Volume 56, Numbers 2, 3, 4

Proceedings of the West Virginia Academy of Science

1984

Papers of the Fifty-Ninth Annual Session

Proceedings of the West Virginia Academy of Science 1984

Vol. 56—Nos. 2, 3, 4

PAPERS OF THE FIFTY-NINTH ANNUAL SESSION

West Virginia Wesleyan College

Buckhannon, West Virginia

April 6-7, 1984

Printed by
McClain Printing Company
Parsons, West Virginia
May, 1986

Cover Design
Meredith Pearce
West Virginia University
Office of Publications
Morgantown

West Virginia Academy of Science, Inc.

The West Virginia Academy of Science was founded at Morgantown, November 28, 1924. The Academy was incorporated under the Code of West Virginia on May 9, 1959 as "a nonstock corporation, which is not organized for profit but for the advancement of learning and scientific knowledge."

Officers

1983-84

President	B. Das Sarma, Institute
President-Elect	Dr. Thomas K. Pauley, Bradford, PA
Past President	David Blaydes, Morgantown
Treasurer	Roy B. Clarkson, Morgantown
Assistant Treasurer	John R. Warner, Buckhannon
Archivist	Arthur S. Pavlovic, Morgantown
Secretaries	Elizabeth Bartholomew, Morgantown
	John Chisler, Glenville
Proceedings Editor	E. C. Keller, Jr., Morgantown
Talent Search Chairman	Joseph Glenco, Buckhannon
Chairman of West Virginia Junior Academy of Science	Zeke Wolfe, Buckhannon
Chairman of Annual Meeting at Buckhannon	Roger McCormick

Dues Structure

Student	$ 5.00
Regular	10.00
Contributing	20.00
Sustaining	40.00
Life	100.00
Corporation	200.00 minimum
Institutional	200.00 minimum
Patron	1,000.00

Institutional Members

Concord State College
Fairmont State College
Glenville State College
Marshall University
University of Charleston
West Virginia State College
West Virginia College of Graduate Studies
West Virginia University
West Virginia Wesleyan College

Contents

Proceedings of the West Virginia Academy of Science

E. C. Keller, Jr., Editor

Section Editors

Published by the West Virginia Academy of Science, Inc. Manuscripts for publication (which normally must have been read at an annual meeting of the Academy) should be sent to the Editor, E. C. Keller, Jr., Department of Biology, West Virginia University, Morgantown, W. Va. 26506-6057. All manuscripts are peer reviewed. Proof, edited manuscripts, and all correspondence regarding papers for publication should be directed to the Editor.

Applications for membership in the Academy and dues should be sent to Roy Clarkson, Treasurer, at the above address. Changes of address should be sent to Roy B. Clarkson, at the above address. Correspondence concerning library exchanges should be directed to the Director of Libraries, West Virginia University, Morgantown, W. Va. 26506.

The West Virginia Academy of Science and the Editors of the Proceedings of the West Virginia Academy of Science assume no responsibility for statements and opinions advanced by contributors.

Botany Section

Seven New Species and Other Noteworthy Collections for West Virginia

William Homer Duppstadt
Department of Biology
West Virginia University
P.O. Box 6057
Morgantown, West Virginia 26506

Abstract

Recent study at the West Virginia University Herbarium has revealed seven species new for the state.

The new species here reported are:

Najas guadalupensis (Spreng.) Magnus, Doddridge County (*Loy R. Phillippe* and *Denise Schmidt* 11809) August 27, 1982 and Doddridge County (*Loy R. Phillippe* 11818) August 28, 1982. (In our range. To be expected.)

Ranunculus sardous Crantz, Upshur County (*Floyd Bartley* s.n.) July 28, 1972 and Upshur County (*Floyd Bartley* s.n.) July 29, 1972. (Naturalized from Europe.)

Cassia tora L., Mercer County (*William N. Grafton* s.n.) October 1, 1982. (In our range. To be expected.)

Vicia hirsuta (L.) S.F. Gray, Greenbrier County (*William N. Grafton* s.n.) June 3, 1981. (Naturalized from Europe.)

Rhamnus cathartica L., Greenbrier County (*Harper W. Via, Jr.* s.n.) April 11, 1939; Greenbrier County (*William N. Grafton* and *Emily K. Grafton* s.n.) May 28, 1981 and Greenbrier County (*William N. Grafton* and *Emily K. Grafton* s.n.) September 6, 1981. (Introduced and naturalized from Europe.)

Epilobium hirsutum L., Tucker County (*Michael Berdine* s.n.) August 28, 1983. (Naturalized from Europe.)

Eupatorium capillifolium (Lam.) Small, Raleigh County (*Orpha Bailey* s.n.) October 20, 1982. (To our immediate south. To be expected.)

After a lapse of fifty years *Isoetes riparia* Engelm. has again been collected in the state. Our specimens are: Upshur County (*P.D. Strausbaugh* s.n.) July 20, 1933; Upshur County (*P.D. Strausbaugh* s.n.) July 30, 1933; Morgan County (*William N. Grafton,* s.n.) September 18, 1982; Morgan County (*Rodney Bartgis* s.n.) September 17, 1982 and Morgan County (*Rodney Bartgis* s.n.) September 15, 1983.

Carex eburnea Boott has again been collected after a lapse of forty-three years. Our specimens are: Pendleton County (*William Basil Fox* s.n.) July 13, 1940; Greenbrier County (*Rodney Bartgis* s.n.) June 30, 1983 and Grant County (*Rodney Bartgis* s.n.) August 14, 1983.

Ecology Section

The Occurrence of the Leech *Myzobdella lugubris* on *Notropis atherinoides* Rafinesque from West Virginia

Donald C. Tarter and Mark F. Sheridan
Department of Biological Sciences
Marshall University
Huntington, West Virginia 25701

Abstract

The emerald shiner, *Notropis atherinoides* Rafinesque, is a new host record for the leech *Myzobdella lugubris* Leidy. Other cyprinid hosts for the leech include the golden shiner *Notemigonous crysoleucas* (Mitchill), carp *Cyprinus carpio* Linnaeus, and the common shiner *Notropis cornutus* (Mitchill).

Introduction

During a recent survey of the fishes in selected tributaries of the Kanawha River drainage in West Virginia, the authors found the leech *Myzobdella lugubris* Leidy on the emerald shiner *Notropis atherinoides* Rafinesque. Previously, this leech had been reported on the black bullhead, *Ictalurus melas* (Rafinesque), and the mottled sculpin, *Cottus bairdi* Girard, from West Virginia (Schramm et al., 1981). White (1977) found the leech on the freshwater drum, *Aplodinotus grunniens* Rafinesque, from the nearby Gallipolis Locks and Dam, Ohio River Mile Point 279.2.

