some variation is due to the design and operation of the preparation plant, but some of it is due to the physical properties of the coal material. The influence of the physical properties, which are primarily thought to be the size and maceral associations of the pyrites, have not been sufficiently evaluated. The objectives of this project were to devise a microscopic procedure for assessing these properties, and to compare the results with float-sink tests for a few samples.

Microscopic measurements were made on polished specimens of samples crushed to less than 840 um in size. The apparent diameter of pyrites was measured in micrometers along a line superposed on the grain so as to bisect the grain (Martin's Statistical Diameter). Precision tests indicated that at least 1000 grains selected at random must be measured to obtain a reproducible mean diameter characteristic of the sample. The maceral-mineral association of each measured grain was classified as one of seven different types (modified micro-lithotypes).

The procedure used was to study three feed samples and six to seven float-sink fractions from each. The mean diameter of all pyrites in the specimens ranged from 6 to 30 um. Pyrites in low-density fractions were almost entirely associated with maceral-rich particles, and these averaged 6 to 10 um in diameter. The largest grains were associated with other pyrite grains in pyritic coal particles.

The characteristic found most useful for evaluating the float-sink behavior of coal was the percentage of the grain diameters within the various associations. Pyrite grains judged easy to remove were free grains, and grains enclosed in carbominerite or pyritic coal particles; pyrite grains judged hard to remove were those enclosed in vitrite, inertite, liptite, and bi- and trimacerites. The ratio of the percentage diameters within these two groups of association gave a value we have defined as the pyrite cleanability index (PCI). PCI correlated very closely with pyritic sulfur content, measured chemically, and it may provide a useful means to evaluate and compare the cleanability of feed coals to various preparation plants.

DIAGENESIS OF FOSSIL-FUEL PRECURSORS

by

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Studies of the diagenesis of wood in anoxic sediments by solid-state ^{13}C nuclear magnetic resonance (NMR) and stable isotopes show that microbiologically resistant components (lignin and resins) are selectively preserved whereas labile components (carbohydrates) are decomposed and lost. The selective degradation occurs with little alteration of cellular morphology. Coalification alters the lignin as the remnant cells coalesce to form a structureless mass (vitrinite). Similar studies of the diagenesis of algae in anaerobic sediments show that precursors of algal coal and kerogen evolve by a process of selective preservation and suggest that these precursors exist in algae and other microfloras. NMR spectra identify the chemical structure of the precursors as complex paraffinic macromolecules. Diagenesis essentially degrades microbiologically labile components such as carbohydrates, proteins, and lipids.

SEDIMENT YIELDS IN WATERSHEDS DRAINING THE APPALACHIAN COALFIELDS AND SURROUNDING AREAS

by

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U.S. Geological Survey

Large amounts of sediment leaving a watershed can have undesirable effects downstream. Deposition in downstream channels can result in increased flood peaks, and deposition in reservoirs reduces reservoir capacity. Deposition in streams can destroy benthic plants and animals, and high suspended-sediment concentrations in the water column can stress and produce undesirable changes in water-column biota. In addition, some plant nutrients and toxic materials in rivers are more likely to move as materials associated with sediment particles rather than as dissolved load.

The amount of sediment leaving a mine's watershed can be far greater than that leaving an undisturbed watershed because surface mining greatly disturbs the landsurface. Undisturbed, forested watersheds in the eastern United States have a mean annual sediment yield of about 30 megagrams (metric tons) per square kilometer. Annual yields as much as 7300 megagrams per square kilometer have been measured in small, mined watersheds. The amount of sediment leaving any mined watershed depends not only upon mining activities, but also upon vegetation, soil characteristics, topography, rainfall, watershed size, and the use of sediment controls.

Preliminary results of work quantifying the sediment yields in watersheds draining the Appalachian coalfields and surrounding areas are presented in two maps. Mean annual suspended-sediment yields for the study area are given in one map. The second map indicates whether the sediment loads and concentrations in selected rivers have been increasing or decreasing. These two maps are based upon a compilation of available sediment-yield data.

INFLUENCES OF VOLCANISM ON COAL QUALITY--EXAMPLES FROM THE WESTERN UNITED STATES

by

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Several small Tertiary coal deposits in Idaho, Nevada, and Washington formed in fresh-water basins located near active continental (salic) volcanic centers. Metastable glassy material (tephra) ejected during volcanic eruptions was introduced into the coal-forming environment of these basins as ash falls. This tephra contributed to the high ash content of many of the coal beds, formed laterally persistent partings ("tonsteins") in the coal, and constitutes a large part of the strata enclosing the deposits.

In order to study the possible relationships between the presence of tephra and coal quality, chemical data for 65 coal samples from 12 of these deposits were compiled and statistically analyzed. The results indicate that, in addition to the high ash content, coal from Tertiary deposits containing appreciable amounts of tephra generally is enriched in many elements compared to 460 coal samples from 11 deposits of similar ages remote from volcanic activity. Amounts of some elements, notably Co, Cr, Cu, F, Mo, Nb, Ni, U, V, Y, Zn, and Zr, are significantly higher in the tephra-containing deposits, and are not related to ash content (12.3 to 56.1 percent) or apparent rank (lignite to high-volatile A bituminous coal). Amounts of some other elements, particularly As and Sb, appear to be directly related to the sulfur content of the coal. Many of the coal samples from deposits influenced by volcanism also contain unusually high amounts of some less common trace elements, including Ge, rare-earth elements (Ce, La, Nd, Yb), and W.

Tephra in the coal beds and enclosing strata is the probable source of most of the elements enriched in these deposits. Volcanic glass deposited in the coal-forming environment remains largely unaltered during coal formation. Diagenetic alteration of the glassy material in the surrounding tuffaceous strata and subsequent leaching by groundwater mobilizes soluble oxides of such elements as Mo, U, and V. These oxides are transported in solution from the surrounding rocks and introduced into the coal deposit, where they precipitate in the reducing environment of the organic-rich sediments.

LASER MICROPROBE ANALYSIS AND PYROLYSIS OF GEOPOLYMERS

by

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Laser microprobe mass spectrometry was used to examine chemical structural components of plant biopolymers, coal, and related substances. The new Laser Micropobe Mass Analyzer (LAMMA 1000, Leybold-Heraeus Inc.) utilizes a neodymium-YAG laser to desorb, photolyze, pyrolyze, and subsequently ionize organic and inorganic components. The system is capable of detecting organic and inorganic species in both the positive and negative ion modes and has the potential of serving as an organic microprobe. However, it cannot analyze neutral species which, in some cases, may be produced in greater abundance than charged species. Results indicate that characteristic organic ions, some molecular ions, elemental ions as well as some recombination ions are produced by the laser ionization process. The interpretation of the LAMMA spectra of the complex geopolymers is a difficult task at this stage due, in part, to the lack of a sufficient LAMMA spectral data base. A systematic study of the laser-induced spectra of plant biopolymers and geopolymers with various laser energies, sample preparation methods, reproducibility, and so on, is required before attempting fingerprinting. In our evaluation, the commercial system available presents certain limitations, especially in data processing, and further development of this new technique may facilitate routine use.

Chemical structural information may also be obtained with related alternate microprobe techniques. Neutral species produced by laser interaction can be directed to a gas chromatograph for identification. A laser microprobe gas chromatograph system has been built to analyze trapped volatiles and contents of fluid inclusions in a variety of materials. Volatiles are swept into a chromatograph equipped with a helium ionization detector. Laser pyrolysis of bulk organic geopolymers followed by detection with suitable detectors such as flame ionization, alkali flame ionization and so on, is an approach that is currently being pursued.

In addition to the laser techniques, flash thermal pyrolysis techniques on samples also yield structural information. Kerogens, coals, humic substances, separated plant fragments, and so on, have been analyzed by pyrolysis gas chromatography. Information obtained from bulk analysis as well as by microprobe will provide specific knowledge on the origin, conditions of formation, and transformation of coal and related substances.

LASER MICROPROBE CHARACTERIZATION OF VITRINITES FROM THE LOWER BAKERSTOWN COAL BED

by

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The Laser Microprobe Mass Analyzer (LAMMA 1000) is a state-of-the-art microprobe system capable of analyzing mineral and maceral components in coal. All elements and isotopes (including hydrogen) and organic fragments up to m/z 2000 can be detected by this system. Our research group has been "fingerprinting" various minerals and macerals in bituminous coal. We have succeeded in "fingerprinting" iron sulphide (probably pyrite) and different types of vitrinites within the Lower Bakerstown coal of medium volatile bituminous rank.

The spectra for the banded and nonbanded vitrinite show the elements Na, Mg, Al, K, Ca, and Fe. However, the banded vitrinite is characterized by Li, Ti, Sr, Ba, F, $\pm$Cl, and an organic mass peak at m/z 65 amu, probably representing the aromatic ion, $C_5H_5^+$. These latter components are absent or lacking in spectra of the nonbanded vitrinite. These differences in elemental chemistry possibly indicate chemical variations in tissues or other organic components from which the banded and nonbanded vitrinites were derived and/or elements entrapped from fluids mobilized during diagenesis.

COAL-QUALITY ANALYSIS UTILIZING THE NATIONAL COAL RESOURCES DATA SYSTEM (NCRDS)

by

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U.S. Geological Survey

Coal quality, the thermal, physical, and chemical properties of coal, has become an increasingly important issue with changing technology and legislative usage restraints. There are many aspects to this issue today and many more developing with changes in economic and technologic requirements of coal usage. Some of these aspects are: boiler design related to proposed feedstock chemical composition, potential emissions from coal consumption, effectiveness of coal cleaning in reducing chemical components and emissions, beneficial components that can be used to optimize certain coal-utilization processes, and definition of sufficient coal resources that meet specific quality criteria. Both computer techniques and adequate coal-quality data are essential components in responding to the current needs for synthesis and identification of problems and solutions as well as meeting further analytical requirements.

NCRDS provides users with a national data base of documented coal-quality data and the computer-analysis tools to study the data in a variety of ways. The USCHEM data base contains the results of several thousand analyses of coal samples collected according to U.S. Geological Survey standards. The analytical data include: proximate and ultimate values, oxides, and 61 major and minor trace elements. Some of the current capabilities and applications include: trends in coal quality for individual or combined chemical elements within coals, calculation of potential emissions from coal consumption, delineation of coal resources with defined coal quality characteristics. In addition, the system is designed to be flexible and useful in future applications by providing general graphic and tabulation functions. System users can continue to use the system capabilities for their particular analysis or application as technology and constraints change.

IN-SITU ELEMENTAL ANALYSIS OF COAL BY NEUTRON ACTIVATION

by

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U.S. Geological Survey

The U.S. Geological Survey (USGS) has worked to develop neutron techniques for the borehole measurement of the elemental composition of ores since 1969, and first demonstrated a borehole ultimate analysis of coal in 1977. Borehole measurements such as these permit real-time evaluation of coal quality without the expense of coring or the delays associated with laboratory analyses. Two technological innovations make such measurements possible: the availability, from Savannah River Operations Office, DOE, of small californium-252 (^{252}Cf) fission neutron sources, and the development, by USGS and Princeton Gamma-Tech, of the melting-cryogen-cooled high-purity germanium borehole gamma-ray detector. A technique of relating mass fractions to measured gamma-ray intensities, which eliminates the need for detailed knowledge of the geometry of the neutron distribution, is used to calculate elemental compositions without resorting to the test pits or computer borehole modeling. In coal, all of the major constituents (C, H, N, S, Si, Al, Fe, Ti) except oxygen can be determined quantitatively by thermal neutron capture gamma-ray spectroscopy. The newest innovation in this field is the replacement of the ^{252}Cf neutron source with a neutron generator, a type of ion accelerator. These generators, used for many years by the petroleum logging industry, produce neutrons having an energy of 14 MeV. The neutron generator is a safer tool than is californium, as no radiation is emitted by the device until it is turned on, after it has been lowered into the borehole. The coupling of a neutron generator with a high-resolution detector to form a borehole measuring system was pioneered by workers at Sandia National Laboratories. USGS has built and put into service a neutron generator based on the Sandia design, and has a second under construction. This new device enables the experimenter to use higher energy (n,n'), (n,p), (n,2n), and (n,α) reactions as well as the (n,γ) thermal neutron capture reaction. Both the (n,n') and the (n,p) reactions on ^{16}O permit quantitative measurement of oxygen in coal, and the inelastic scattering excitation of carbon provides increases sensitivity over that of the (n,γ) reaction.

THE USE OF THE NATIONAL COAL RESOURCES DATA SYSTEM IN COAL QUALITY STUDIES

by

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The Virginia Division of Mineral Resources, in cooperation with the U.S. Geological Survey and the U.S. Bureau of Mines, has collected and analyzed 849 coal samples from 122 coal beds in the southwestern Virginia coal fields. The analytical data were entered into the National Coal Resources Data System (NCRDS).

The Dorchester coal bed in Wise County was selected to demonstrate the capability of potential users of NCRDS to access this data for coal-quality studies. The analytical information was entered into the USCHEM and USTRAT data bases. PACER was used to extract the data from USCHEM and USTRAT. The data were manipulated with GARNET to produce county maps showing the outcrop of the coal bed and the sample localities. GARNET was also used to create isopach maps of the coal bed and of the overburden and to produce isoline maps illustrating the distribution of the BTU's and a variety of elements, such as sulfur, in the coal bed.

Coal analyses of the Dorchester coal bed were transferred from USCHEM to the local Tektronix 4054 terminal, where they were manipulated by Micro GRASP to produce ternary plots of ash, volatile matter, and fixed carbon. X-y plots were also made to characterize the distribution of sulfur and BTU's in the samples of Dorchester coal.

The isopach maps, isoline maps, ternary plots, and x-y plots are useful both to industry and in geologic research. Use of the NCRDS enables these maps and plots to be produced quickly and easily.

MODERN ANALOGS ILLUSTRATING CONTROLS ON COAL QUALITY

by

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Modern analogs of coal deposits (peat) can provide valuable information on the geologic factors that control coal quality. Modern peat-forming environments may be categorized into topogenous or ombrogenous deposits representing two different chemical/ physical depositional systems. Topogenenous peat deposits are dominated by mesotrophic to eutrophic ground and surface water; thus they are confined to topographic depressions. Thickness of a topogenous peat deposit is limited by the water table resulting in a relatively flat (planar) upper surface. Floral distribution, dependent on water depth, forms random mosaic patterns. Varying vegetal-production and peat-accumulation rates cause shifts in water depth and floral-distribution patterns both laterally and vertically within peat deposits. The quality of planar-peat deposits may be influenced by 1) influx of dissolved load and suspended sediments and 2) significant levels of microbial degradation which can develop in the mildly acid environment. The mineral-matter content of the peat tends to be relatively high and variable.

Ombrogenous peat deposits are dominated by oligotrophic precipitation which maintains a raised water table within the peat, independent of the local water table, resulting in domed-peat deposits that are not necessarily flooded. Peat thickness is dependent on the rate of peat accumulation. The flora show diminishing stature and even complete changes in floral assemblages in concentric zones from the periphery to the center and horizontal stratification from the bottom to the top of a peat dome. Highly acid conditions, net hydrologic flushing, absence of dissolved and detrital influx, and limited microbial activity generally result in a low mineral matter content in ombrogenous peat.

Our studies in the Appalachian Basin suggest that the more variable and higher mineral matter content in coal beds of the upper Middle and Upper Pennsylvanian series is primarily the result of topogenous peat deposition. The coal beds of the Lower and lower Middle Pennsylvanian series are more uniform and lower in mineral-matter content because they were derived form ombrogenous peat.

REDUCING AND PREDICTING SULFUR CONTENT OF MISSOURI COAL THROUGH BENEFICIATION AND GEOLOGIC MODELING

by

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Economic coal seams of northern and western Missouri are in Middle Pennsylvanian rocks of the Western Interior coal basin, and are high volatile A to bituminous C. More than half contain 4 - 5 percent S, one-fourth contain 3 - 4 percent S, and most of the others contain >5 percent S; only a small fraction contain <3 percent S. Missouri coal averages 4.27 percent S: 2.52 percent pyritic, 0.08 percent sulfate, 1.67 percent organic material. Because of increasing concern about SO_2 emissions in burning high-sulfur coals, the Missouri Department of Natural Resources, Division of Geology and Land Survey is sponsoring research on desulfurization through beneficiation, combustion with lime, and geologic modeling.

Missouri coal desulfurization is being evaluated at the University of Missouri-Rolla Mining Engineering Department. Research consists of beneficiation and combustion- zone and flue-gas desulfurization. Beneficiation (such as heavy-media separation, tabling, and floatation) shows that most coals can be cleaned to produce acceptable ash content and that considerable quantities of nonorganic sulfur can be removed. Combustion-zone and flue-gas desulfurization experiments indicate that flue-gas desulfurization is more effective when lime and limestone are used as SO_2 absorbing agents.

A southwest Missouri coal-field evaluation shows that geologic modeling can help predict sulfur content. The thicker portions of Riverton coal were formed in a lake-margin environment. Detrital material, transported along drainages, added clay to the coal. The clay was probably a source of ferrous iron and it also formed a parting which apparently prevented H_2S from escaping the decaying peat. A combination of these factors would be conducive to pyrite formation. The lower coal bench contains twice as much sulfur as the upper; they average 8.96 percent S and 3.25 percent S, respectively. Field relations indicate that the bog at Sylvania was elevated, thereby escaping much detrital influx. A southeastward-prograding delta deposited Warner Formation sediments in erosional scours. The elevated bog escaped inundation by muddy prodelta sediments; instead, it is largely covered by cleaner, fluvial sandstones. The latter are more conducive to peat-bog oxidation, which is unfavorable for pyrite formation. The coal in the elevated Sylvania bog contains the least sulfur, averaging 1.59 percent S.

COMPARISONS OF THE CHEMICAL CHARACTERISTICS OF GULF COAST LIGNITE SAMPLES

by

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U.S. Geological Survey

Proximate and ultimate analyses, calorific values, forms of sulfur, and concentrations of 10 minor and 29 trace elements, have been determined for 116 lignite samples from the lignite beds of the Gulf Coast. The lignite beds sampled range in age from Paleocene to Upper Eocene, are from the Wilcox Group in Texas, Arkansas, Mississippi, and Alabama; the Claiborne Group in Arkansas, Mississippi, and Tennessee; the Jackson Group in Arkansas; and the Midway Group in Alabama.

On a whole-coal basis, elements such as Ga (5-13ppm), Hg (.08-.4ppm), Mo (1.3-2.6ppm), Sc (2.9-6.8ppm), U (1.5-2.8ppm), V (22-48ppm), and Y (8-18ppm) exhibit very little variation among samples over the entire area. In contrast, Co (3-19ppm), Cr (13-73ppm), La (9-52ppm), Mn (39-330ppm), Se (1.6-8ppm), Zn (5-30ppm), and Zr (24-290ppm) show the greatest regional variation among samples.

The lignite samples contain 4 to 5 times the concentrations of B, and 5 to 7 times the concentrations of Mn and Nb, found in Appalachian bituminous coal samples, whereas the levels of other elements are comparable to bituminous coal.

Geometric means for lignite ash (525°C) range from 12.5 percent in the Calvert Bluff Formation of the Wilcox Group in Texas to 38.2 percent in the Claiborne Group in Tennessee. The geometric mean of the ash for all lignite samples is 20.3 percent compared to 10.0 percent for the Appalachian bituminous coal samples.

Geometric means for major and minor oxides in the lignite ash indicate that SiO_2 is highest in the lignite beds from the northern part of the Gulf Coast embayment.

Comparing arithmetic means of proximate with ultimate analyses reveals that moisture, oxygen, and sulfur are highest in the eastern part of the Gulf Coast embayment and volatile matter, fixed carbon, carbon and calorific value are highest in the western part.

THE ASSESSMENT OF MODES OF OCCURRENCE OF TRACE ELEMENTS IN COAL MINERALS USING SIZE AND DENSITY SEPARATION PROCEDURES

by

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The growing concern over the environmental hazards associated with coal utilization has produced a need for a detailed understanding of the occurrence and distribution of trace elements in coal. Previous attempts to determine the distribution of trace elements among coal components have yielded only a partial understanding of this problem. Many elements are difficult to detect because they exist in minor or trace quantities in minerals or are found in minerals that are extremely fine grained, Because of this, it is often difficult to determine the relative concentrations in various components.

A procedure has been developed to determine the association of major and trace elements in the minerals found in coal. Low-temperature-ashed bituminous coal is separated into six size fractions ranging from <0.08 um to >20 um. The four fractions >0.2 um are further subdivided into heavy (specific gravity >2.96) and light (specific gravity <2.96) fractions. These fractions and the unseparated low-temperature ash are analyzed by X-ray diffraction analysis to determine major mineral concentrations. The concentration of trace elements are determined in each of these fractions and the whole coal by instrumental neutron-activation analysis. Mass balance calculations are made to account for the distribution of 28 elements among the various size and density fraction of the low-temperature ash. Elemental concentrations of the various fractions are compared with the mineral concentrations in the fractions determined by X-ray diffraction analysis.

This approach provided both quantitative and qualitative information of the modes of occurrence of the trace elements in coal, the size distributions of the minerals, and concentrations of the major minerals in the coal. In addition, the presence of trace minerals and their effect on the trace-element content of a coal are considered.

A GEOSTATISTICAL APPROACH TO ASSESSING COAL-QUALITY DATA

by

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U.S. Geological Survey

A demonstration of kriging as an estimation technique has been done with a database for a coal bed in the San Juan Basin, New Mexico. The study was made of an area that includes both densely spaced and sparsely distributed data and excludes suspect data near outcrops and channels.

Contour maps of thickness, feet-percent sulfur, and feet-percent ash were prepared from grid values estimated by point kriging. Variance maps, showing relative measures of the accuracy of the contour maps, were constructed from variance values calculated along with the estimates. Coal quantity and quality were estimated by block kriging for a square-mile block within the study area.

Properties that are often estimated for coal are thickness, elevation, and sulfur, ash, moisture, or Btu values. These, like most other geologic variables are spatially autocorrelated, which means values close together are more similar than values at points farther apart. The semi-variogram, the basic tool of geostatistics, is used to model the physical and statistical structure of a spatially correlated variable. The kriging algorithms calculate a set of weights to be assigned to data points used in estimating blocks or grid nodes. Values for the nugget, range, and sill, which quantify the relation between distance between sample values and the variation of the geologic variable, are computed from the theoretical semi-variogram and are used in the calculation of the estimation variance. The advantage of kriging is that it yields unbiased estimates that have minimum error variances; also the estimation variances provide a measure of the reliability of the estimates.

CATHODOLUMINESCENT PROPERTIES OF QUARTZ IN COAL: A METHOD FOR DETERMINING VARIATION IN COAL QUALITY

by

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U.S. Geological Survey

Cathodoluminescent (CL) properties of quartz grains in the Upper Freeport coal bed were measured to determine their origin. CL (the emission of visible light during electron bombardment) is useful in genetic studies of minerals; quartz, in particular, has definitive luminescent characteristics that are apparently related to the temperature of crystallization. Analyses of quartz grains taken from representative samples of the Upper Freeport coal bed show that 77 percent of the quartz are nonluminescent and therefore are inferred to be authigenic in origin. In contrast, the remaining 23 percent are luminescent and are inferred to be detrital in origin. These CL data are in agreement with other data from low-temperature ash, maceral, and major, minor, and trace-element analyses that suggest a plant-derived origin for most mineral matter, exclusive of calcite and pyrite, in the Upper Freeport coal bed.

The luminescent properties of quartz in a coal bed can give information that may be directly related to the variation in coal quality. Plant-derived mineral matter predominates in interior portions of the paleoswamp of the Upper Freeport coal bed where sediment influx was limited. The percentage of luminescent or detrital quartz is expected to increase because of the increased sediment supply along the margins of the paleoswamp and approaching contemporaneous stream channels that cut through the peat body.

MAGNETIC PROPERTIES OF COAL

by

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U.S. Geological Survey

A study has been made of the magnetic susceptibility of coal and coal constituents. As the ferromagnetic component of the bulk magnetic susceptibility of coal is small, the measured susceptibility is made up of diamagnetic and paramagnetic components. The diamagnetism resides in the organic part of the coal whereas the paramagnetism originated (1) in the mineral inclusions and (2) in the unpaired electron spins in the organic structure. The fundamental information acquired in this study has been used to investigate several practical problems.

Coal Grinding. It has been found that when coal is ground in a steel grinder, the pulverized coal is contaminated with abrasion particles from the grinder. Because coal is a soft material, these particles are extremely small (< 30 um) and we have shown them to be superparamagnetic. In pulverized coal, these particles tend to agglomerate and the clusters so formed take on ferromagnetic properties.

The concepts learned in this study can be directly applied to coal cleaning. One of the methods of industrial coal cleaning is density separation using a slurry of finely powdered magnetite as the heavy liquid. There are two problems with this method: (1) there is a significant loss of magnetite, which is expensive, and (2) the magnetite trapped in the coal adds to the ash. The larger magnetite particles can be recovered magnetically because magnetite is ferromagnetic. However, the very fine particles lose their ferromagnetism and become superparamagnetic. Proper processing of the magnetite to eliminate the supermagnetism can reduce the losses substantially.

Magnetic Separation of Pyrite. Pyrite is a very weakly magnetic mineral, and cannot be practically separated using conventional low-field magnetic separation. By heating coal in a vacuum or an inert atmosphere to about 350°C the pyrite can be converted to pyrrhotite, a slightly magnetic mineral. By using a relatively expensive high-gradient magnetic-separation (HGMS) method, the pyrrhotite content, and hence the sulfur concentration, can be reduced. The USGS is currently experimenting with an alternative method. The coal is heated to about 400°C in an inert gas containing a carefully measured trace of oxygen. Under these conditions, the pyrite grains are coated with a thin layer of magnetite, a strongly magnetic mineral. By this technique, 60-80 percent of the pyrite can be removed using ordinary low-field magnetic separators.

By standardizing the heating and anoxic gas flow, the change in magnetization can be used to measure the pyrite concentration in the coal.

The chemical reactions and mechanism of formation of magnetite from pyrite under these conditions is not yet completely clear. Further work is being done to more fully understand the reactions and reaction rates.

HIGH-TECHNOLOGY FUEL

by

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High-technology fuel has been defined as coal or other organic solid fuel from which the inorganic ash-producing phases have been nearly completely removed. Because much of the mineral inclusion in coal is extremely finely divided and disseminated throughout the coal material, the production of high-technology fuel generally involves complete solution of coal, removal of the insoluble mineral matter, and reconstitution of the organic matter. The organic source materials should be low-grade or high-ash coals that are unsuitable for fuel application, and are relatively inexpensive to obtain. An alternative to natural organic sources might be the ever-increasing amount of human and industrial waste, such as sewage sludge.

Coal as a Source Material. Coal is insoluble in aqueous solutions primarily because of its aromatic nature. If the aromatic rings are opened, a large fraction of the coal becomes soluble. Certain elements, because of their electronegative properties, are strongly electrophilic and can open aromatic rings. Experiments with the electronegative elements tellurium and gold have opened the aromatic rings and caused the coal to go into solution. Once in solution, the insoluble fraction containing many of the ash-forming components is removed by filtration. The organic fraction in solution is reconstituted into a solid by polymerization. NMR measurements indicate that the polymer is highly condensed and in this respect resembles anthracite. The chemical reactions leading to the polymers are very complex and further work needs to be done before a full-scale application can be proposed. Laboratory experiments utilizing benzene as a simple starting material are currently being performed in an effort to understand the process.

Sewage Sludge as a Source Material. Sewage sludge is becoming a valuable national resource. Approximately 40 percent of most sludge is organic material. Concentrated sulfuric acid attacks the aliphatic compounds in the organic fraction of the sludge and renders them soluble in acid. The insoluble matter containing the aromatic compounds is treated similarly to the coal discussed above, so that it becomes soluble in acid. After filtration, the solutions containing the converted aliphatic and aromatic compounds are polymerized using separate techniques to reconstitute the organic materials into a solid coal-like material. The heat content of this material is variable; however, a product with a heating value as high as 6000 BTU/lb (1.396×10^4 kJ/kg) has been obtained.

This work is still in a development stage, but the results look very promising for using coal and sewage sludge as fuels and hydrocarbon sources for the chemical industry.

COMPUTER MAPPING OF QUALITY DATA FOR COALS IN WEST VIRGINIA--AN AID IN MATCHING A SPECIFIC COAL GRADE TO A SPECIFIC END USE

by

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In 1907, the first studies of the State's coal reserves were initiated as part of the West Virginia Geological and Economic Survey's Statewide geological mapping program. Since then, extensive work has been conducted to map and characterize the State's 62 minable seams. This effort has shown that the coals have a wide diversity of quality, and this diversity provides the coal-user with a choice of grades to meet specifications for varied applications. Approximately 6,000 coal samples have been analyzed, and a computer data base of coal-quality information is now maintained and continues to grow. An extensive coal-quality mapping project makes this information convenient to use.

The objective of coal-quality mapping is to produce a series of contour maps showing the variations in coal quality for the most important seams. Parameters being mapped include sulfur, ash, Btu, fuel ratio, Hardgrove grindability, volatile matter, fixed carbon, and kilocalories per kilogram. This type of information is extremely valuable for someone interested in buying, selling, evaluating, or developing West Virginia coal.

The maps are computer-generated at a scale of 1:500,000 and show the trends of coal-quality parameters for individual seams. The maps are supplemented by a computer program which searches the database and generates a printout of geographical areas within the State where coal has been sampled that meets the desired specifications. These computer techniques go a long way in helping the user find target areas within the State to match the right coal to the desired end use.

PHYSICAL AND CHEMICAL VARIABLES RELATED TO COAL WASHABILITY: UPPER FREEPORT COAL BED FACIES

by

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Stratigraphic analyses of a coal bed (chemical, physical and descriptive analyses by facies) show that variability in quality and washability characteristics is related to variation in coal-bed facies. The washability characteristics of a coal bed can be inferred from the stratigraphic analysis of the bed. In addition, certain petrographic, physical, and chemical values of coal-bed facies can be related to washability characteristics such as weight percent recovery and pounds of sulfur/million Btu's recovery at a particular specific gravity of separation.

The most significant variables measured on the head (unprocessed) sample that can be used to estimate the weight percent of coal recovered from size-gravity separation of coal include sample density, inertodetrinite content, certain trace-element contents such as lanthanum, niobium, cesium, and selenium, and illite content. The best estimates for sulfur recovery for Upper Freeport coal-bed samples can be calculated from petrographic characterization of pyrite form and association, weight percent pyrite, and density.

Sulfur variability, within a profile of the Upper Freeport coal bed, is commonly greatest in the uppermost facies and results from differences in the forms of pyrite. Specifically, pyrite that replaced organic matter is more highly variable than other forms. This variability is probably the result of the origin of the pyrite, which may be related to the lithology of the roof rock, in particular sandstone. This variability of minerals other than pyrite and calcite is related primarily to detrital surges which are superimposed on predominant amounts of authigenic minerals that originated from plant degradation.

QUALITY AND EXTENT OF FACIES WITHIN THE UPPER FREEPORT COAL BED: WEST-CENTRAL PENNSYLVANIA

by

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Coal-bed facies within the Upper Freeport coal bed were identified and correlated using core and mine face descriptions. In addition, relative coal quality was determined by comparing x-ray radiographs and in-mine visual descriptions. The facies are relatively uniform in thickness and less variable in quality than the whole bed because the whole bed is not composed of the same number of facies throughout the deposit. Mapping of facies can be used in conjunction with chemical and petrographic data to areally delimit the shape and quality variability of the bed and to infer geologic factors that control coal-bed quality. Recognition of 10 or more Upper Freeport coal bed facies is based on visual descriptions of the bed underground and descriptions obtained from x-ray radiographs of core. These facies are interpreted to have resulted from three different stages of peat formation: (1) topogenous, low-lying, widespread peat formation, which included deposition of detrital sediments and formation of attritial-rich banded coal-bed facies; (2) sediment-starved peat formation which resulted in vitrain-rich banded coal-bed facies; and (3) peat-island formation which resulted in facies of cannel/splint and banded coal. Isopleth maps indicate trends in concentrations of ash and sulfur data in the first stage (lowest coal-bed facies) which contrast with the more random distribution of ash and roof-related variability of sulfur in the second stage (the middle coal-bed facies). Additional points of control are required to construct isopleths of ash and sulfur data of stage three.