Materials and Methods

The emerald shiner, *Notropis atherinoides*, was collected 29 September 1982 in a "common-sense" nylon minnow seine from Little Hurricane Creek, Putnam County (38°31′18″N, 81°55′02″W), West Virginia. The leech was pressed between two slides and fixed in 10 percent formalin.

Results and Discussion

The emerald shiner is a new host record for *Myzobdella lugubris*. Of the 89 shiners collected from Little Hurricane Creek, only one shiner was parasitized by the leech. The place of attachment was the caudal fin.

Myzobdella lugubris is found in both freshwater and estuary habitats. It is widely distributed in 25 states throughout the range (Sawyer et al., 1976; Klemm, 1972; and Schramm et al., 1981). Other cyprinid hosts for *M. lugubris* include the golden shiner, carp and common shiner (Meyer, 1940; Maloney and Chandler, 1976; and White, 1977). White and Crisp (1973) reported the *Notropis atherinoides* as a new host record for the leech *Piscicolaria reducta* Meyer.

Acknowledgments

The authors are grateful to Dr. Donald Klemm, Research Aquatic Biologist, United States Environmental Protection Agency, for identification of the specimens of *Myzobdella lugubris*. Special thanks are given to Ms. Vickie Crager for typing the manuscript.

Literature Cited

1. Klemm, D. J. 1972. Freshwater leeches (Annelida: Hirudinea) of North America. Environmental Protection Agency, Project 18050ELD. Washington, D.C. 53 pp.
2. Maloney, S. D., and C. M. Chandler. 1976. Leeches (Hirudinea) in the upper Stones River drainage of middle Tennessee. *Amer. Midl. Nat.*, 95:42-48.
3. Meyer, M. C. 1940. A revision of the leeches (Piscicolidae) living on freshwater fishes of North America. *Trans. Am. Microsc: Soc.*, 59(3):354-376.
4. Sawyer, R. T., A. R. Lawler, and R. M. Overstreet. 1976. Marine leeches of the eastern United States and the Gulf of Mexico with a key to the species. *J. Nat. Hist.*, 9:633-667.
5. Schramm, J. C., C. H. Hardman, and D. C. Tarter. 1981. The occurrence of *Myzobdella lugubris* and *Piscicolaria reducta* (Hirudinea: Piscicolidae) on fishes from West Virginia. *Trans. Am. Microsc. Soc.*, 100(4):427-428.
6. White, G. E., and N. H. Crisp. 1973. The occurrence of four leeches (Hirudinea: Rhynchobdella: Piscicolidae) on Kentucky River drainage fishes. *Trans. Ky. Acad. Sci.*, 34:47-48.
7. White, G. E. 1977. New distribution records of fish leeches in the Ohio River. *J. Parasit.*, 63(6):1138.

Limnological Investigations in Fourpole Creek, Cabell County, West Virginia

Dale Adkins, Mike Carlisle, Bill Hampton,
Jim Meadows, Denise Schmidt, Diane Shirley,
Barry Wyant, and Donald Tarter
Department of Biological Sciences
Marshall University
Huntington, West Virginia 25701

Abstract

Fish populations, benthic macroinvertebrates and water samples were collected from nine stations in Fourpole Creek, Cabell County, West Virginia. Eight fish families comprising 21 species were identified from the stations. A total of 367 fish which weighed 5.4 kg was collected during the investigation. Game fishes comprised 7.1 percent of the total number of fishes and 9.6 percent of the total weight; forage fishes 80.1 percent by numbers and 60.3 percent by weight; and rough fishes 12.8 percent by numbers and 30.1 percent by weight. Benthic macroinvertebrates were represented by 11 orders, 20 families and approximately 26 species. The following benthic taxa were ranked according to percent frequency by number: Ephemeroptera (28.9), Gastropoda (12.3), Oligochaeta (11.2), Odonata (10.7), Isopoda (9.9), Decapoda (9.1), Diptera (8.6), Coleoptera (3.7), Hemiptera (2.7), Pelecypoda (2.1) and Megaloptera (1.6). The following physical and chemical parameters were recorded: dissolved oxygen, $\overline{X}$ = 7.2 (3.0-12.0) mg/1; total hardness, $\overline{X}$ = 235 (136.8-559.1) mg/1 $CaCO_3$; bicarbonate alkalinity, $\overline{X}$ = 113 (34.2-290.7) mg/1 $CaCO_3$; pH, $\overline{X}$ = 7.8 (7.5-8.5); and temperature, $\overline{X}$ = 25 (17-30) C.

Introduction

Fourpole Creek originates in the southeast part of Cabell County, West Virginia and flows 17.5 km northwest to the Ohio River. It travels through environments varying from rural pastureland at its headwaters to the residential, industrial and commercial areas near Huntington, West Virginia (Langford, 1981) (Figure 1). The stream has been subjected to at least three fish kills (Miles, 1972; Muth, 1974; Hoeft, 1980).

Materials and Methods

Between September 9, 1983, and November 16, 1983, the following nine stations were sampled for five water quality parameters and fish and benthic populations (Figure 1).

Station 1. Longitude 82°30′8″, Latitude 38°24′30″; near confluence of Fourpole Creek and the Ohio River.

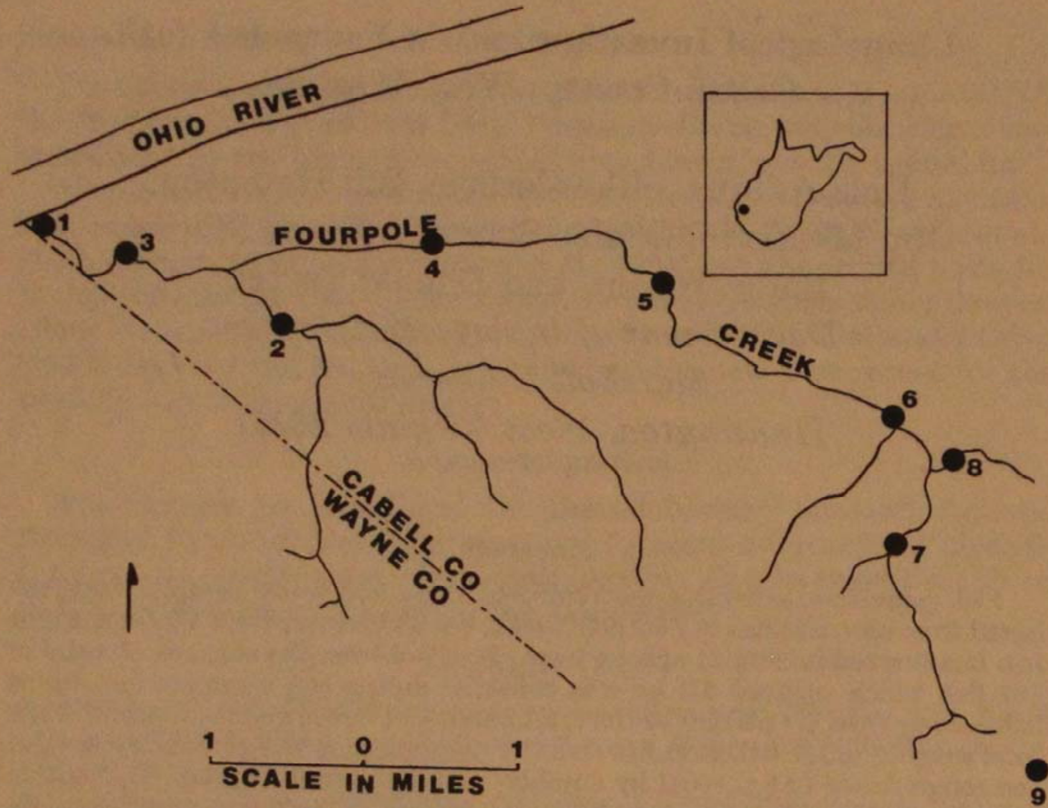


FIGURE 1. Map of Fourpole Creek, Cabell County, West Virginia, showing locations of collecting stations.

Station 2. Longitude 82°27′40″, Latitude 38°23′53″; Hisey Fork, off Memorial Blvd.

Station 3. Longitude 82°29′23″, Latitude 38°29′17″; Fourpole Creek near radio tower, Monroe Ave.

Station 4. Longitude 82°27′50″, Latitude 38°24′42″; Fourpole Creek at Ritter Park.

Station 5. Longitude 82°25′45″, Latitude 38°23′28″; Fourpole Creek at Meadows School.

Station 6. Longitude 82°24′03″, Latitude 38°23′28″; Fourpole Creek at junction at Woodville Rd.

Station 7. Longitude 82°24′03″, Latitude 38°22′41″; Fourpole Creek at Mount Union Rd.

Station 8. Longitude 82°23′37″, Latitude 38°23′11″; Grapevine Branch.

Station 9. Longitude 82°22′28″, Latitude 38°21′10″; Prices Creek.

Fish were collected at Station 1 by stretching a Trammel net (30 x 1.2 m) across the width of the stream. The net had an outer wall mesh of 25 cm and an inner wall mesh of 1.2 cm. A seine (1.2 x 2.4 m) with a 0.64 cm mesh was used for Stations 2-9. Specimens were immediately fixed and stored in 10 percent formalin. In the laboratory, fishes were air dried after sorting and weighed to the nearest tenth of a gram. Percent frequency by number and weight was then computed for each station. Although the sampling method was only loosely quantitative, the authors felt that the collection data represented a reasonable estimate of the relative abundance of the fish fauna.

Nomenclature followed that of the American Fisheries Society (1970). All populations were grouped into three categories (Tables 1-3): game (Centrarchidae, Scianidae), forage (Cyprinidae, Percidae, Percopsidae, Clupeidae) and rough (Catastomidae, Ictaluridae).

Benthic populations were sampled with a long-handled dredge with a net opening of 31.4 cm x 40.5 cm and a mesh size of 3 mm. Each station was sampled by disturbing the substrate while holding the dredge immediately downstream to catch the dislodged benthos. Specimens were then preserved in 70 percent ethanol and returned to the laboratory for

Table 1. List of Fishes Collected from Fourpole Creek, Cabell County, West Virginia, 1983

GAME FISHES	
Family Centrarchidae—Basses and Sunfishes	
Lepomis cyanellus Rafinesque	Green sunfish
L. macrochirus Rafinesque	Bluegill
L. megalotis (Rafinesque	Longear sunfish
Micropterus punctatus (Rafinesque)	Spotted bass
Family Scianidae—Drums	
Aplodinotus grunniens Rafinesque	Freshwater drum
FORAGE FISHES	
Family Cyprinidae—Minnows	
Campostoma anomalum (Rafinesque)	Stoneroller
Cyprinus carpio Linnaeus	Carp
Ericymba buccata Cope	Silver jawed minnow
Notropis atherinoides Rafinesque	Emerald shiner
N. chrysocephalus (Mitchell)	Striped shiner
Pimephales notatus (Rafinesque)	Bluntnose minnow
Phoxinus erythrogaster (Rafinesque)	Southern redbelly dace
Rhinichthys atratulus (Hermann)	Blacknose dace
Semotilus atromaculatus (Mitchell)	Creek chub
Family Percidae—Perches	
Etheostoma nigrum Rafinesque	Johnny darter
Family Percopsidae—Troutperches	
Percopsis omiscomaycus (Walbaum)	Troutperch
Family Clupeidae	
Dorosoma cepedianum (Lesueur)	Gizzard shad
ROUGH FISHES	
Family Catostomidae—Suckers	
Catostomus commersoni (Lacepede)	White sucker
Hypentelium nigricans (Lesueur)	Northern hogsucker
Family Ictaluridae—Freshwater Catfishes	
Ictalurus melas (Rafinesque)	Black bullhead
I. natalus (Lesueur)	Yellow bullhead

Table 2. Composition, Number (Parentheses) and Collecting Stations of Fishes in Fourpole Creek and Selected Tributaries, Cabell County, West Virginia, 1983

GAME FISHES—26
- Sunfishes and Basses
  - Spotted bass (1) 5
  - Green sunfish (3) 3
  - Bluegill (1) 6
  - Longear sunfish (20) 5,6,8
- Drums
  - Freshwater drum (1) 1

FORAGE FISHES—294
- Herrings
  - Gizzard shad (3) 5
- Minnows
  - Stoneroller (14) 7,8,9
  - Silver jawed minnow (18) 2,6,7,9
  - Emerald shiner (31) 3,4,5,7
  - Striped shiner (131) 2,3,4,5,6,7,8,9
  - Bluntnose minnow (16) 4,5,6,7,9
  - Southern redbelly dace (5) 8,9
  - Blacknose dace (6) 2,9
  - Creek chub (59) 2,3,4,5,6,8,9
  - Carp (1) 1
- Perches
  - Johnny darter (1) 3
- Troutperches
  - Troutperch (9) 6

ROUGH FISHES—47
- Suckers
  - White sucker (35) 4,5,6,7
  - Northern hogsucker (1) 9
- Freshwater catfishes
  - Black bullhead (2) 5,6
  - Yellow bullhead (9) 3,4,6,7

identification. Sampling was not quantitative, and numerical data were only computed for comparisons of relative abundance.

Water quality parameters measured at each station with a Hach chemical kit Model AL-36-WR were dissolved oxygen (mg/1), pH, total hardness (mg/1) and bicarbonate alkalinity (mg/1). The water temperature was measured at the surface with a mercury thermometer.