Correlation of coal-bed facies provides coal-quality data which is more reliable in the assessment of quality than comparison of whole-bed analyses and should become useful in mine planning. In addition, the stratigraphic data (facies characteristics, quality, and extent) of a bed can aid in mining and preparation evaluation and can be used to interpret the conditions of paleo-peat formation and the shape and composition of the paleo-peat body.

CHEMICAL AND PETROLOGIC CHARACTERISTICS OF DEEP-SUBSURFACE WILCOX LIGNITES (EOCENE) FROM EAST AND EAST-CENTRAL TEXAS

by

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Seven cores from the deep-subsurface Wilcox Group in East and east-central Texas provided samples from 18 lignite seams representing five stratigraphic intervals. The seams occur at major facies transitions at depths ranging from 240 to 1,040 ft (70 to 315 m). Complete chemical and petrographic analyses of the lignites provide new data for comparison with near-surface seams.

On a moisture-free basis, the deep East Texas seams are low in ash and high in calorific value (11.4 percent and 11,300 Btu/lb, respectively) compared to near-surface seams (23 percent ash and 9,550 Btu/lb). In east-central Texas, deep seams average 18.7 percent ash and 10,185 Btu/lb on a moisture-free basis, whereas near-surface seams average 21 percent ash and 9,722 Btu/lb. Most of the deep-basin samples from both areas are borderline subbituminous, estimating rank from dry, ash-free carbon values.

The average Na_2O content of ash from the deep East Texas seams is more than 6 percent; in east-central Texas it is only 1.3 percent. Na_2O content is highest in the deepest seams in both areas and is related to sodium content in the ground water. In both areas, deep-basin lignite ash contains greater percentages of SO_3 and Na_2O than near-surface lignites

Whole-coal trace-element concentrations are widely variable. Average uranium content falls below, and selenium and arsenic concentrations equal or exceed, average values for these elements in other U.S. lignites.

Petrologic examination of the deep-basin seams reveal limited well-preserved plant material. Many huminities have undergone partial or complete gelification. Liptinite content is high and can exceed 30 percent; higher liptinite correlates with lower inertinite. Comparison between petrographic and chemical data shows that seams with larger percentages of liptinite have higher hydrogen contents and calorific values.

Current characterization work is focused on near-surface Jackson Group (Eocene) lignites to complement the existing data on Wilcox coals.

COAL RESERVE CHARACTERIZATION FOR EMISSION CONTROL

by

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The objective of the Coal Reserve Characterization (CRC) Study is to develop models to optimize mine planning and operation, coal preparation and utilization while complying with performance standards for specific flue gas emissions. The CRC Study is being conducted at Homer City Generating Station, located in Indiana County, Pennsylvania, and owned by Pennsylvania Electric Company and New York State Electric and Gas Corporation.

The presentation shows the interrelationship of techniques for coal-reserve characterization, mine planning, coal preparation and ultimately prediction and control of as-burned coal quality without Homer City owners sacrificing either economic or environmental concerns.

The result is a series of computerized geologic and engineering models that will enable the user to model a reserve, predict in-seam and ROM quality, project the effect of feed blending to a coal-cleaning plant, and the subsequent emission level from clean-coal utilization.

SULFUR CONTENT OF COAL IN THE APPALACHIAN AND ILLINOIS BASINS

by

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The U.S. Geological Survey has submitted samples of coal from beds in 11 States for chemical analysis to the Coal Analysis Section, Department of Energy (formerly of the U.S. Bureau of Mines). The amounts of the total sulfur, organic sulfur, and pyritic sulfur are shown on a series of panels. The first panel shows the location and number of coal samples by State and County. The coal analyses are presented on a second panel as arithmetic mean values for ash, Btu-content, total sulfur, and for the three forms of sulfur, by State. Additional panels show computer-generated trend maps of the distribution of the total sulfur, pyritic and organic sulfur.

The amount of sulfur that potentially can be recovered from coal is estimated using the published State coal-resource data and the mean sulfur concentrations. The area that has the greatest potential for recovery of sulfur is Ohio. The total sulfur content is 3.51 percent, the highest of the 11 States sampled; most of that is pyritic sulfur, 2.09 percent, which is easier to remove from the coal because organic sulfur is locked in coal constituents (molecular). The second- and third-ranked potential sulfur-from-coal resource areas are western Kentucky and Alabama where the coals contain 1.75 and 1.74 percent pyritic sulfur, respectively.

THE PREMIUM COAL SAMPLE PROGRAM

by

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The Premium Coal Sample Program at Argonne National Laboratory will provide the coal-science research community with long-term supplies of a small number of premium coal samples that can be used as standards of comparison. These samples will be as chemically and physically identical as possible, have well-characterized chemical and physical properties, and will be stable over long periods of time. Coals will be selected, collected, transported, and processed into the desired particle and sample sizes, and sealed in environments as free of oxygen as possible. The samples will be checked for homogeneity, characterized in an extensive interlaboratory program, and then periodically monitored for stability. Samples will be distributed to researchers after the samples are characterized.

STABLE-ISOTOPE AND INCLUSION-FLUID COMPOSITION SHADES OF EPIGENETIC PYRITE AND SPHALERITE FROM ILLINOIS BASIN COALS

by

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Kaolinite-pyrite-sphalerite-calcite mineralization occurs in cleats and clay dikes of mid-Pennsylvanian coals in Illinois. σD and $\sigma^{18}O$ values of inclusion fluids in this pyrite range from -137 to -61 and -12.3 to -5.2, respectively. These compositions are D- and ^{18}O-depleted with respect to any depositional or diagenetic fluid previously known to have existed in these rocks. If, as we believe, these fluids reflect coal-pore water at the time of pyrite formation, then such waters must have exchanged with or been generated from organic compounds in the coal. Gases in pyrite-hosted inclusions contain CO_2, CO, or N_2, Ar, H_2S, SO_2, abundant hydrocarbons (CH_4, C_2H_2, C_2H_6, C_3H_8, C_4H_{10}, and so on), and exhibit alkene:alkane ratios >1. The predominance of alkenes probably reflects the differing solubilities of saturated and unsaturated hydrocarbons in aqueous fluids.

$\sigma^{34}S$ values of pyrite concretions, nodules, bedding-plane concentrations, and cleat fillings from Nos. 2, 5, and 6 coals in Illinois range from -12.4 to -0.1; within individual mines the range is much smaller, often <4. Pyrite $\sigma^{34}S$ values do not reflect the different pyrite morphologies. Bacterial sulfate reduction is the widely accepted source of pyritic A in high-S coals. However, the comparatively small range of $\sigma^{34}S$ values observed contrasts with the large ranges characteristic of bacterial activity. High-S peat and lignite may contain 10 percent or more total S, of which 1-2 percent is pyrite. High-S coals of Illinois also may contain 10 percent or more total S, but with more than half contained in pyrite. We propose that this increase in the proportion of pyritic S in sub-bituminous-(and higher ?) rank coal reflects the formation of coarse pyrite in epigenetic settings (cleat, and so on), from S released during the post-lignite-rank breakdown of S-bearing organic compounds. The isotopic and gas compositions of the fluids, and sulfide $\sigma^{34}S$ values, suggest that coal-pore fluid chemistry was controlled, at times, by coal devolatilization.

Sphalerite in the coals was deposited at 90-100°C from brines chemically similar to those that formed the Upper Mississippi Valley Zn-Pb district. However, σD and $\sigma^{18}O$ data from the sphalerite inclusion fluids trend toward the isotopic composition of pyrite inclusion fluids, which suggests mixing between the coal-pore water and the Zn-transporting brines. $\sigma^{34}S$ values of sphalerite are close to those of associated pyrite. This suggests that sphalerite also precipitated from S derived from organics, or that sphalerite inherited S by replacing pyrite. Gases trapped in sphalerite-hosted fluid inclusions are less hydrocarbon enriched than those of pyrite-hosted inclusions.

COMPARATIVE GEOCHEMISTRY OF TWO COAL BEDS FROM CONTRASTING DEPOSITIONAL ENVIRONMENTS OF LATE CRETACEOUS AGE IN THE WESTERN PART OF THE WIND RIVER BASIN, WYOMING

by

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Coal-bearing rocks in the Wind River Basin record a transition from marine deltaic (paralic) to non-marine intermontane (limnic) depositional environments. The coal-bed geochemistry indicated changes in source and nature of sedimentation during this evolutionary period. Samples from two thick coal beds, the Signor in the Mesaverde Formation and the Welton in the Meeteetse Formation, exhibit significant differences in the quality of coal from contrasting environments.

Preceding and during deposition of the Mesaverde Formation, peat accumulation coincided with extensive marine regressive cycles. These peat deposits accumulated in coastal swamps that overlay former seaward-prograding linear-shoreline and lobate-deltaic sand bodies. The Signor coal bed, which formed in this environment, was influenced by post-depositional marine and brackish-water incursions. Proximity to the sea is indicated by the high content of sulfur, boron, phosphorous, and other marine-related elements.

Extensive air fall of volcanic ash accompanied sedimentation throughout Late Cretaceous time and was a significant component of the Meeteetse Formation. During deposition of the Meeteetse Formation, emergence to the north and subsidence to the east, coupled with tectonically active source areas to the west transformed this area into an intermontane basin. The Welton coal bed formed in this setting and was subject to the influx of volcaniclastic terrigenous sediment. Silicon, rare earth, and chalcophile-related elements are concentrated in the ash residue of the Welton coal bed and are indicative of the restrictive terrestrial conditions. Subsequent episodes of intensified tectonic deformation in the area of the Wind River Basin gradually shifted the depocenter eastward into the Power River Basin where enormous deposits of peat accumulated. The geochemical signatures of coal beds in this region corroborate this change in patterns of deposition that began to the west in the Green River Basin during evolution of the Frontier Formation and ended to the east with basin filling during the Eocene Period.

PART IV: SUPPLEMENTARY PAPERS

SOME THOUGHTS ON FUTURE NEEDS FOR THE CHARACTERIZATION OF COAL RESOURCES

by

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Changes in the manner in which and extent to which our coal resources are characterized must conform to the constraints which will be imposed upon the coal-mining and utilizing industries within the next decades. Failure to do so will result in industry being unprepared to provide the assurances that mine safety and health and environmental standards would be met. Major constraints will be limits on emission of sulfur oxides and possibly of toxic volatile elements from coal-burning plants, the risk of curtailment or abandonment of operations which endanger the health or safety of personnel, and the threat of closure of mining operations which detrimentally affect the quality of surface or ground waters.

Some of the special requirements and opportunities will be considered in this talk, from energy policy formulation through resource assessment and mining to major end uses.

Energy Policy

The time may come when indigenous oil and gas resources, because of their limited availability, will be earmarked for certain priority uses such as transportation, fertilizers and other chemicals. Coal and nuclear energy might have to satisfy the lion's share of utility and industrial demand. Coal, however, is likely to have to meet exacting specifications for a diverse market that will be both pollution-shy and able to pick and choose from a wealth of potential suppliers, foreign as well as domestic.

The formulation of a comprehensive energy policy involving coal could depend upon the availability of tried and true predictive methods which can be used on in situ data to gaze into the future of, for example, mine safety, potential for acid mine-water production, preparatory-plant behavior, sulfur, and trace-element emissions from utilities, the type of slagging, operating and fouling potential in utilities, and suitability as a blend component in metallurgical coking or as a feedstock for conversion.

The kinds of national resource data presently reported may be insufficient for future policy purposes. Previously, resources were characterized by quantity, depth, thickness, sulfur, rank, and a few other physical characteristics. However, the current National Coal Resource Data System (NCRDS) could be the means of storing and providing the variety of other data which may be needed, including information on the enclosing strata. So, for example, instead of just resource quantities, we could include qualifications such as "highly faulted" or "potentially dangerous roof conditions" or "coal capable of meeting the specifications for utility plants A, B, and so on, if cleaned at specific gravity X in prep plants C, D, and so on." Such an approach might render the current distinction between resources and reserves redundant.

Exploration

Coal is a bulk commodity of relatively low value. So, an ability to estimate quantities of a reserve to the nearest several hundred tons may not be critically important to the feasibility of opening a large mine. One might therefore question whether the greater precision of complicated geostatistics is always a worthwhile effort. However, geostatistics could be a valuable aid in treating those coal qualities which are highly variable, especially where these variables are important considerations for the end use. Sulfur in eastern coals and sodium in western coals are two good examples.

In evaluating coal, we often have been concerned with the accuracy of analyses, but precision often is ignored. What is needed is the proper usage of appropriate statistical methods. The danger is that our understanding of statistics frequently is inadequate. For example, factor analyses have been used to produce factors from coal data on the assumption of linear interrelationships among properties, although coal is notorious for its curvilinear relationships. Also, several geostatistical methods require that data points be random, our coal data points rarely are. In fact, for practical exploration purposes, it is preferable that data points are not random.

Another aspect of precision relates to our selection of samples for large-scale testing. We are all aware of reports of testing performed on, for example, "Illinois No. 6," "Wyodak" coal or "Pittsburgh No. 8." One gets the impression that almost any old coal would do; such a seam designation pays only token lip service to the idea that one coal might behave differently from another. Another aspect of the same problem is that coal for testing from bore cores has cost as much as $40,000/ton. In all these cases it should be essential to know what the samples represent. When the testing itself is so expensive and the implications of that testing are financially staggering, then the effort must be expended to ensure that the sample represents an average composition, a best case or worst case, or that it provides an indication of the expected range of results.

A statistical approach might provide some interesting alternatives to the present means of classifying reserves into measured, indicated and inferred categories based on circular areas of influence around data points. For example, probability distribution curves plot probability against quantity of reserves. They enable categories of reserves to be established; for example, "proved" (say greater than 95 percent probability), "probable," and "possible." The shapes of the curves reflect the reliability of estimates.

Special consideration needs to be given to the estimation of reserves of anthracite in silt dams and culm banks. Here, the variability is different in kind and magnitude from that of *in situ* coals.

The application of geophysical methods for estimating quality data is established, although the use of standards and calibration tests apparently is not uniform. Possibly some minimum requirement for the number of logging techniques needed to establish individual coal parameters might be expected, as might the number of calibration holes run and the length of intervals of coal core analyzed in such calibration tests. The effectiveness of these techniques, of geophysical prediction should be detailed following the actual mining of several prospects.

Coal Mining

In situ analysis of coal and geophysical interpretations of roof and floor rocks will be used to predict mining conditions and mine production not only for current mining methods, but possibly also for future methods. Models have been developed to predict roof and floor problems and for reconnaissance of possible gas and rock blowouts ahead of mining. In the future, explorationists may have to examine the feasibility of large-scale open-pit mining for anthracite, hydraulic mining, and of telechiric mining. In the last, both automation and remote handling could be used to avoid the need for mine ventilation, roof support, accidents and health hazards. Input for modeling this type of mining could include not only depth, thickness and simple structure, but also seam continuity, cleat measurements, strength and friability. Models to predict the formation of acid mine waters could include sulfur levels and forms in the coals and associated strata, pyrite size distributions and estimates of available carbonate to buffer the acidity. Many of these parameters might even be interpreted from down-hole logging techniques.

Power Generation

Better methods of estimating and making uniform the moisture contents of as-fired coal are likely to be sought. This particular property could be critical in the case of low-rank coals.