Table 3. Percent Frequency of Total Numbers and Weight of Game, Forage and Rough Fishes in Fourpole Creek, Cabell County, West Virginia, 1983. N = total number and weight

	Percent Frequency (Numbers)			*Percent Frequency (Weight-kg)*		
Station	*Game*	*Forage*	*Rough*	*Game*	*Forage*	*Rough*
1	2.5	75.0	0.0	10.9	89.1	0.0
2	0.0	100	0.0	0.0	100	0.0
3	16.7	72.2	11.1	3.5	92.0	4.5
4	0.0	94.1	5.9	0.0	72.7	27.3
5	11.8	79.4	8.8	12.2	62.7	25.1
6	11.5	79.4	9.1	15.2	48.0	36.8
7	0.0	36.6	63.4	0.0	93.6	6.4
8	37.5	62.5	0.0	44.9	55.1	0.0
9	0.0	97.0	3.0	0.0	97.3	2.7
N		367			5.4	

Results

A total of 367 fish was collected which represented 8 families and 21 species, and weighed 5.4 kg (Tables 1-3). Game, forage and rough fishes comprised 7.1, 80.1 and 12.8 percent, respectively, of the total number of fishes and 9.6, 60.3 and 30.1 percent, respectively, of the total weight (Table 3). The most abundant game fish by numbers was the longear sunfish. Striped shiners, creek chubs and emerald shiners were the most abundant forage fish by numbers while white suckers were the most abundant rough fish by numbers.

One-hundred and eighty-seven benthic macroinvertebrates were collected which represented 11 orders, 19 families and 25 genera of arthropods and mollusks (Table 4). Also present was one class of annelids. The following benthic taxa were ranked according to decreasing numerical percentages: Ephemeroptera (28.9), Gastropoda (12.3), Annelida (11.2), Odonata (10.7), Decapoda (9.1), Isopoda (9.1), Diptera (8.6), Coleoptera (3.7), Hemiptera (2.7), Pelecypoda (2.1) and Megaloptera (1.6).

The following ranges of chemical and physical parameters were within the acceptable ranges of good water quality (W. Va., 1974) (Table 5); dissolved oxygen, 7.2 (3.0-12.0) mg/1; pH, 7.8 (7.5-8.5); total hardness, 235 (136.8-559.1) mg/1; bicarbonate alkalinity, 113.0 (34.2-290.7) mg/1 $CaCO_3$; and temperature, 25.0 (17.0-30.0) °C.

Discussion

A fish kill resulting from a carbolic acid spill revealed 20 species from five different families (Department of Natural Resources, 1980). Except for the fantail darter, banded darter and yellow bullhead, the same fish species were found to be present in the 1983 study. Freshwater drum and gizzard shad were not reported in the 1980 fish kill, however.

Table 4. Composition, Number (Parentheses), and Percent Frequency of the Benthic Fauna in Fourpole Creek and Selected Tributaries, Cabell County, West Virginia, 1983. The Station Numbers are Found After the Number of Specimens. N = 187

ARTHROPODA
- Insecta
  - Coleoptera (7) 3.7%
    - Dytiscidae (1) 7
    - Hydrophilidae
      - *Hydrophilus* (6) 3,6
  - Diptera (16) 8.6%
    - Chironomidae (6) 1,3
    - Stratiomyidae
      - *Odontomyia* (1) 6
    - Tipulidae (1) 9
      - *Tipula* (8) 2,6,8
  - Ephemeroptera (54) 28.9%
    - Heptageniidae
      - *Heptagenia* (2) 6
      - *Stenonema* (52) 2,5,6,7
  - Hemiptera (5) 2.7%
    - Corixidae
      - *Sigara* (2) 6
    - Gerridae
      - *Gerris* (1) 6
      - *Limnogonus* (1) 6
    - Veliidae (1) 6
  - Megaloptera (3) 1.6%
      - *Sialis* (3) 6,7
  - Odonata (20) 10.7%
    - Anisoptera
      - *Boyeria* (1) 6
      - *Cordulegaster* (1) 6
      - *Lanthus* (8) 2,6,7
      - *Libellula* (2) 3,7
    - Zygoptera
      - *Agrion* (5) 2,3,5,7,8
      - *Amphiagrion* (2) 6
      - *Chromagrion* (1) 3
- Crustacea
  - Decapoda (17) 9.1%
      - *Orconectes* (17) 2,3,4,5,6,7
  - Isopoda (17) 9.1%
      - *Asellus* (3) 2
      - *Lirceus* (14) 2,9

MOLLUSCA
Gastropoda (24) 12.3%
Physa (23) 1,2,3,5,6,7,8,9
Pelecypoda (4) 2.1%
Corbicula (4) 3
ANNELIDA (21) 11.2%
Oligochaeta (15) 1
Flumbricilidae (6) 3,8,9

Table 5. Water Quality Analyses from Fourpole Creek, Cabell County, West Virginia, 1983

Station	*Temperature (°C)*	*pH*	*Dissolved Oxygen (mg/1)*	*Bicarbonate Alkalinity (mg/1 $CaCO_3$)*	*Total Hardness (mg/1 $CaCO_3$)*
1	28	7.5	7	85.5	205.2
2	28	8	12	119.7	153.9
3	30	7.5	6	136.8	205.2
4	28	8	4	76.95	171
5	23	8	8	85.5	239.4
6	17	7.5	3	102.6	559.1
7	21	8.5	8	290.7	205.2
8	——	8	9	85.5	239.4
9	——	8	8	34.2	136.8
Mean	25	7.8	7.2	113.0	235.0

In the Fourpole Creek investigation, game fish accounted for 7.1 percent of the total number of fishes. In other streams in the nearby area, game fish comprised 5.1 percent in the West Fork of Twelvepole Creek (Hardman et al., 1980) and 25.4 percent from the East Fork of Twelvepole Creek (Tarter, 1972). Olson (1971) reported that game fish composed 5.4 percent in a pre-impoundment study in the Beech Fork area of Twelvepole Creek.

In Fourpole Creek and selected tributaries, ephemeropterans, odonates and dipterans comprised 28.9, 10.7 and 8.6 percent of the sample, respectively. Tarter (1972) noted ephemeropterans (42.7%), odonates (7.4%) and dipterans (13.9%) in the benthic samples from the East Fork of Twelvepole Creek. In the West Fork of Twelvepole Creek, Hardman et al. (1980) reported ephemeropterans, odonates and dipterans made up 54.3, 9.2 and 7.6 percent of the benthic taxa, respectively. Ephemeropterans (15.6%), odonates (0.2%) and dipterans (18.7%) were recorded from benthic samples in a small, woodland tributary of Fourpole Creek (Ashley, 1977).

The overall productivity of Fourpole Creek is low, as is typical of similar streams in the area. It appears the stream has not completely recovered from the various fish kills. It is hoped that this study may serve as baseline data for any possible future development in the region.

Acknowledgments

The authors express thanks to Vickie Crager for her assistance in typing the manuscript.

Literature Cited

1. American Fisheries Society. 1970. A list of common and scientific names of fishes from the United States and Canada. Spec. Pub. No. 6. 150 pp.
2. Ashley, D. L. 1977. Life history and ecology of *Diploperla robusta* Stark and Gaufin (Plecoptera: Perlodidae) in a small, woodland stream, Cabell County, West Virginia. Unpublished Master's Thesis, Marshall University, Huntington, WV. 45 pp.
3. Hardman, C., M. Arcuri, K. Bledsoe, S. Lawton, J. Schramm, G. Tolley, and D. Tarter. 1980. A limnological investigation of the fishes, benthos and water quality of the West Fork of Twelvepole Creek, Mingo and Wayne counties, West Virginia. Proc. W. Va. Acad. Sci. 52(2):66-74.
4. Hoeft, M., B. F. Dowler, and R. Ross. 1980. Survey of streams. W.V. D-J Project F-10-R-23g.
5. Langford, S. 1981. Fourpole Creek: a water budget analysis. Unpublished Report, Marshall University, Huntington, WV. 169 pp.
6. Miles, R. 1972. Fish kill evaluation: Fourpole Creek. W. Va. Dept. Nat. Res., Charleston, WV.
7. Muth, S. 1974. Fish kill evaluation: Fourpole Creek. W. Va. Dept. Nat. Res., Charleston, WV.
8. Olson, D. E. 1971. A pre-impoundment investigation of the aquatic biology, and surveys of the wood vegetation and early socio-economic impact of a reservoir project on Beech Fork Basin, Twelvepole Creek, Wayne and Cabell counties, West Virginia. Unpub. Master's Thesis. Marshall University, Huntington, West Virginia. 87 pp.
9. Tarter, D. C. 1972. A preimpoundment investigation of the limnology of East Fork of Twelvepole Creek, Lincoln, Mingo and Wayne counties, West Virginia. Proc. W. Va. Acad. Sci. 44(1):94-103.
10. West Virginia. 1974. Administrative regulations of the State and West Virginia for water quality criteria on inter and intra state streams. West Virginia Department of Natural Resources, Division of Water Resources, Charleston, W. Va. 47 pp.
11. West Virginia. 1980. Department of Natural Resources.

Comparison of Brook Trout Populations in an Acidic, and a Circumneutral Stream

David M. Jordahl
Biology Department
West Virginia University
Morgantown, West Virginia 26506

Abstract

Little Laurel Run and Roaring Creek, Preston County, West Virginia, are third order soft water brook trout streams of similar mean annual discharge. Comparisons were made of brook trout population density and structure in two 200 meter sections of each stream. Sampling was done during late summer by electrofishing. Population density was estimated using single-census Petersen mark and recapture. Population structure was compared by length-frequency distribution. Young of the year brook trout were counted on three separate days during late spring 1983 in each 200 meter section. Physical and chemical parameters including discharge, temperature, pH, alkalinity, hardness, and aluminum were monitored in each section at biweekly intervals for one year.

Little Laurel Run had a pH range of 4.7 to 5.8; with annual means of 5.2 and 5.4 for the two sections. The pH range for Roaring Creek was 5.6 to 7.2 with annual means of 6.0 and 6.7. Late summer population estimates were 7 and 73 brook trout per 100 meter stream length for Little Laurel Run and Roaring Creek, respectively. The late summer length-frequency distribution of Little Laurel Run brook trout sampled shows a low frequency of young of the year trout and absence of some larger size classes compared with complete representation of expected size groups and abundant young in Roaring Creek. The late spring young of the year observations for both sections on Little Laurel Run averaged 0 and 2.7 per 100 meters of stream length, comparative values for Roaring Creek were 8.2 and 11.1.

The low population density and altered population structure of Little Laurel Run brook trout with extremely low frequency of young seems to be indicative of marginal reproductive success primarily related to the acidic character of this stream.

Introduction

Native brook trout (*Salvelinus fontinalis*) are generally confined to small tributaries and the headquarters of larger streams in West Virginia. Frequently these are soft water streams of low conductivity and low buffering capacity and therefore tend to be susceptible to acidification. The chemical characteristics of these streams is dependent upon the geology of their watersheds which determines the capacity of the soil and groundwater to neutralize acids (Henriksen, 1982; Norton, 1982).

The effects of low pH on fish populations has been extensively studied and many reviews are available (Haines, 1981; Schofield, 1976).

The chemical characteristics of some acid streams may not be detrimental to adult fish but can have chronic effects on the population that may ultimately lead to extinction. Disappearance of fish populations often occurs at pH levels that are not toxic to adults, however the species may fail to reproduce (Haines, 1981). Declining reproductive success leads to a decrease in population density and changes in population structure. Reproductive failure can be manifested as decreased hatchability and survival of eggs and fry (Menendez, 1976; Peterson *et al.*, 1982; Schofield, 1976; Trojnar, 1977), and as altered spawning behavior and reductions in egg viability (Menendez, 1976). The early life history of stages, especially the embryo and fry stages are most vulnerable to the effects of acidification (Haines, 1981). The effects of reproductive failure often result in a small population of older and larger fish (Harvey, 1982).

Roaring Creek and Little Laurel Run are soft water brook trout streams. Little Laurel Run is acidic with a mean pH below 5.5, Roaring Creek is circumneutral. The objective of this study was to compare the brook trout populations of these two streams and to determine if the extent of difference in population density and structure might warrant further study. It would be expected that the brook trout population of Little Laurel Run would exhibit the characteristics of a fish population under acid stress, by having a low density of predominantly older and larger fish.

Study Area

Little Laurel Run, a tributary of Laurel Run, is located within the West Virginia University forest in eastern Preston County, West Virginia approximately ten kilometers west of Bruceton Mills, West Virginia. Its watershed geology consists mainly of Pottsville sandstone. Little Laurel Creek, a tributary of Little Laurel Run, is also located within the West Virginia University forest. Roaring Creek, a tributary of the Cheat River, is located about five kilometers southeast of Lennox, West Virginia, in Preston County. Some exposed Greenbrier limestone occurs within the watershed. An abandoned limestone quarry is located less than one kilometer from one of the study sites. Roaring Creek, Little Laurel Run, and Little Laurel Creek are third order coldwater brook trout streams of low conductivity and hardness. Roaring Creek has slightly greater discharge, more gravel in its bed, and a generally steeper gradient than Little Laurel Run.

Methods

Two 200 meter sections on each stream were selected as sampling sites. For Little Laurel Run one section is about 500 meters upstream from its confluence with Little Laurel Creek and the other site was located the same distance downstream from the confluence (Figure 1). A third 200 meter section was located on Little Laurel Creek. Two similar sites were selected on Roaring Creek approximately one kilometer from each other (Figure 2).