Improved methods of predicting slagging and fouling properties of coals are being sought. It is revealing that the predictions seem to improve as the level of sophistication of the analyses goes up. So, although acid/base ratios are essential as a first step, a clearer picture can emerge if one also has information on the oxidation/reduction state of the iron, on whether or not the alkalies are water soluble or ion exchangeable, and on the distribution of inorganic matter through the coal particles. Possibly, still better interrelationships could be obtained if mineralogical analyses were used to relate to fusion and slagging behavior. Consequently, for this and many other investigations, it would be useful to have improved methods for obtaining mineralogical analyses of coals. Can this be done? At least more standards for X-ray identification of coal minerals should be made available.

Concern about inefficient combustion resulting in high levels of unburnt carbon in the fly ash is one reason why the petrographic composition of coals should not be ruled out as a useful quality parameter for coal combustion. Although a petrographic analysis may not be a required analysis in the same way that it is necessary for characterizing metallurgical coal, knowing the reflectance, maceral composition and level of oxidation have helped to identify the source of problems in problem coals.

Pertinent data for the production of coal/water fuels would include those related to the stability of the suspension. These could include such properties related to hydrophobicity as maceral composition, rank index, mineralogy, mineral levels, and oxidation levels.

Some Other Special Directions for Coal Science

There appear to be some special needs in the following areas:

- Investigations of the detailed crystal chemistry of coal pyrite and marcasite and of the organic structures in which sulfur occurs.

- Programs to characterize the size distribution of iron sulfide forms in in situ coals in order to predict the liberation of pyrite in improved cleaning processes.

- Studies of the provincialism of coal properties. Coals of different basins formed from different starting materials in different environmental settings, and underwent different thermal and burial histories with high and low heating rates for long and short times. The differences in the relationship between properties, although only recognized in recent years, are not necessarily subtle; for example, the anomalous porosity, reflectance, and coking characteristics of Illinois coals. Provincialism is not just a topic for scientific investigation; there could be important implications for utilization.

PROBLEMS WITH ESTIMATING COAL-QUALITY CHARACTERISTICS OF TONNAGE RESERVES

by

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Estimating coal-quality characteristics of tonnage reserves is a complex and difficult problem. It is one, however, of substantial importance in evaluation of coal lands and establishment of public policy dealing with resource utilization. In order to make such estimates, two basic approaches appear necessary. The first is establishment of an organized bank of extant data that is generally and rapidly accessible. Such an approach should lead to evaluation of the existing data base and recommendations for upgrading. The second approach amounts to a re-examination of concepts and procedures now used in estimation of coal quality and essentially is a series of research problems directed to rationalization of quality measurements. It is to this second approach that this paper is directed.

Parameter Specification

The first step, either for organization of extant data or re-examination of basic concepts, is definition of parameters that make up "coal quality." The difficulty here arises from the fact that coal is a commodity and that many of the well-established parameters have arisen more or less ad hoc to meet a specific need at a specific time. As a result, the number of parameters, for instance, ash fusion, grindability, sulfur forms, maceral composition, etc., continues to grow, and can be expected to increase as coal utilization becomes more sophisticated due to operational or environmental constraints. Although each quality parameter will doubtless be needed, the question arises whether coal characterization is not in the same position as the study of minerals prior to the discovery of atomic structure. Most geologists have memories of qualities of "hardness," specific gravity, color, crystal form, and refractive index of mineral species which can now be related to the basic properties of atomic structure. Mineral identification today proceeds using both basic and derivative criteria, but the relationships between them are, for the most part, known and understood. The question then is: "What are the basic properties of coal that are analogous to atomic structure in minerals and which will explain other derivative properties?" Resolution of this question should lead to a better understanding, if not a simplification, of existing quality parameters.

Sampling Units

Once specific quality parameters--basic or derived--can be decided upon, the next question is definition of the object or sampling unit upon which measurements or observations are to be made. Measurements such as the height of men, weight of pigs, or wheelbase of automobiles are relatively straightforward as the sampling unit is obvious. With coal (or wheat or sand), however, the problem is more difficult and the definition is more or less operational. In the case of much "in place" coal, the sampling unit is a column of varying width or diameter from the top to the bottom of the seam, obtained by coring or direct removal. Measurements of properties from columns averaged across the areal extent of the seam represent the characteristics of the entire body. Samples from belts, cleaning plants, railroad cars and stockpiles are defined by a volume increment which presumably represents a volume of coal from the "in place" seam. As these systems are designed, there should be a predictive link from "in place" to delivered product, and past experience shows that this is often the case. There are examples, however, of rejected carloads or barges that indicate that the system does not always work. However, it is generally not known whether this failure is one of procedural error or a failure of the system to accurately represent the quality of the coal body.

Precision of Estimates

Once the parameter and sampling units have been defined, methods for attaching statements of precision of estimates have been well established by both sampling theory and practice. In general, the level of precision of the estimate is inverse to the variation found among the samples and proportional to the number of samples. If variation is great, the level of precision is low; if the number is large, precision is increased. If the level of precision is stated in advance, then the number of samples required to attain this given level of precision is dependent upon variation of the parameter found in sampling units; large variation requires a greater number of samples than small variation. Practical application of this relationship is found in volume increment samples of loose, broken coal on belts and stockpiles (ASTM D-2234-82 1984). In such cases, the size of the increment is dependent on the size of the coal particles relative to the total volume of the sample. If too few particles are included, they will bias the results toward their particular qualities. Clearly, the sampling system anticipates variation between coal particles, and in loose increment type samples efforts are being made to include particles that have varying properties in proportion to their occurrence in the sampled material. The point is that variation is expected between coal particles, but because there is no known physical relationship between pieces on a stockpile or belt, the only alternative is to assure that variation among particles is proportionally included in the sample.

Coal columns from either cores or channels cut into the seam can be considered in different ways depending on the treatment of the sample. If the entire column is treated as a single sample, it does not differ in substance from a belt or stockpile sample in that all variation in the seam is aggregated into a single sample in proportion to its occurrence in the seam. Such a procedure, however, does not identify and locate specific parts of the seam that may have desirable or undesirable characteristics which are amenable to isolation during preparation. In addition, such procedures ignore the advantages of stratified sampling, which minimizes sample variance by selection of subsamples which are characterized by variance that is smaller than for the entire sample. In the case of a coal column, utilization of this method requires identification of strata suspected of having minimum variance before the subsample is taken.

This form of subsampling is attempted in some cases by sampling individual coal benches which upon analysis have shown substantial differences. Some recent experiments, however (Esterle, 1984; Miller, 1984), have shown that there is almost as much variation in ash, sulfur, and maceral content within benches as there is between them. This suggests that there is a major sampling problem in which it is known that variance can be partitioned, but that there is no clear physical procedure for identification of relatively homogenous strata in advance of subsampling. Moreover, it is not known at what practical level subsampling with minimum variance occurs. Some experiments by Stanton and others (1983) suggest that radiography may assist in identification of subsampling units, and the previously cited studies of Esterle and Miller suggest that subsampling based on purely megascopic criteria may be useful. But the number of such studies is small, and it is obvious that much experimental work will be required if efficient descriptive and subsampling procedures are to be devised.

Quality Per Ton

Definitions and procedures of sampling quality parameters represent one set of problems. Projection of quality parameters onto estimated tonnages categorized by seam thickness, depth of burial, and structural attitude combine problems of quality estimates with those of reserve (resource) estimates. Estimates of tons are products of area and thickness, and as currently practiced, require knowledge of seam continuity and rate of thickness variation. As indicated elsewhere, there are no standard procedures for expressing a degree of confidence in either of these estimates and substantial effort will be required to bring these areas under control (Tewalt and others, 1983; Ferm, 1983). One of the more hopeful aspects of this problem is represented in the results of some recent studies by Cecil and others (1981), Esterle (1984), and J.R. Staub (personal communication, 1985). These studies suggest that quality parameters of ash, sulfur, and maceral content are associated to some degree with variation in thickness and partings of some coal seams. Should such relationships be firmly established, they could greatly simplify estimation of quantity per quality. It is also clear that investigations of this type are still small in number, the results preliminary, and substantial effort will be necessary to bring this information to the application stage.

Summary

It is certain that estimates of quality parameters of coal reserves will require substantial efforts in standardizing existing testing methods for known quality properties and establishment of workable and efficient data bases for absorbing extant information about them. It is also obvious that substantial effort will be required in the area of research. One of these areas is concerned with the establishment of basic coal parameters to which other operationally defined properties can be related. Such a system would permit not only clear conceptual notion of coal quality but would also enhance the large body of extant quality data. Another area is the development of a system of description of raw, in-place coal that will allow for more efficient sampling in advance of analysis. Finally, considerable effort should be devoted to establishment of relationships of morphologic properties of minable coal bodies--thickness, area and character of adjacent strata--to quality parameters. Controlled experiments and hypothesis testing of relationships between coal-body morphology and quality properties should ultimately lead to rational estimates of quality attributes of coal reserves or resources.

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EFFECTS OF COAL QUALITY ON PRODUCTION COST-- A UTILITY'S PERSPECTIVE

by

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The philosophy or procedure a utility uses in the procurement of fuel is influenced by many factors. To understand these, you must understand the utility itself and its environment.

The New York State Electric and Gas Corporation (NYSEG) is an investor-owned utility located in central New York State. Our service area covers 34 percent of the State. NYSEG operates six steam-generating plants in New York State and co-owns with the Pennsylvania Electric Corporation (PENELEC), Homer City Station, which PENELEC operates. Our total capacity is 2,400 megawatts, 98 percent of which is coal fired. If we exclude Homer City Station, NYSEG's coal burn is 3.2 million tons/year. It is important to note that although 98 percent of NYSEG's generation is coal fired, 56 percent of the installed generating capacity in New York State is oil fired. Our generating station production cost is the lowest in the State with any surplus generation marketable to our neighboring utilities.

Because of NYSEG's location in the State, our generating stations are very close to the outer edges of the northern Pennsylvania coal fields. This coal, however, tends to be of lower quality and can cause an assortment of operating problems at the generating stations. This situation has posed an interesting problem to our management through the years. Do you purchase this lower quality fuel at a favorable purchase price, or do you go deeper into Pennsylvania or West Virginia for the higher quality, generally higher cost coals? Items which influence this decision are the F.O.B. mine costs, freight rates, generating-station design, handling and maintenance costs, ash-disposal costs, environmental limitations and replacement power costs.

To understand the total cost of operation of a generating unit based on the cost and quality of a fuel, NYSEG developed a computer model of each unit to simulate the burning of coal in the unit and to predict its production cost. Figure 1 illustrates the parameters modeled in the program and the influence each has on the resulting electric production cost. The boxes highlighted on

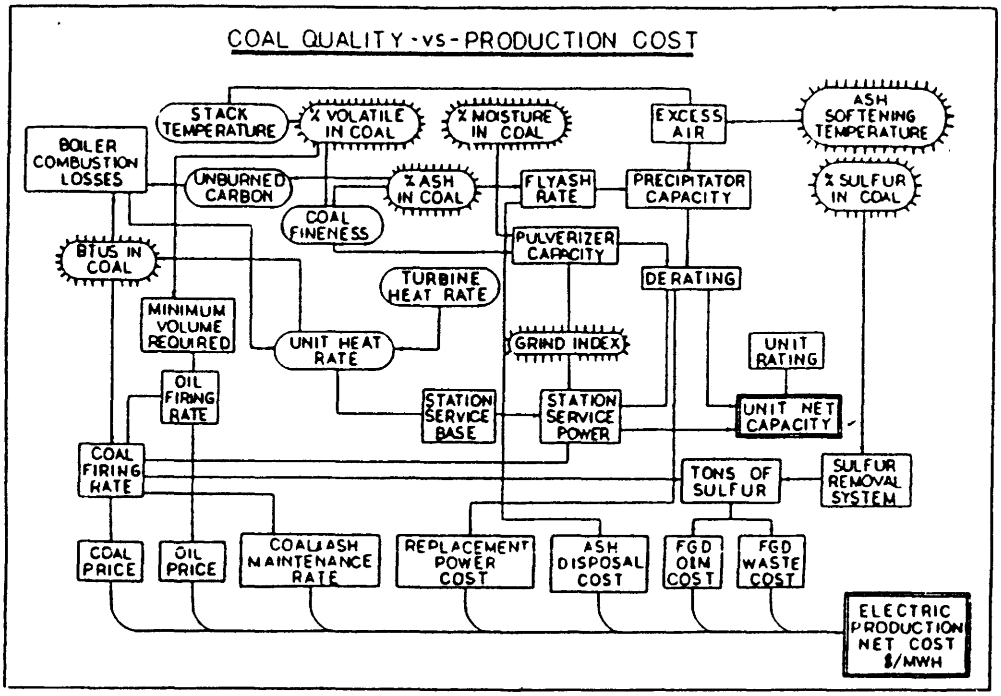

Figure 1. Coal quality versus production cost.

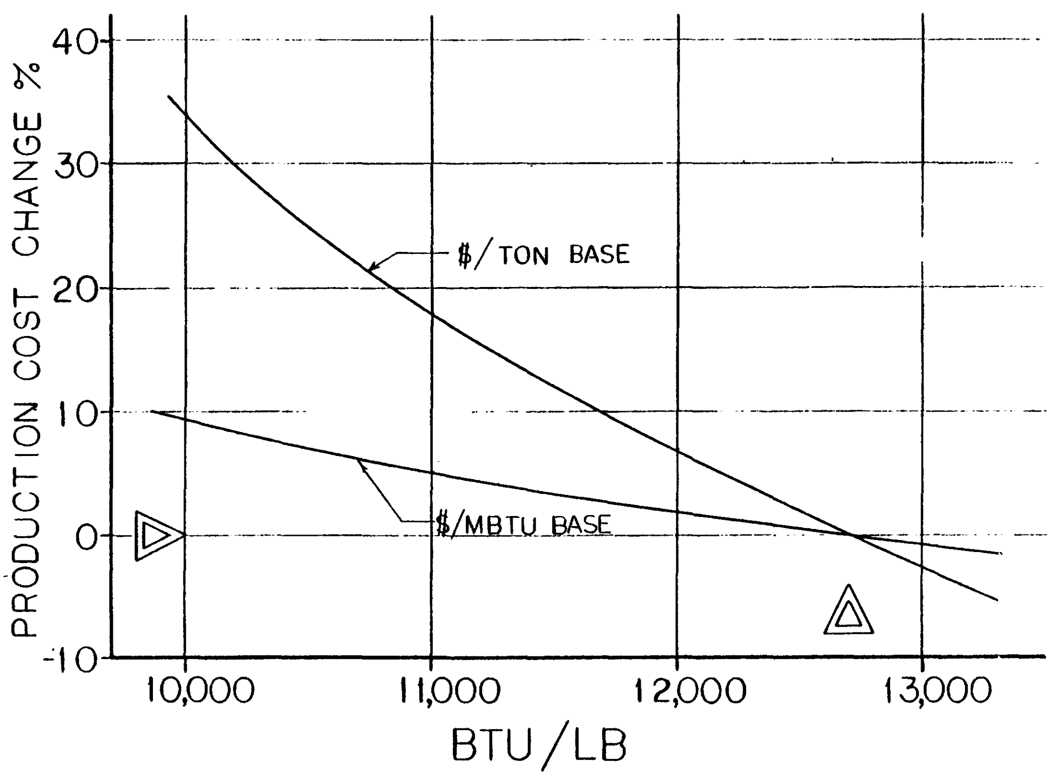

Figure 2. Coal quality versus production cost.

this figure are the coal-quality parameters used by our models. These models also predict deratings which will be illustrated in figure 3.

Figure 2 presents an example of how the production cost on a unit might vary with the fuel quality. The top curve illustrates the change in production cost as the quality varies for coal purchased on a dollar-per-ton base. The lower curve uses the same fuel quality information, but is determined by pricing the fuel on a cents-per-MBTU base. It is assumed in this example that coal represented by the various qualities will not cause any generating deficiencies.

I'd like now to give some examples of how the model could be used.

Figure 3 illustrates the effect that coal from three different vendors has on the operation of a unit. The information presented in this example actually occurred in the NYSEG system. The lower histogram illustrates the effect that the coal from three different vendors has on the ability of a unit to meet full capacity. The two plots shown for each vendor represent the average quality and the quality at one standard deviation based on the variability of the coal received. In this example, the average quality of the coal received from Vendor 1 would burn with no deficiencies in generation whereas the swings in quality on the low side could derate the unit 25 percent. Vendor 2's coal causes derates in both the average and low quality, whereas vendor 3 causes no derates in either case. Derates or generating deficiencies in this model would result from the inability of the pulverizers to handle enough material for steam generation or from exceeding the opacity limits through precipitator limitations.