Discharge and temperature were recorded in the field at two week intervals for one year. Discharge was determined from measurements of

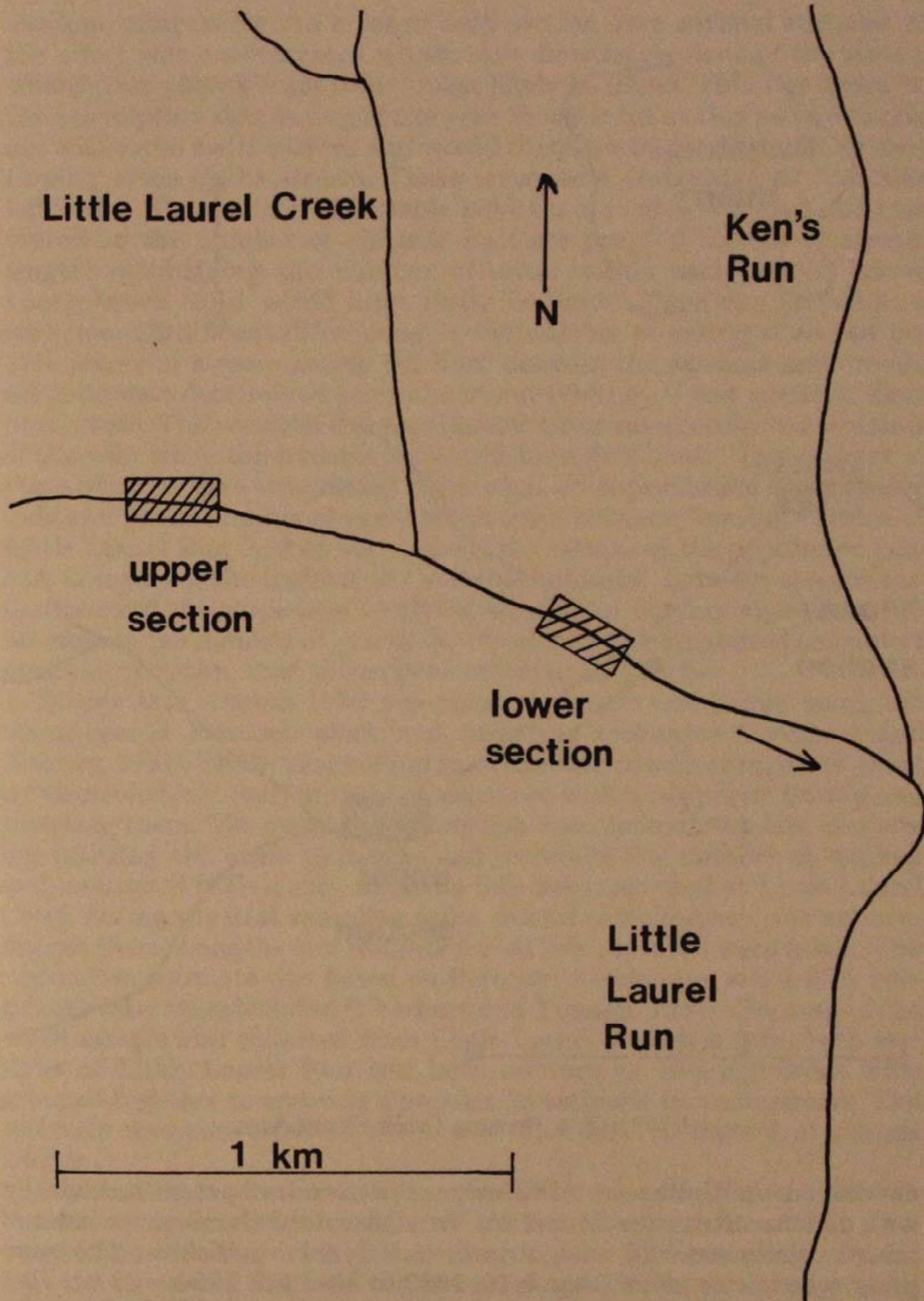


FIGURE 1. Little Laurel Run Study Area.

width, depth, and current velocity using a Teledyne Gurley pygmy current meter (Model 625). Water samples were collected at the same time and analysis done in the laboratory for pH, alkalinity, hardness, and total dissolved aluminum. pH was determined with a Corning pH meter (Model 7), hardness was determined by volumetric titration with Erio-