The upper histogram illustrates the relative production cost associated with these coals. It is interesting to note that the component is virtually the same for the three products; yet, the total cost to the corporation differs significantly. These examples were specifically taken to illustrate the variation that could exist for the same coal cost.

This may cause one to conclude that only fuels of high quality should be bought that do not cause any generating deficiencies. This is true up to a point. Figure 4 illustrates an evaluation made by NYSEG for a long-term coal contract. All of the coals supplied by these vendors would allow the unit to achieve full generating capability; yet, each affords a different production cost. Would it be prudent for a utility to purchase from Vendor C when supplies from Vendor G or Vendor A are readily available?

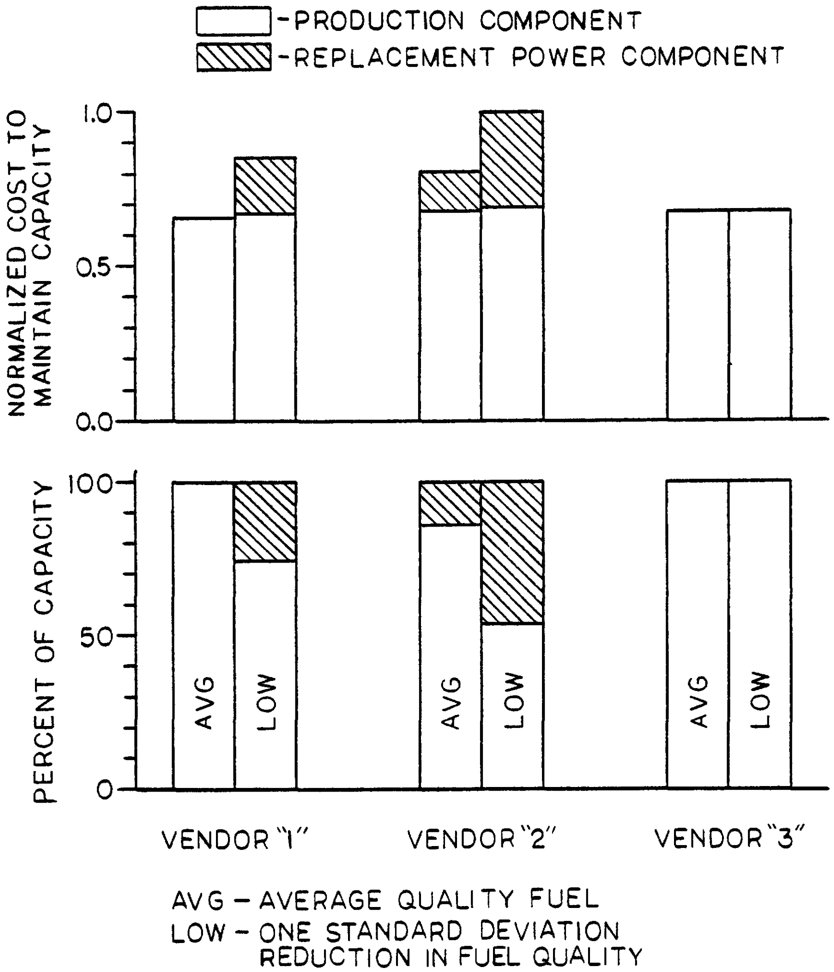

Figure 3. Production cost versus coal quality.

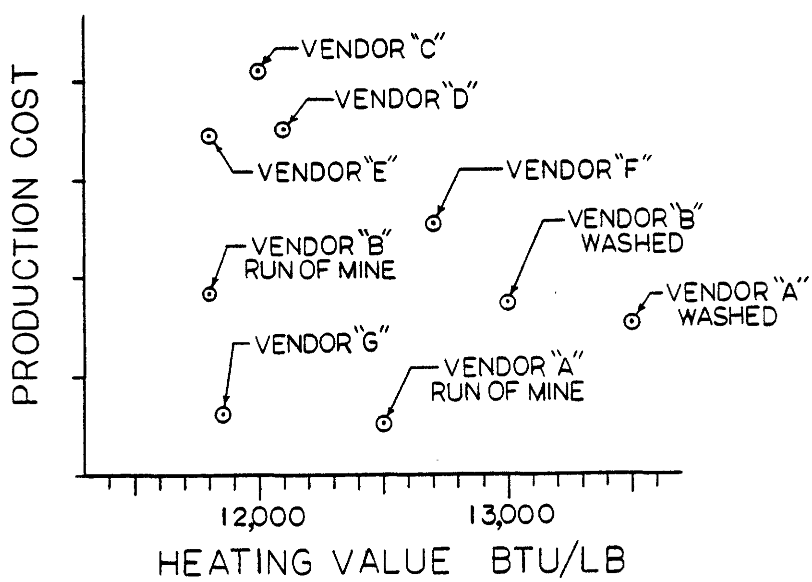

Figure 4. Production cost versus heating value.

Other observations that can be made from this figure are:

1. Vendor A Run of Mine and Vendor G have similar production costs, yet their quality varies significantly. What risks are associated with purchasing Vendor G over Vendor A or the reverse?

2. Also, notice the difference between Vendor A Run of Mine versus Vendor A washed. This suggests there is no incentive to purchase the washed product over the Run of Mine.

3. However, for Vendor B, the production cost for the Run of Mine is slightly more expensive than the washed product. Obviously, the washed product in this case would be a better buy.

My intent is to present a concept. Some of the information presented in these examples would not result in the same conclusions if applied to other utilities. Also, our model does not include all of the parameters or variables that could or should be looked at in understanding the effect of coal quality on production cost. Our model provides insight to support our fuel procurement policies and long-term strategies. I believe this is only the "tip of the iceberg" on what challenges we may face in the cost of service. This is one utility's perspective.

COAL RESERVE CHARACTERIZATION FOR EMISSION CONTROL

by

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The state-of-the-art in Coal Reserve Characterization (CRC) methods has undergone a major change as a result of a combination of factors including, but not limited to, the ever-changing energy requirements and science. Therefore, any comprehensive coal-reserve characterization study should incorporate the technology advancements currently available in the areas of exploration, mining engineering, processing, and combustion. The mineability and utilization of a coal reserve is to be assessed to determine if it will be environmentally and commercially economic over its productive life. This is because major planning and economic decisions are made based on the results of a coal-reserve study with the following considerations in mind:

- Most of the coal used by utilities is purchased under long-term contracts.
- Utilities require decision-making in all aspects from power-plant design to coal-procurement strategies.
- A coal reserve's quality and usability must be determined within environmental constraints.
- The uncertainty of whether a mine's coal product is of sufficient quantity and quality for the life of a contract must be reduced.
- New advances in coal combustion and coal-cleaning technology require a higher level of accuracy.

Inadequate or improper reserve data assessment may have a disastrous impact on a utility's coal procurement and utilization program. In many instances, utilities, although making huge financial commitments, have relied on mining consultants and mining companies for assurances of coal-reserve assessment without particular regard to the methods used to project or predict the information. If the expected conditions do not materialize, the coal company will appeal to the utility for relief and the utility will be faced with a number of difficult alternatives, such as: (1) providing additional financial compensation, (2) taking over the mine and seeking another operator, or (3) acquiring alternative sources of supply. In any of these circumstances, the utility may still have a problem with quality and/or high-cost coal, and may be forced to acquire new reserves in an unfavorable economic atmosphere. Thus the coal reserve must be used in the most effective and efficient manner. Because today's coal-mine development costs often exceed $100 million and power generation $1 billion, it is only logical that technology advancements to identify the degree of confidence (risk) associated with a coal-reserve's utilization should be sought.

I will now explain some aspects of Pennsylvania Electric Company's (PENELEC) and New York State Electric and Gas Corporation's (NYSEG), coal reserve characterization (CRC) used at the Homer City Generating complex.

PENELEC is one of three operating companies of the General Public Utilities Corporation (GPU). About 85 percent of the electricity PENELEC produces comes from coal-fired power plants which burn approximately 17-20 percent of all the coal produced in the State of Pennsylvania. The primary reason for this is that PENELEC sits right in the heart of the eastern coal field. Coal is our primary fuel source, but does not always provide satisfactory results because the quality varies; the quantity fluctuates; or cost varies despite carefully planned mines and crafted contracts.

Because of these factors, the primary question raised when the management looks at a coal reserve is, "can we utilize it to our advantage?" If we develop better qualifying capabilities to evaluate a coal reserve, the true utilization potential can be quantified and the optimum utilization of coal will be realized.

For example, a Pennsylvania utility spent approximately $4.5 million to improve precipitator efficiency. The upgraded facilities worked with some coals and not with others, primarily because of an inability to obtain the precise quality of coal necessary to meet both particulate and sulfur dioxide standards at the same time. This utility diligently sought bids from approximately 60 coal producers and accepted seven who promised to deliver coal within the necessary, stringent sulfur range. The suppliers didn't live up to their promises, because they didn't have the knowledge (or perhaps the desire) to develop their mines in a way which would produce a uniform product, and the utility did not have the tools to determine the fact in advance.

All of the points I have made are known to coal producers and utilities. However, most are slow to make use of them. Because of the fragmentation of the industries and the relatively modest size of many operations, few are actively seeking a better way. Although we may do a bit more than go out with a divining rod, many of us have not adopted data-collecting technology and computer analysis which the miners of other minerals are using successfully.

The CRC is a method to delineate the particular qualities, features, and peculiarities of a given coal reserve. We envision it as a tool to meet present and future requirements for supplying a uniform quality fuel to coal burning and cleaning facilities within the best environmental and economical manner possible.

The CRC program should include:

- Information analysis utilizing computers and other advanced technology, equipment, and procedures.

- Mathematical modeling to interpret information gained.

- Scientific projections to guide and improve mine development procedures.

Underground coal-mine planning traditionally focused on the mine design aspects concerning safety and efficiency in the quest to produce low-cost coal. Very little attention has been given to predetermination of coal qualities and surrounding geologic characteristics. Yet, voids, sandstone washout, unstable roofs, high-water seepage, and quality transitions are conditions found underground, usually unexpectedly, and then overcome only by brute force at substantial cost. In the past, it was not uncommon for an operator to abandon a work place when any of these things occurred, because it was relatively easy to start another heading or even start mining some distance away, ignoring the resource potential or the bottom-line cost. Now, with practically all of the easily accessible reserves mined out or being mined, and with development costs of deeper mines soaring, it is an economic requirement that once mining is underway, it should continue along the original plan.

Some predetermination of coal qualities and surrounding geologic characteristics could have easily reduced the impact of those ills just mentioned. For example, it has been discovered that a strong relationship exists between underground fractures and surface water courses. Knowledge of the exact location of probable faults prior to deciding upon the final layout of a mine offers an opportunity to reduce development and operating costs with improved coal-quality control.

Advance knowledge will also help work around the problems caused by the undulating nature of a coal seam whose high point is referred to as the anticline and low point as the syncline. A work area at the syncline sustains pressure from both sides and top resulting in the need for stronger roof supports and larger pillars to lessen the vertical pressure, and escapes the high horizontal tectonic forces which makes mining along the syncline more difficult and expensive. Of course, to maximize the coal recovery, it is necessary to work the syncline areas; but the problems and cost can be mitigated by orienting the main heading in a different direction with prudent mine planning to help offset poor roof and bottom conditions.

Another important reason to predetermine coal qualities and geologic characteristics of any given coal reserve is the proliferating number of environmental regulations.

To comply with State and Federal clean-air regulations, the quality of coal must be carefully controlled within narrow limits. At each coal burning station, stack emissions generally fluctuate in tandem with coal quality. Emission violations can be caused by mechanical malfunctions, but a constant fluctuation in coal quality also makes it very difficult for the operator to keep his stacks clean. It is a known fact that coal delivered to a generating station can vary as much as ±100 percent in sulfur content and ±70 percent in ash content. This occurs in spite of the best efforts of the coal buyers and the coal producers to obtain a consistent supply of contract compliance coal.

The reason coal varies so much in chemical characteristics is that it is a heterogeneous material whose composition varies substantially along the vertical and horizontal planes of any specific coal seam. This variation is graphically depicted in figure 1. Figure 2 shows sulfur content ranging from 2 to 6 percent in a particular coal seam.

If we are to control the coal quality, we must be able to first predict with a certain degree of accuracy and confidence. This is where geostatistics can be applied to predict the short-term coal qualities.

The first historical (as well as present-day) step in answering the question as to whether a prospective reserve is acceptable and should be mined is the collection of data from the geophysical and chemical characteristics of the reserve body. Traditionally, the core drilling is done at random locations, analyzed, and isopleths drawn. A CRC program identified more scientifically the selection of drill sites and the use of 75 percent air drilling with 25 percent coring of the coal along with electric logging to more economically explore the coal field.

A reduction in the number of drill holes, while increasing the confidence of the findings, is made possible by the use of

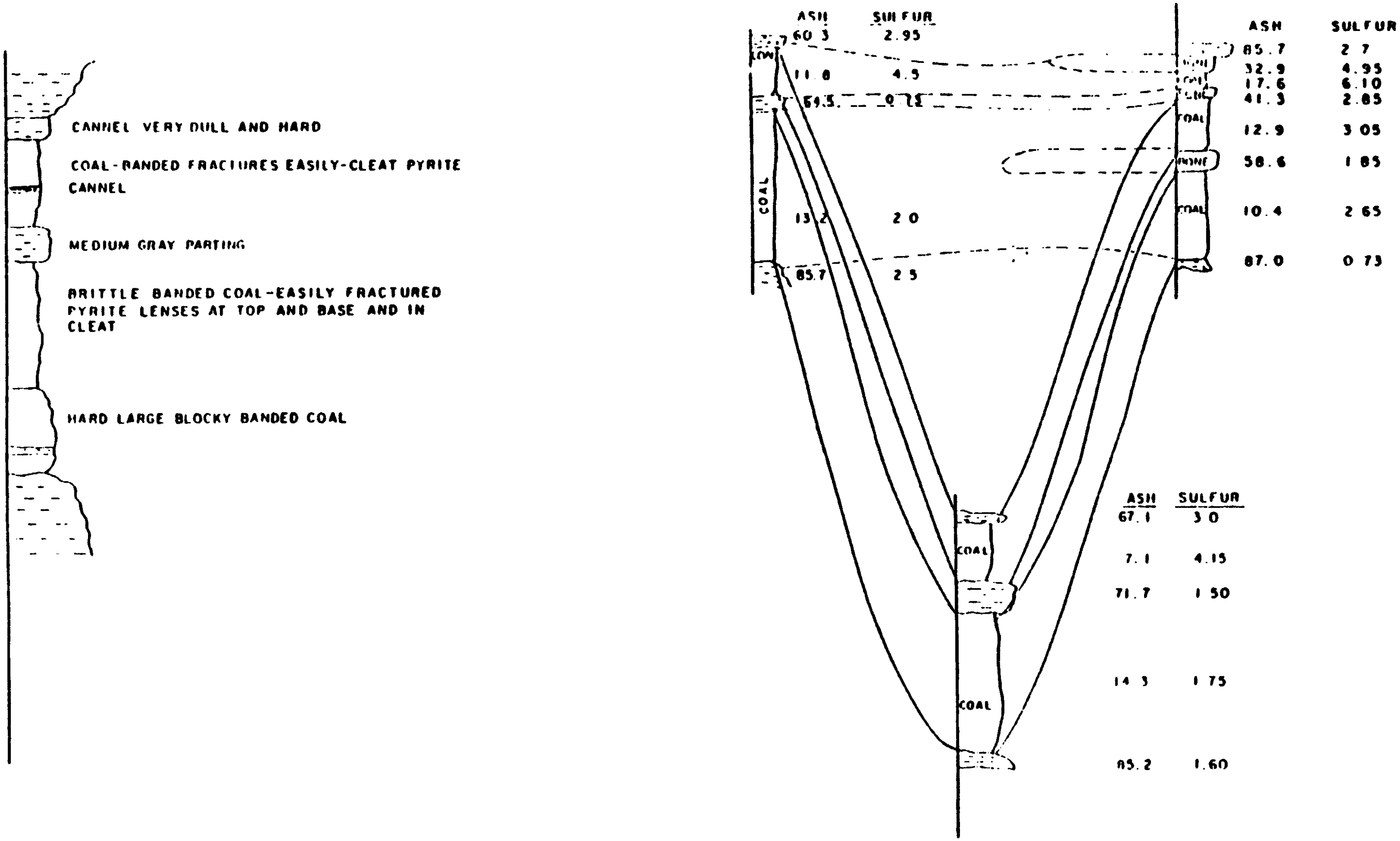

Figure 1. Illustration of typical coal qualities.

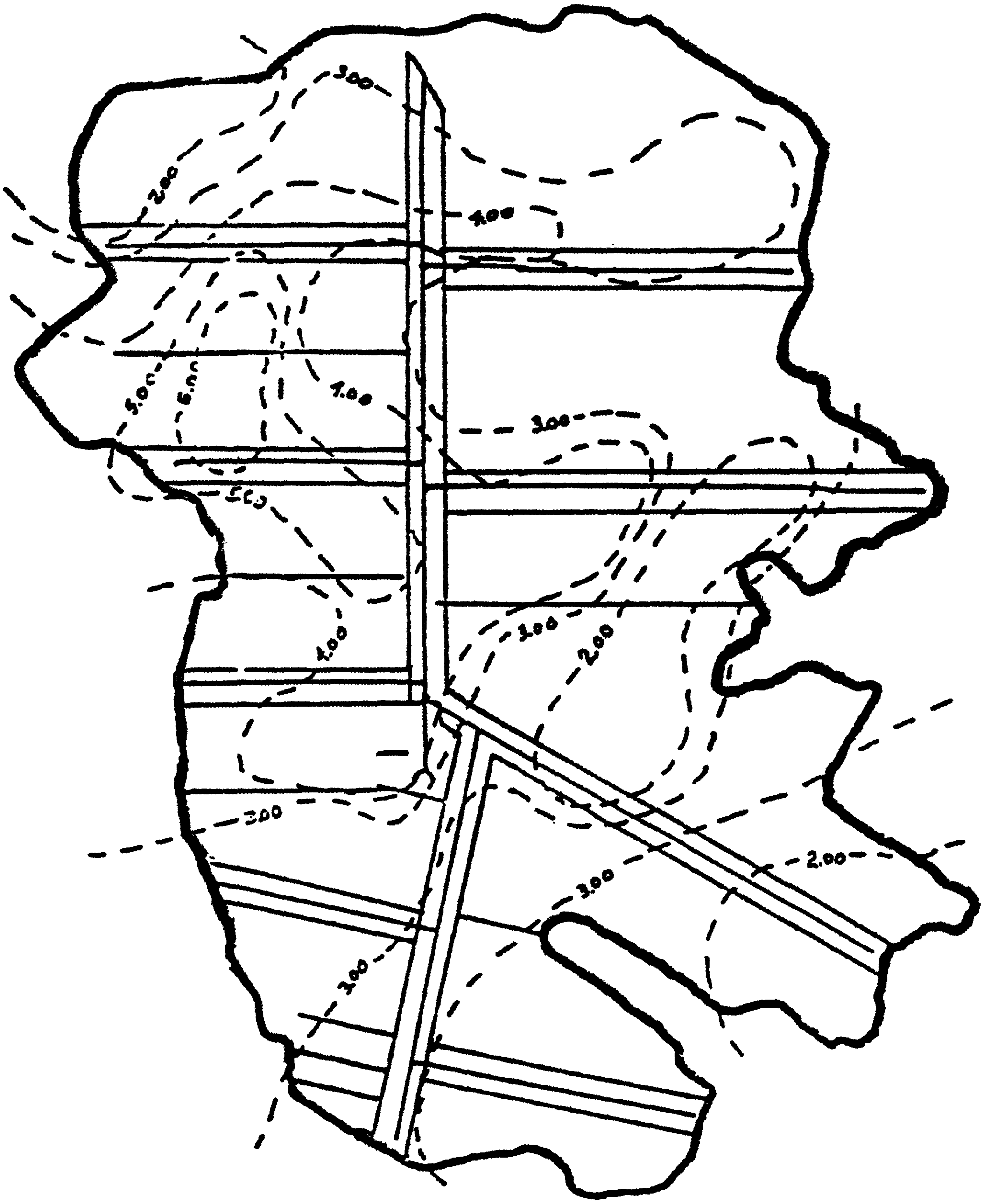

Figure 2. Sulfur variation in a coal seam as shown by total percent sulfur contours.

geostatistics. This technique mathematically optimizes the information, location, and number of cores necessary to define the geology, ash, sulfur, BTU's, and thickness of a coal reserve with the least possible variance and costs. Now, by formula, it is possible to calculate the probable error of the predicted value of any geologic feature and from this probable error, it is possible to calculate the probability that the predicted value will fall within a certain range of the mean value.

In a process called Kriging, a series of maps defining the average thickness, ash, sulfur, BTU, or other characteristic along with their associated error limits can be constructed in blocks of any dimension desired. A section of a mine is shown in figure 3 consisting of nine of the 1,000-foot-square blocks used in a Kriging exercise. The upper number in each block is the average value of total sulfur, in percent, in that block; the lower number is the associated probable error.

In contrast, the traditional method of translating core data to isopleths produces varying results. For example, figure 4 shows two sets of sulfur isopleths of a mine. Both the solid and the dashed lines were drawn by highly respected consulting firms and followed accepted procedures in arriving at contradictory predictions.

Geostatistics was applied to sulfur, ash, and thickness values of drill holes in the Upper Freeport ("E") seam. The deposit was then Kriged on 1,000 by 1,000 foot panels and then 18 new holes were drilled to validate the predictions. More than one-half of the Kriged values predicted were within 2 percent of the actual values. Six predictions came within 11 percent of the actual values and two were within 14 percent. These are considered very good results in the mining industry. They are clearly better than other estimates.

A short-term quality prediction model was developed to better predict in-situ coal qualities from the immediate working areas in the mine. This model is designed to utilize both existing diamond-drill holes and other sampling information during its quality prediction. The geostatistical technique of linear Kriging is used to make the best estimate of the characteristics of future production areas.

From an optimal mine-planning and emission-control standpoint, accurate characterization (or prediction) of in-site coal qualities is a must simply because this prediction is the basic input to all subsequent processes. This fact can be further emphasized by figure 5, which shows schematically an overall emission-control strategy available to a typical utility company.

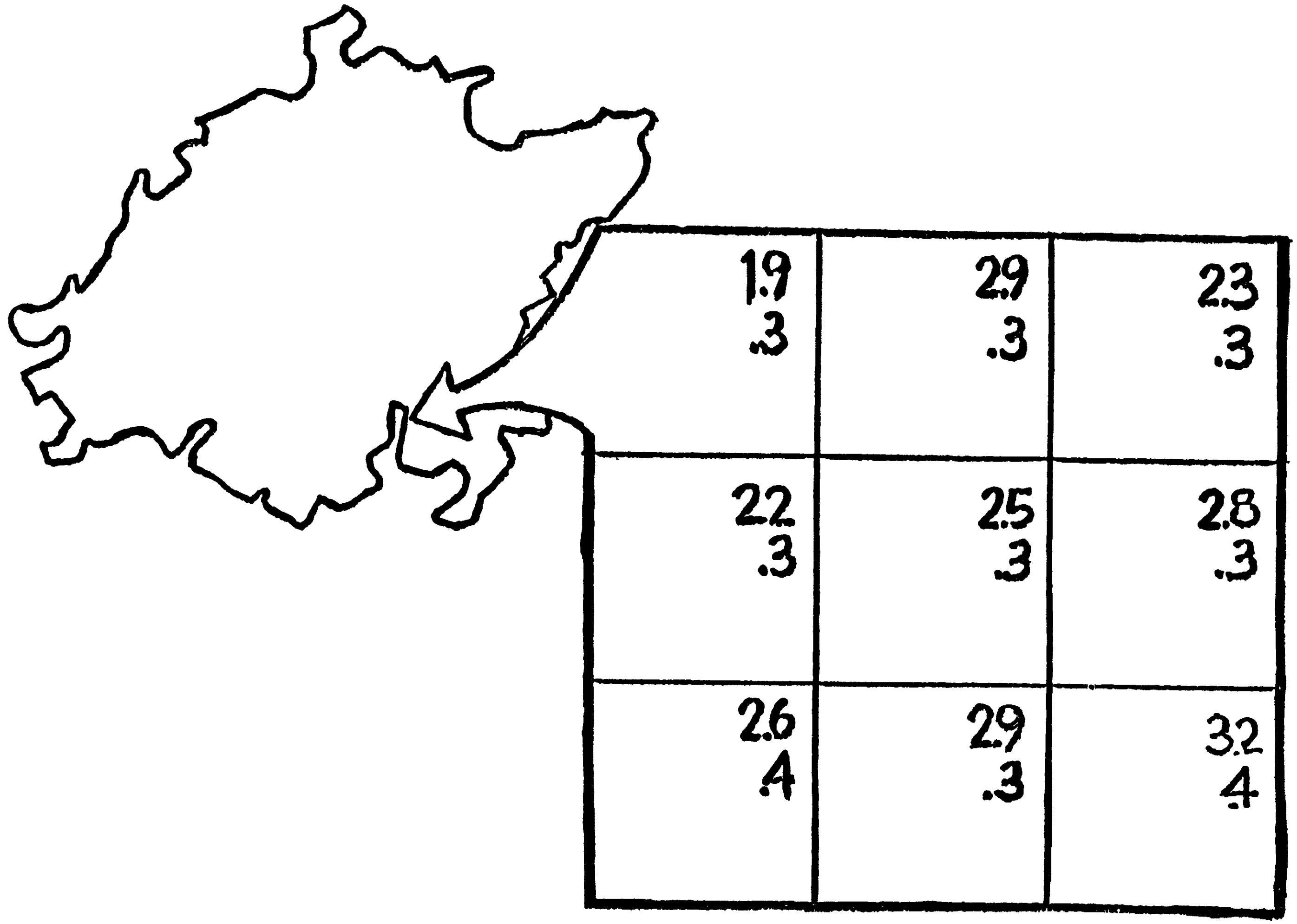

Figure 3. Expanded view of a coal property showing results of a Kriging exercise for total sulfur in one coal bed. Blocks are 1,000-feet square; upper numbers in each block are percent total sulfur; lower numbers are probable errors.

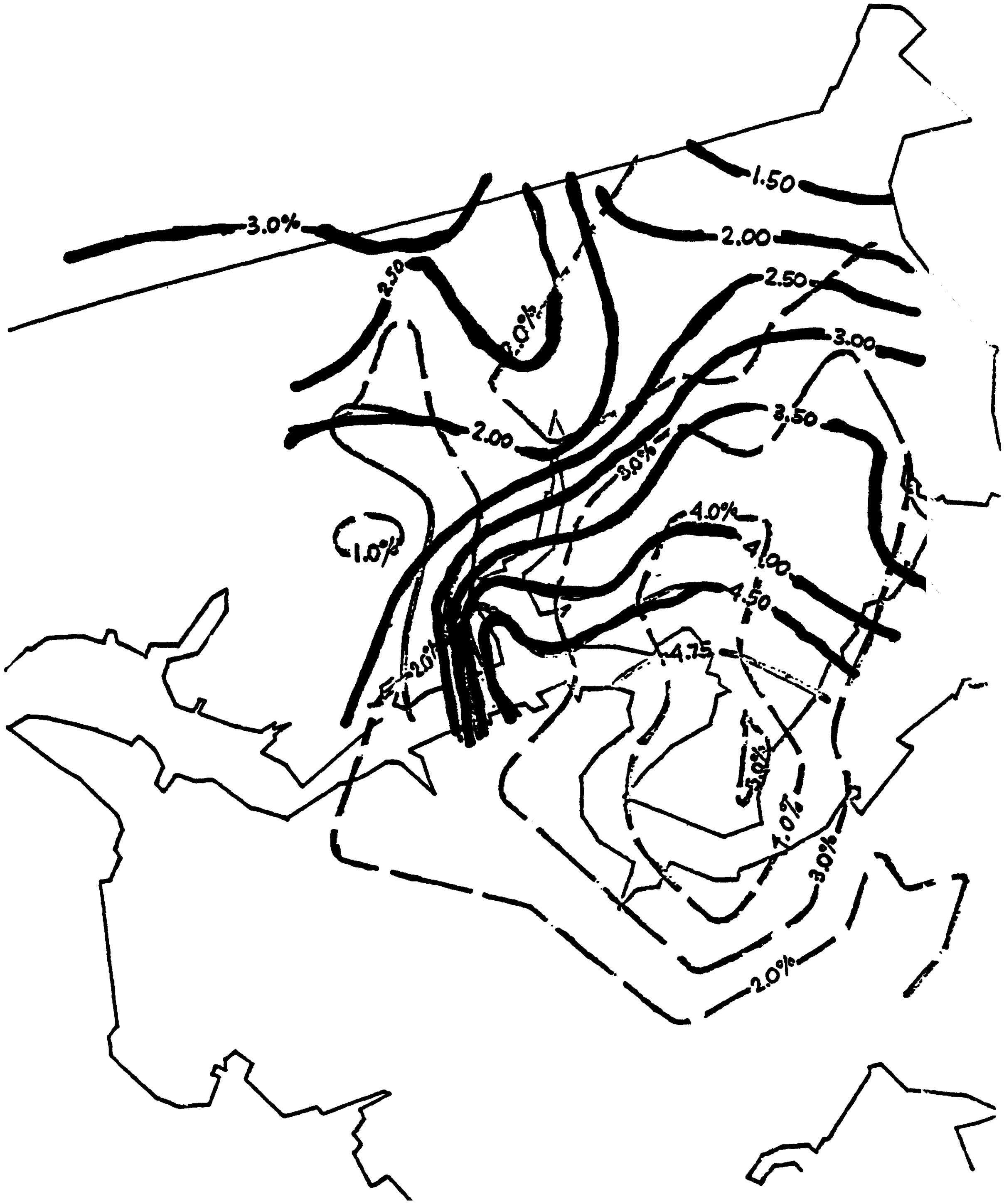

Figure 4. Map showing two contrasting interpretations (solid vs. dashed isopleths) of sulfur distribution in a coal bed as produced by traditional methods by different interpreters. Isopleths are percent total sulfur.

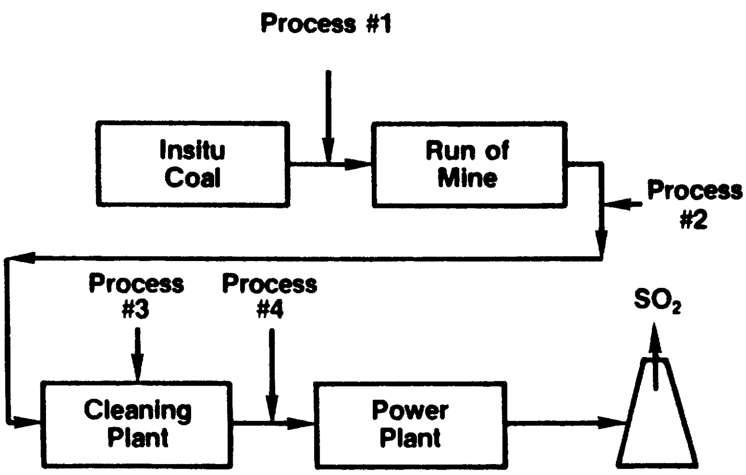

Figure 5. Schematic of an overall emission-control strategy.

Each process shown does provide the possibility of emission control. For example, different working areas can be scheduled so as to minimize the sulfur variability of run-of-mine (ROM) coal qualities in Process No. 1. In Process No. 2, the use of Bradford breaker and air table eliminate coal partings and out-of-seam dilution material. Another possible control is the temporary stockpiling of high-sulfur coal for future blending with low-sulfur coal.