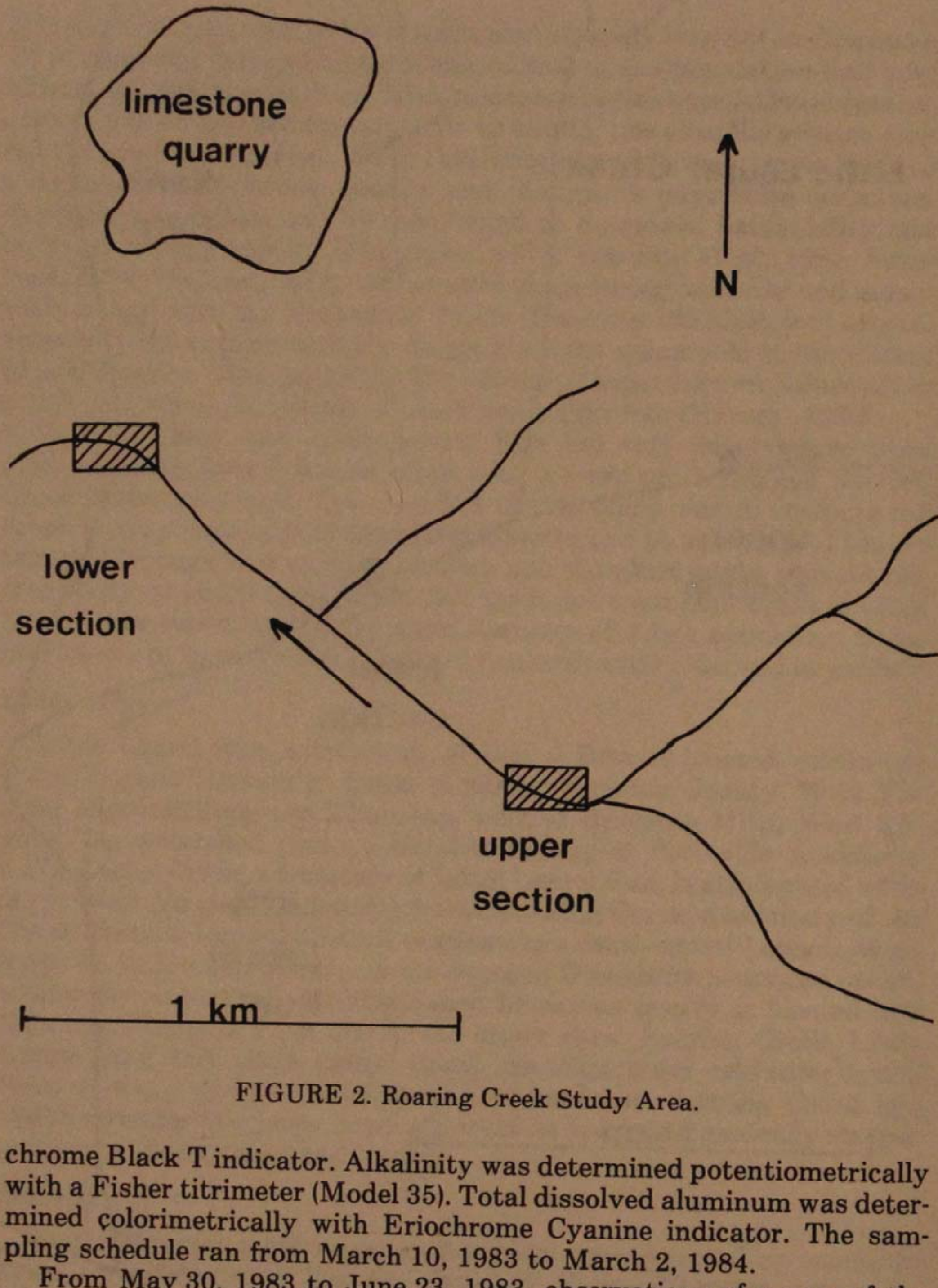


FIGURE 2. Roaring Creek Study Area.

chrome Black T indicator. Alkalinity was determined potentiometrically with a Fisher titrimeter (Model 35). Total dissolved aluminum was determined colorimetrically with Eriochrome Cyanine indicator. The sampling schedule ran from March 10, 1983 to March 2, 1984.

From May 30, 1983 to June 23, 1983, observations of young of the year (age 0 brook trout) were made on three separate days for each 200 meter section. Data collection consisted of walking upstream within the stream and recording the number of age 0 brook trout seen. The time required to cover 200 meters was recorded which was usually one hour. These observations were converted to the number of young observed per 100 meters of stream length per hour; this conversion expresses the data on a per unit effort basis in order to make observations between stream sections comparable. All areas of each section were covered but most of the effort was concentrated within slow flowing sections of the stream where young brook trout would most likely be found. This was based on the assumption that young of the year brook trout at this early age cannot withstand swift current and would therefore be concentrated in slow flowing areas of the stream. These areas were designated as "suitable habitats." The number of suitable habitats was also recorded and converted to the number of suitable habitats per 100 meters of stream length; quantifying the number of areas within each section where young brook trout would most likely be found. Each day served as a replicate. Significant differences in the number of young observed per 100 meters of stream length per hour between the streams and stream sections were determined using the Mann-Whitney U test statistic (Conover, 1980). The young of the year observations were conducted at a time of the year when the streams were near base flow levels. The purpose of these observations were meant to serve as an approximate comparative indicator of the number of age 0 brook trout between Roaring Creek and Little Laurel Run, and to supplement the results of the population census. Comparing the number of "suitable habitats" between stream sections served the purpose of verifying whether or not any significant differences in the number of young observed could be attributed to habitat availability rather than differences in water chemistry.

During late August 1983 a population census was begun using the single-census Petersen mark and recapture technique (Everhart and Youngs, 1981). The first sampling run consisted of collecting brook trout by electrofishing, marking all fish captured with a left pelvic fin clip and releasing them. The second sampling run was made during late September utilizing the same technique and recording the number of marked and unmarked individuals. Since no fish were captured at Little Laurel Creek during the first sampling run a second sampling run was not conducted there. Lengths and weights for all fish captured were taken. The population estimate was based on Petersen's technique and a 95% confidence interval calculated (Everhart and Youngs, 1981). Because of the small sample size collected from Little Laurel Run, fish from both sections of Little Laurel Run and both sections of Roaring Creek were grouped together to arrive at a population estimate for each stream. The estimate was converted to number of fish per 100 meters of stream length.

Population structure was determined using length-frequency distribution histograms constructed from the data for brook trout that were caught once (all those fish collected during the first sampling run and only the unmarked fish from the second sample). Fish were grouped into 5 mm length classes and the number recorded for each length class. Young of the year (age 0) brook trout were considered to be those individuals less than 80 mm long; which is their approximate maximum length during late summer.

Results

Little Laurel Run and Roaring Creek exhibit the characteristic seasonal fluctuation of discharge and pH showing a general inverse relationship. Low discharge, high pH occurs during summer, and high discharge, low pH during early spring (Figures 3 & 4). High concentrations of total dissolved aluminum generally correspond to low pH levels during periods of high discharge in early spring (Figures 5 & 6). This trend is more apparent in Little Laurel Run than in Roaring Creek which has very low concentrations of total dissolved aluminum at all times of the year (Figure 6). Tables 1 and 2 summarize the physical and chemical parameters of both streams. Mean annual discharge rates are similar for comparable sections on both streams although greater extremes are exhibited by Little Laurel Run (Table 1). Hardness concentrations are less than 20 mg/1 (Table 2) for all sections indicating that Roaring Creek and Little Laurel Run are comparable soft water streams. The lower section of Roaring Creek which has the highest mean pH also exhibits relatively high values for hardness and alkalinity (Table 2). The major difference between the two streams is pH, Little Laurel Run is acidic, Roaring Creek is circumneutral.

Young of the year observations are presented in Table 3 and Figure 7. The number of young of the year brook trout observed per 100 meters of stream length per hour was significantly greater at Roaring Creek than at Little Laurel Run according to Mann-Whitney U test statistic at an alpha probability level of less than 0.005. The number of young of the year brook trout was also significantly greater at upper Roaring Creek than at upper Little Laurel Run at an alpha probability level of less than 0.05, however there was no significant difference between the upper and lower sections of Roaring Creek at an alpha probability level of 0.05. Although some variability in the number of suitable habitats per 100