Coal cleaning as depicted by Process No. 3 (fig. 5) is perhaps the most readily available emission-control strategy for the coal-fired utility companies, whereas Process No. 4 can be the installation of sulfur removal devices or external purchasing of low-sulfur coal for further blending.

All this information can be displayed either in map form or in contour plots. Figure 6 shows a contour map of the Kriged sulfur, ash or any quality values for a coal reserve. In the same figure, the projected working areas are also laid out so that the computer programs can be run interactively to obtain the desired scheduling of mining faces during any given planning period.

The prediction results of the 6 months <u>in-situ</u> coal qualities of those areas that were actually worked from January through June 1982 are given in Table 1. Using the Kriging variance information given in Table 1, the 95 percent error found can be computed for each prediction in order to assess the relative reliability of the prediction.

In Table 2, the 6 months prediction results of the run-of-mine sulfur quality were compared with the actual "as-received" figures. Unfortunately, it was learned through the current research effort that little information is available for performing either an out-of-seam dilution computation or a material balance across our Bradford breakers. Therefore, a new research program was started to better quantify the available information.

Again, experience indicates that we all will benefit financially, environmentally, and operationally from having a better coal-reserve characterization program by developing:

- A <u>methodology</u> on which to base decisions for coal purchases.

- <u>Assurance</u> that suppliers will be able to live up to contract terms.

- <u>Ability</u> to predict, with a high degree of confidence, the quality and quantity of coal in a specific mine so as to properly design boilers, cleaning facilities, and emission-control devices.

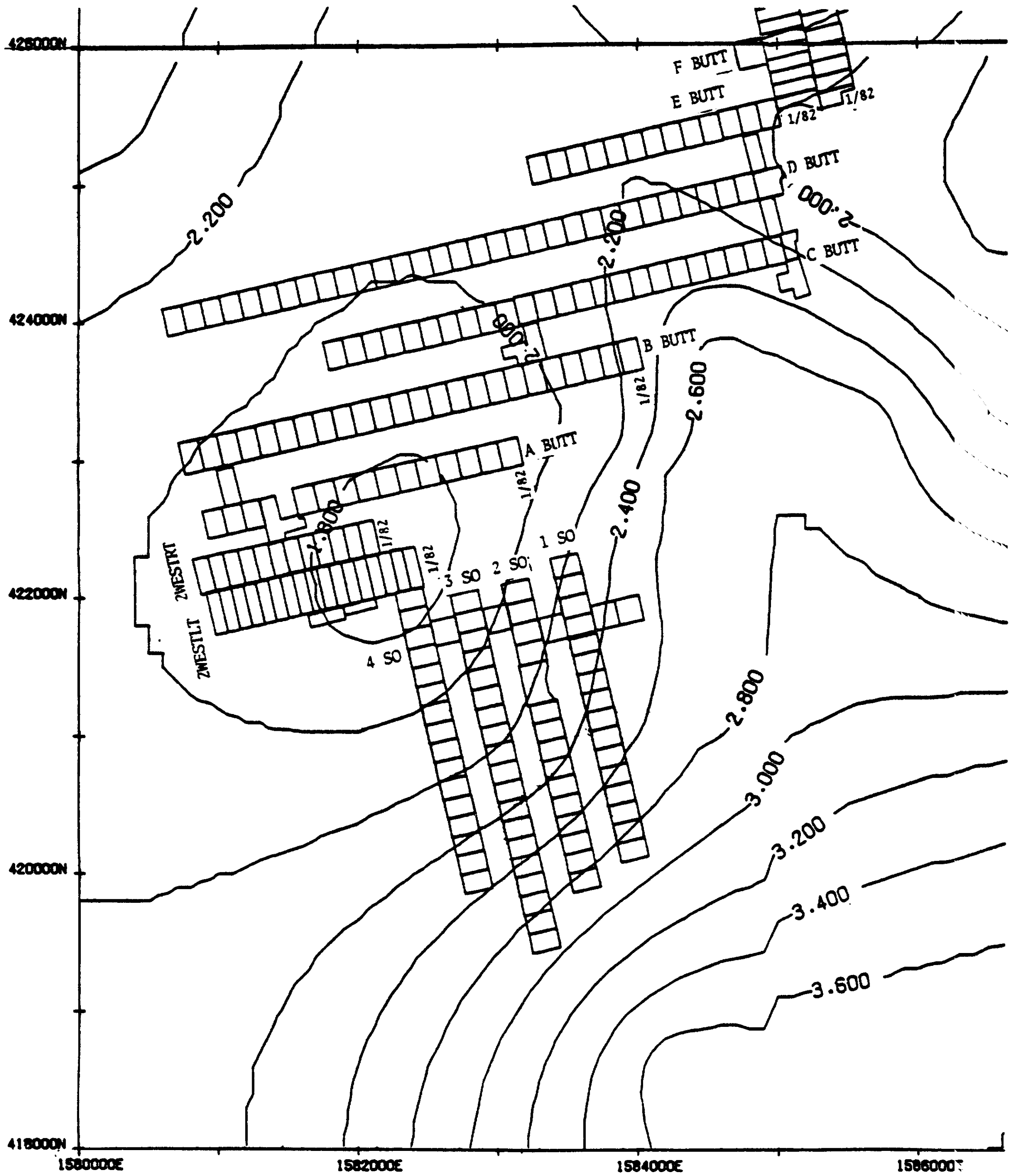

Figure 6. Map showing Kriged iso-sulfur values (total sulfur in percent) and projected coal-mine face advances.

Table 1. Predicted values for the quality of the coal mined from the areas shown in figure 6 during a 6-month period.

Month	Thickness inch	Variance $inch^2$	Ash %	Variance $(\%)^2$	Sulfur %	Variance $(\%)^2$
January - 82	51.84	1.29	18.22	0.461	2.54	0.033
February - 82	51.80	1.37	18.19	0.445	2.54	0.033
March - 82	51.66	1.72	17.88	0.657	2.43	0.044
April - 82	51.67	0.91	17.25	0.281	2.51	0.025
May - 82	51.66	1.01	17.80	0.246	2.50	0.020
June - 82	51.37	1.46	17.71	0.422	2.38	0.033

Table 2. Actual average sulfur values for the coal mined during a 6-month period from the mine in figure 6 compared with the predicted values given in table 1.

Month	Sulfur: Predicted (Insitu) %	Sulfur: Actual Reported (As-Received) %	Deviation From Actual %
January - 82	2.54	2.74	-7.30
February - 82	2.54	2.67	-4.87
March - 82	2.50	2.62	-4.58
April - 82	2.51	2.86	-12.24
May - 82	2.50	2.81	-11.03
June - 82	2.38	2.63	-9.51

- o <u>Confidence</u> in a degree acceptable to regulatory authorities and stockholders that its coal-purchasing program is cost effective, efficient, and productive.

- o <u>Knowledge</u> of the mineability of a coal seam.

To summarize, I have shown that there are many variables to be considered in deciding where and how to mine coal and explained why it is time to get away from the prevalent exploratory type of mining and develop a scientific procedure.

I offer the CRC program as a design tool which will save money and provide confidence that the coal will be mined in a safe and commercial manner. But, most importantly, the flames in the boilers will continue producing electricity in a reliable, cost-effective manner from existing and future generating stations while complying with performance standards for specific flue gas emissions only if research is continued in the areas of:

- o Determining the correlation of drill cores and channel samples to estimate coal-cleaning plant yield and permit optimum plant design through the use of quality control in prudent mine planning.

- o Determining the fine-coal-cleaning (-100 mesh) potential of coals that can be accomplished using dense medium cyclones.

- o Determining the fine coal-cleaning (less than -100 mesh) potential of coals utilizing various flotation devices.

COMMENTS ON CHARACTERIZATION OF THE QUALITY OF COAL RESOURCES AND RESERVES

by

David Mathew
Utah International

I start with a question--what is the one major issue affecting the coal industry in the United States today? From the standpoint of business planning and decision making, the answer is the ever-changing regulation picture. I would like to see this meeting develop an agenda for priorities in basic applied research on the quality of coal resources and reserves that will aid in developing regulations to ensure that we take advantage of the Nation's vast coal resources in a cost-effective and environmentally acceptable way.

For those of you not involved on a day-to-day basis with mining and selling coal, let me offer some insights into the effects that changing regulations have on our business. I will limit the discussion to those regulations directly linked to coal quality, that is emissions regulations.

The Clean Air Act of 1970, the New Source Performance Standards (NSPS) set by the Environmental Protection Agency (EPA) for coal-fired utilities, required all plants constructed after 1971 to meet an emissions limit of 1.2 pounds of SO_2 per million BTU's. The rule allowed plants to choose between technological emissions controls (such as scrubbers) and fuel controls (such as burning low-sulfur coal. The rule caused considerable turmoil in our business. Many utilities chose low-sulfur coal over scrubbers partly because they regarded scrubbers as an unproven technology; also, few wanted to bother with operating them. However, the primary reason for coal switching was that the utilities' commission resisted price increases to cover pollution controls, whereas fuel adjustment clauses made it a simple matter to pass along the increased cost of lower sulfur coal without the approval of the utilities' commission.

The most significant impact of the act was the shift in regional production. Over the period 1971-1983, coal produced in the low-sulfur fields of the western United States moved into the eastern U.S. marketplace. Western production increased 40 percent during this period, whereas eastern U.S. production only increased

5 percent. A similar and perhaps more revealing trend can be observed in the State of Kentucky which has a region of high-sulfur coal reserves (western Kentucky) and a region of medium-to-low-sulfur coal reserves (eastern Kentucky). Over the same period, western Kentucky production decreased 25 percent and eastern Kentucky increased 30 percent.

The fear that utilities would cease buying locally available coal had its effect on Congress. In 1977, Congress passed the Clean Air Act Amendments under the guise of preventing the degradation of existing air quality. EPA required sulfur reduction for all coals high or low in sulfur. Under the rule, all plants built after 1978 would have to have a scrubber or equivalent technology. Not surprisingly, low-sulfur producers thought that they had been legislated out of the market. In fact, the amendments, driven by economics and politics, did for the first time recognize the legitimacy of protecting the Nation's coal resources. This, I believe, should be the cornerstone of this meeting: the protection and judicious use of the Nation's coal resources. A policy that allows or favors fuel switching could have important consequences for the conservation and judicious use of the country's coal resources. The encouragement of the use of the highest quality coal first (in this case low-sulfur coal) is very short-sighted given the finite nature of the resource.

The pendulum of changing regulations is by no means stationary; the trend seems to be towards tightening air-emissions standards. In fact, several current environmental issues are being considered, including acid rain, fugitive dust from coal mining, tall stack regulations, revision to the NSPS for coal-fired power plants, and maybe, later, the greenhouse effect.

Briefly, pending acid-rain legislation would require midwestern States to reduce emissions by as much as 80 percent. Two approaches are being considered. One, the no-cost-sharing flexible approach, would establish each State's emissions reduction, direct the States to devise methods of achieving the reduction, and offer no financial assistance for achieving the reductions. The second type, the cost-sharing, forced-technology approach, would require that some of the reduction be achieved by retrofitting certain plants with scrubbers and would establish a trust fund for distributing the costs. Each approach would result in a shift in regional production and employment. The forced-technology approach would be somewhat more costly in dollars, but would involve less disruption. However, as long as there are market advantages to be gained under the guise of environmental legislation, industry believes that the acid-rain debate will be long. In the meantime, the country's coal resources are being "highgraded."

Turning now to the quality of coal resources and reserves, what is the status of existing information on coal quality and of the methodologies for predicting the quality of coal in place, and where should research monies be spent? To answer the question, let us isolate the steps from exploration to utilization (fig. 1).

Step 1

The distribution of coal resources displays a distinctive difference between regions. Take, for example, the eastern and western United States. Eastern U.S. reserves are defined as medium-to-high sulfur and western U.S. reserves are low in sulfur. Quantification of this distribution, especially at the State level, has not been completed. Currently, only a few States are working on this task. We need to devise a method of defining the coal quality of a region's coal resource. The precision of the distribution should be sufficient for policy issues only.

Step 2

The characterization of coal quality of a reserve at the property scale is normally the responsibility of the mining company and is directed at mine planning and marketing. Monies spent at this step will have limited impact on government regulations because data are often held confidentially by industry. Experience has proven that given the density shown on the map, tonnage calculations don't change very much with additional drilling. However, it is our experience that coal-quality definition often changes with additional drilling. What might have been sufficient drilling to market a coal may not be sufficient to sell it on a day-to-day basis. This is a long-standing problem in the coal business, but especially now with tighter specifications of utility contracts.

Step 3

Coal washing can remove modest amounts (15-30 percent) of sulfur at reasonable costs ($5 to $10 per ton of coal), but costs increase dramatically as more sulfur removal is sought. Washing is currently limited to the removal of coarse forms of mineral matter and inorganic sulfur. Most of the research on washing is being conducted on the engineering technology front. We need to ascertain what parameters of coal quality are important in this new research and make sure they are presented at the regional level.

Step 4

Coal slurry fuels could be a near-term solution to making coal competitive with oil and would allow coal to be burned in facilities currently designed for oil. As in step 3, most of the

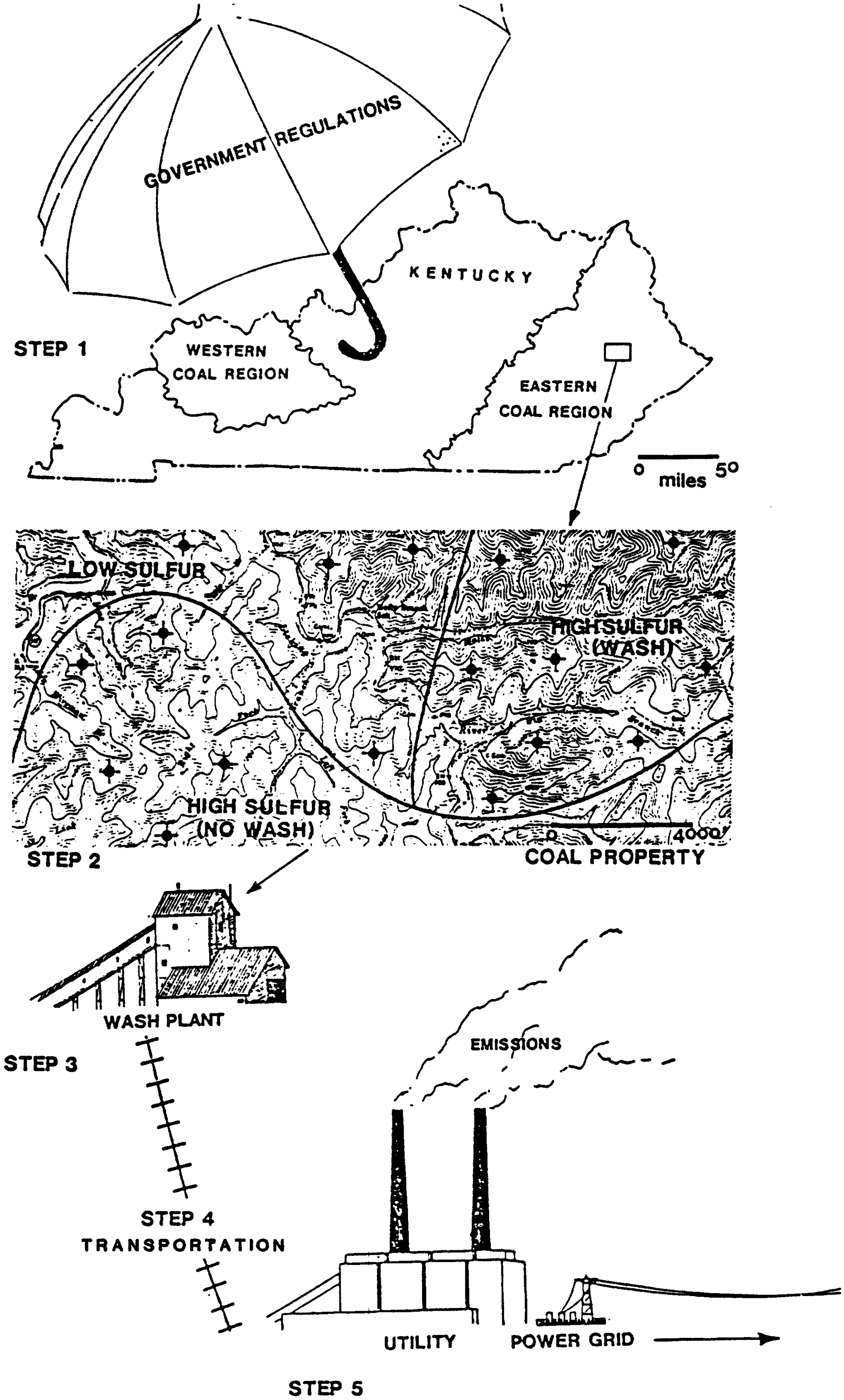

Figure 1. Five steps from exploration to utilization of coal where coal-quality research is needed.

research is on the engineering front. Again, coal-quality parameters of importance to the new research should be ascertained and documented at the regional level.

Step 5

The issue with the greatest potential to affect the coal industry is related to coal utilization. Regulations controlling the utility industry will dictate how we mine and process coal in the future. Utilities are searching for the most economically efficient way to produce power. Research is underway to develop fluidized bed combustion, flue gas desulfurization, coal water slurry fuels and synthetic fuels.

As already pointed out, information on coal quality by region will be essential for rational legislation to take advantage of the Nation's vast coal resources. This workshop should devise a plan of attack to document the distribution of the quality of coal resources by region.

PREPARED STATEMENT

by

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PANEL I - CHARACTERIZATION OF THE QUALITY OF COAL RESOURCES AND RESERVES

As Director of the Pittsburgh Energy Technology Center's (PETC) Division of Coal Science, I have two major responsibilities relevant to the characterization of coal that pertain to the subject matter of this meeting. The first responsibility is for the routine characterization of coal using standard methods of analyses as described by the American Society for Testing and Materials (ASTM). In this capacity, PETC laboratories determine whether or not selected coal purchases by government agencies meet contractual specifications regarding the quality of the coal. The second responsibility is to perform coal-characterization research designed to elucidate the basic chemistry and physics of coal conversion processes and coal-utilization technologies. This second responsibility frequently involves the use of highly sophisticated and often very expensive scientific instruments including, but not limited to, magnetic-resonance spectrometers, X-ray diffractometers, surface-sensitive instruments, and optical spectrophotometers. In the remarks that follow, my distinct preference for the use of standardized methods for characterization of coal quality for the purposes of this discussion will become apparent. I wish to assure the audience and the readers of these proceedings that my recommendations are based on some 27 years of experience in coal research in which both standardized and nonroutine methods for coal characterization have been used extensively.

In addition to the issue of the use of standardized versus nonstandardized methods of coal analyses, I also wish to call attention to the need for a better defined statement of the purposes for which measurements of quality are required and to remind the audience that the site chosen for the measurements may also influence the results. I would also point out that probably no absolute answers to the various issues before this panel exist, and, perhaps more important, that the novice coal researcher (and even the experienced one) will face a number of perils and pitfalls should he fail to appreciate this fact.

One of the objectives stated in the announcement of this meeting is "to identify research and information needs about coal quality for application to resource assessment, coal mining and preparation, coal utilization, and pollution control technologies." Missing from this list are several coal technologies that not very long ago were considered as emerging technologies; coal liquefaction and coal gasification are two examples that immediately come to mind. It should be noted that a high-quality coal for one technology may not be a high-quality coal for another. For example, low-sulfur coals are considered high-quality coals for combustion. Nevertheless, sulfur in the form of pyrite appears to promote the conversion of coal to liquid products (fig. 1). The question for consideration is, then, to what extent and for what purposes should existing coal reserves be characterized? What is needed is a series of tests that will provide good general information at a reasonable cost. Coal samples earmarked for a specific technology could then to subjected to more specific characterization techniques consistent with the end use of the coal.

Although certain characterization needs, for instance, sulfur and nitrogen contents, mineral matter or ash "content," may be common to each of the applications cited above, others may be of importance to only one or two. It would appear that basic characterization needs, especially for coal resource assessment, include ultimate and proximate analyses, calorific values, Hardgrove grindability index, ash-fusion temperature, and sulfur forms. More sophisticated needs, such as trace-element determinations, although of great significance for environmental concerns, may prove too expensive to be performed on every sample that will eventually be included in a data base. Furthermore, data of this type simply will not be available for samples from depleted mines, whereas ultimate and proximate analyses will very likely be available. The obvious questions are whether or not data on mined-out portions of a seam are important and whether or not old data are still useful. The answer from the coal geology community is a resounding yes to each! Certainly, data from mined-out areas have considerable value in projecting continuity of a seam over lateral distances.

Another issue for consideration is the use of standardized methods of analyses. Debate on this issue is usually heated, with the "standard methods" community defending its approach on grounds such as the test of time, that is, that the use of standard methods has provided analytical data to assess the quality of coal reserves since (or before) the turn of the century. The believer in modern, mainly instrumental techniques responds with equal vigor, claiming superiority in chemical speciation, laboratory

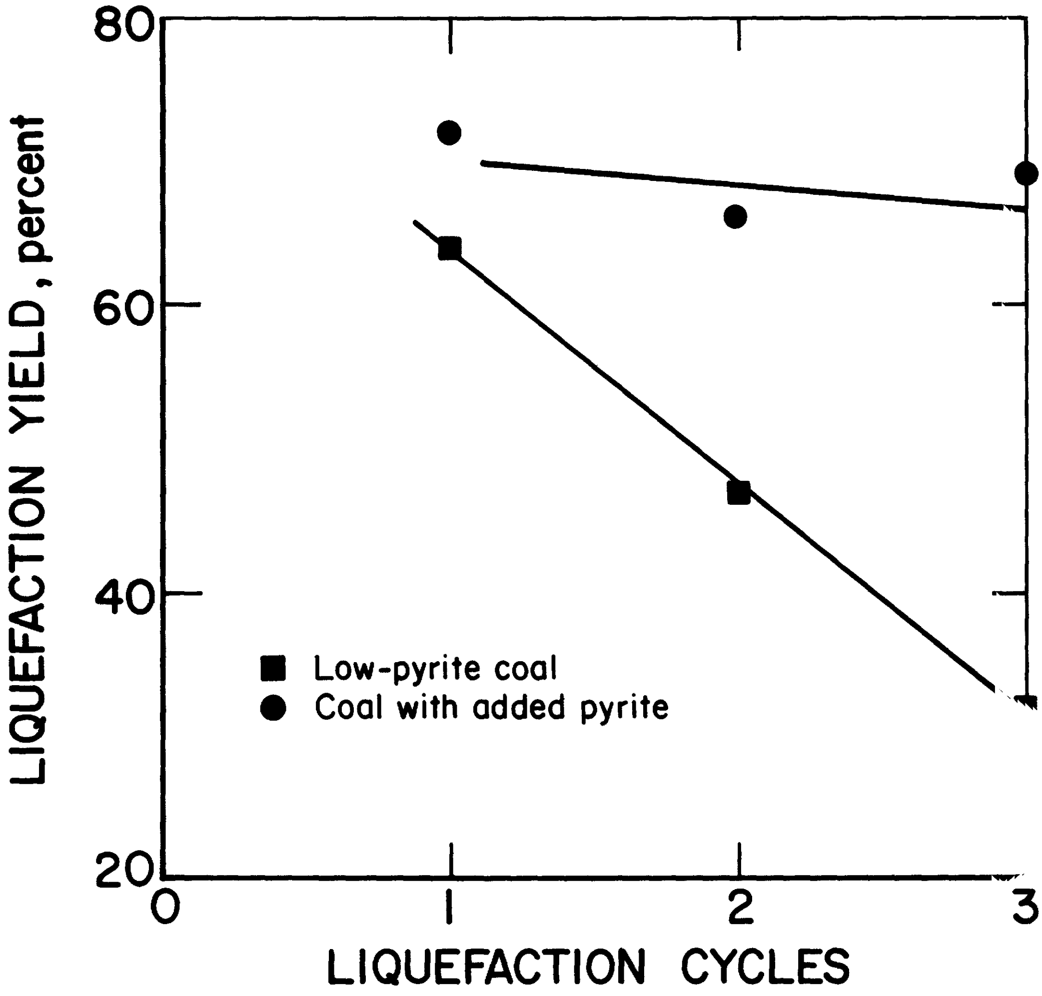

Figure 1. The effect of pyrite on liquefaction.

efficiency, and so on. Clearly, neither side has all the answers, and the merits of each must be considered.

The current and future usefulness of existing data bases is an important factor in this debate. As mentioned above, most of the early data bases relied on the use of standardized methods of analyses to ensure the quality of the data. Although standardized methods are sometimes criticized with respect to precision, accuracy, sensitivity, efficiency, and speciation, the methods have nevertheless survived the test of time and have stood up under litigation. Additionally, thousands of tons of coal are bought and sold each day based on contractual agreements in which the quality of the coal is identified by results obtained by standard methods. This is not to underestimate the power of modern instrumental techniques. Indeed, the use of such techniques in coal-structure investigations is an area of intense coal activity and is well under way in several laboratories. Measurements of such parameters as the carbon aromaticity (solid-state nuclear magnetic resonance), the number and nature of free radicals (electron spin resonance), and the quantity of hydroxyl groups (chemical derivation and infrared spectroscopy) can now be made, and techniques to determine other coal parameters at the molecular level are on the horizon. Whether or not any coal data base can afford such analyses is sure to be a limiting factor. Research into correlations between coal behavior and molecular parameters is worthy of continued support and may very well influence the choice of analytical measurements. Once that choice is made, it becomes prudent to standardize the methods to ensure the integrity of the resulting data. Once an analytical method is standardized, it is critical that standardized procedures be followed without deviation.

Naturally, new adventures into coal technologies will place new demands on the analyst. These demands must not be ignored. For example, new and much more sensitive techniques will be required to determine low levels of sulfur and ash (and perhaps mineral matter) in "ultraclean" coal, and enhanced efforts to characterize coal surfaces, especially with respect to oxidation, are desirable.

The lack of certified standard coal samples is a problem of some significance. Several coal-sample banks capable of providing so-called pristine samples for coal research are now or soon will be in existence. Nevertheless, only a few government-certified coal standards (for instance, Hardgrove grindability standards and sulfur standards) are now available. The need for such standards is underscored by the current entry of commercial laboratories into this market. The issuance of standard samples is traditionally the role of government, and existing government agencies should be designated to fulfill that role in coal research.

Where should a measurement on coal be made? Ordinarily, samples are characterized in laboratories that are remote to the mine or to the reserves. Recent interest in portable analyzers and in-seam analyzers deserve some comment. The question as to where the measurements should be made--in the seam? in the mine? in the laboratory? at the site of use?--must be considered. Sometimes, however, such discussions ignore more fundamental issues of coal stability. Although most coal scientists will readily concur that the sample analyzed at the site of use is not likely to be identical to that same sample as it existed in the mine, few realize the rapidity with which coal samples undergo change. Rapid oxidation that occurs within the first several minutes of exposure of coal to air even at ambient conditions was vividly demonstrated by Japanese scientists in the late 1960's. The experiment involved the measurement of spin centers (presumably organic free radicals) in coal by electron spin resonance spectrometry. Briefly, the samples of coal

> "were taken from coal seams deep from the working faces without exposure to air. The coals were immediately covered with deoxygenated water at the working places of the coal face before being taken to the laboratory. The coals were powdered in a glove-box filled with nitrogen gas in the laboratory, and the powdered coals were placed in the ESR (electron spin resonance) sample tubes..."

The increase in the number of spin centers after exposure of the samples to air, that is, after breaking the tips of the evacuated ESR tubes, is shown in figure 2. Note that changes occur within the first few minutes of exposure to air, and that the rate of change is dependent on rank. Please be aware that the actual phenomenon itself may be of little importance from a practical point of view; I know of no influence of the number of existing spin centers in coal on its behavior during utilization or conversion. The point I make is simply that a measurement made under ordinary laboratory conditions may not yield the same results as a measurement made in the mine or in the seam.

The purpose of these remarks is to bring the following issues and recommendations to the attention of the panelists and audience:

- When assessing the quality of a coal, the ultimate use(s) of that coal should, if possible, be specified. Coals earmarked for specific technologies will most likely require specialized characterization in addition to the more generalized characterization that will probably be performed on all coals for entry into data banks.

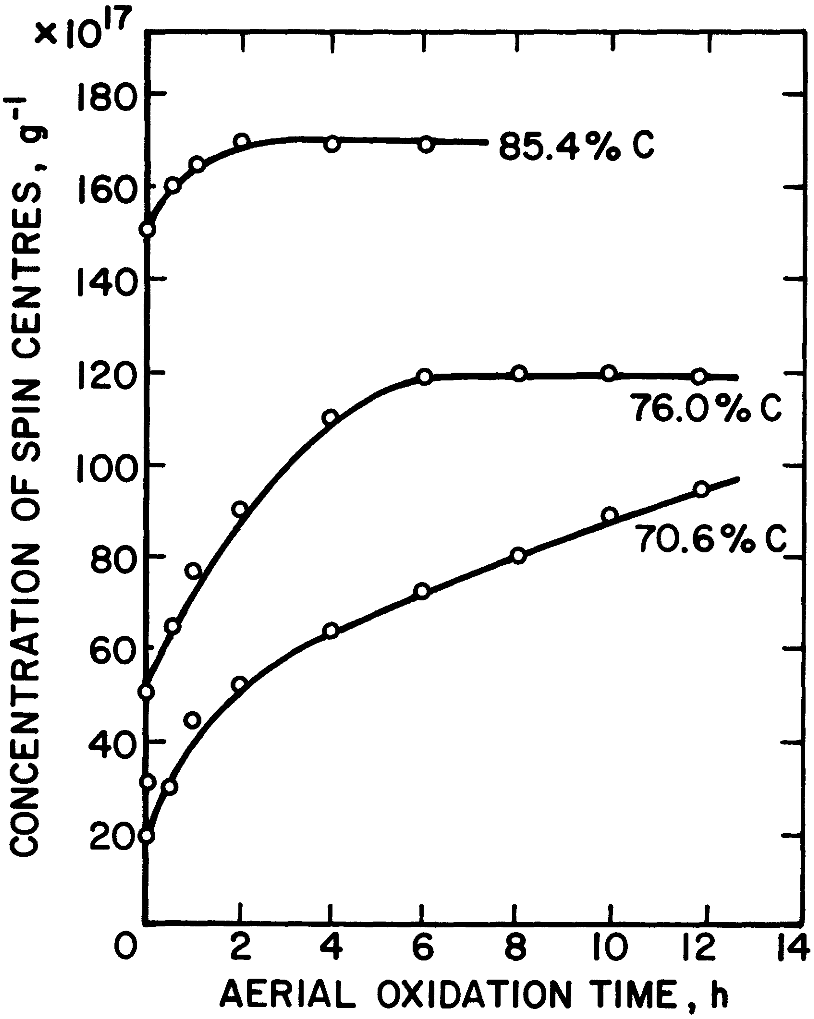

Figure 2. The relation between the concentration of spin centers and aerial oxidation time for virgin coals (reprinted from Ohuci. et al., Fuel, 48, 189 (1969)).

- Potential, as well as current uses of coal should be considered in coal-quality assessment.

- Standard methods should be utilized wherever possible to ensure the quality of data, and such methods should be followed without deviation to allow proper comparison of the data.

- Research into the use of modern instrumental techniques to assess coal quality should be continued with emphasis on precision, accuracy, and standardization of procedures.

- The need for certified coal standards should be addressed, preferably with the aid of appropriate government agencies.

- The coal community should be made aware of rapid changes in coal characteristics that may occur immediately after removal of the coal from the seam.

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SYMPOSIUM ON COAL QUALITY
April 9-11, 1985

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