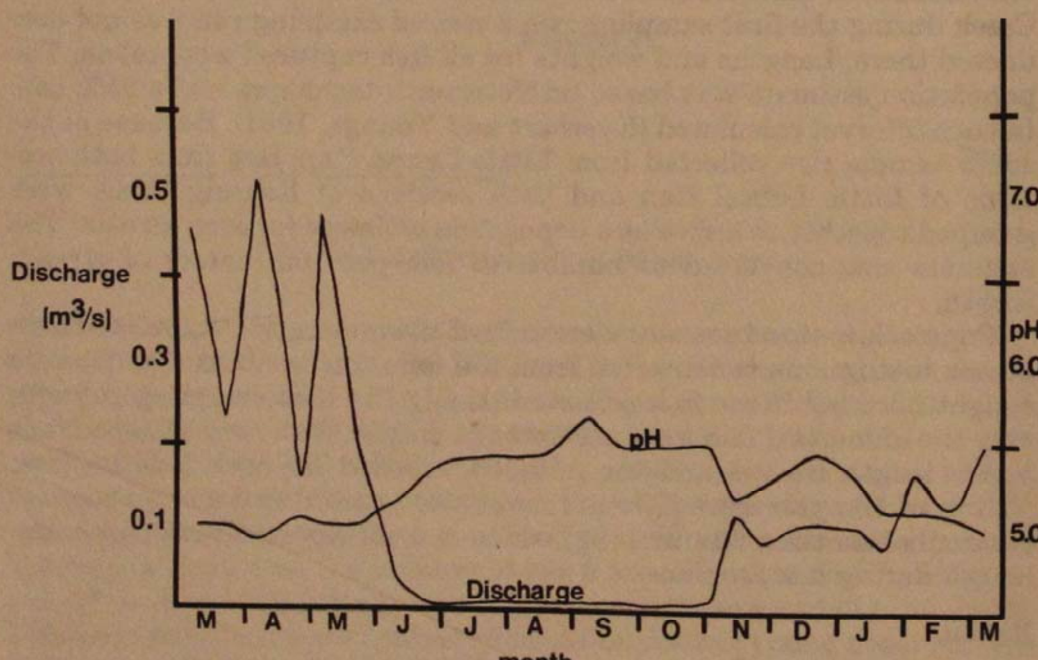


FIGURE 3. Discharge and pH Fluctuations, lower Little Laurel Run (March, 1983 to March, 1984).

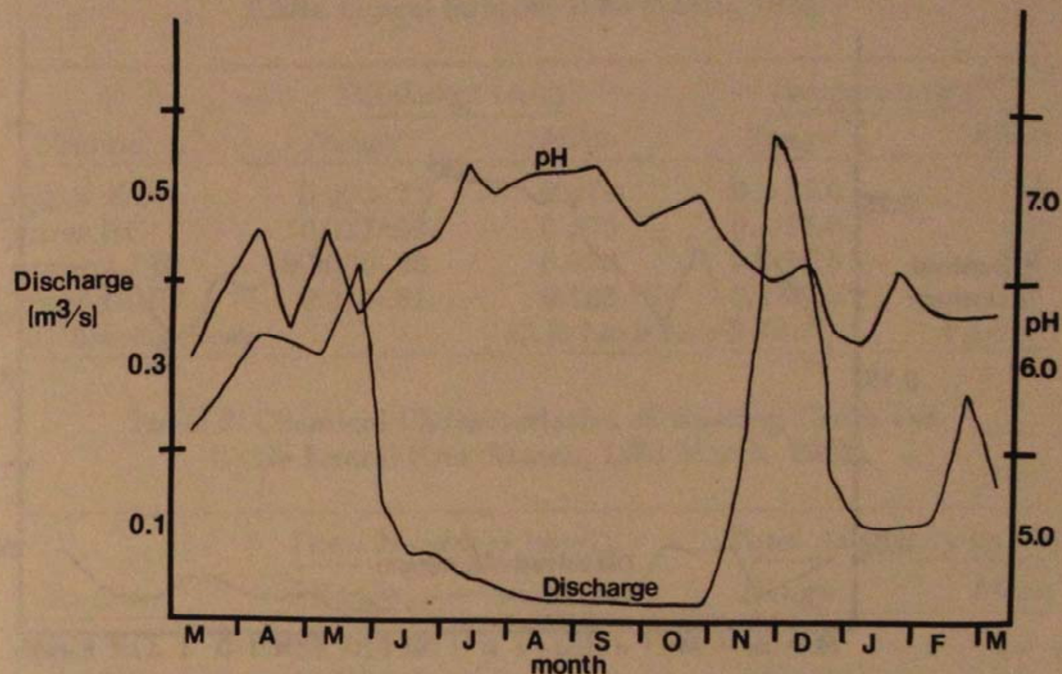


FIGURE 4. Discharge and pH Fluctuations, lower Roaring Creek (March, 1983 to March, 1984).

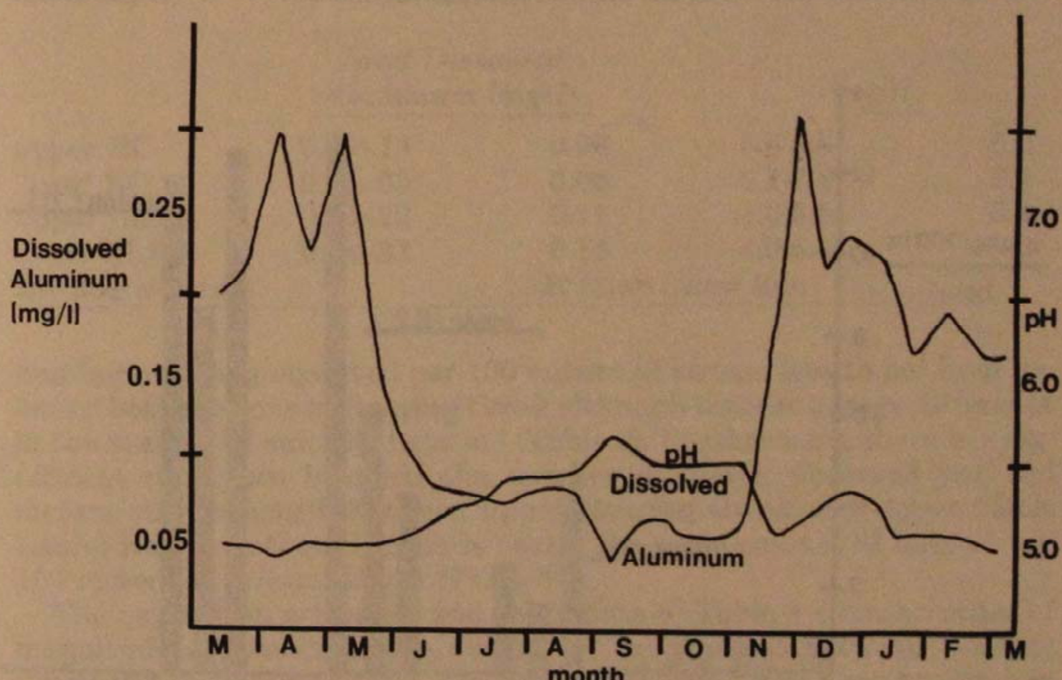


FIGURE 5. Total Dissolved Aluminum Concentrations and ph Fluctuations, lower Little Laurel Run (March, 1983, to March, 1984).

meters of stream length is evident (Table 3), there is no apparent relationship between the number of suitable habitats and the number of young observed. For example, there is no significant difference in the

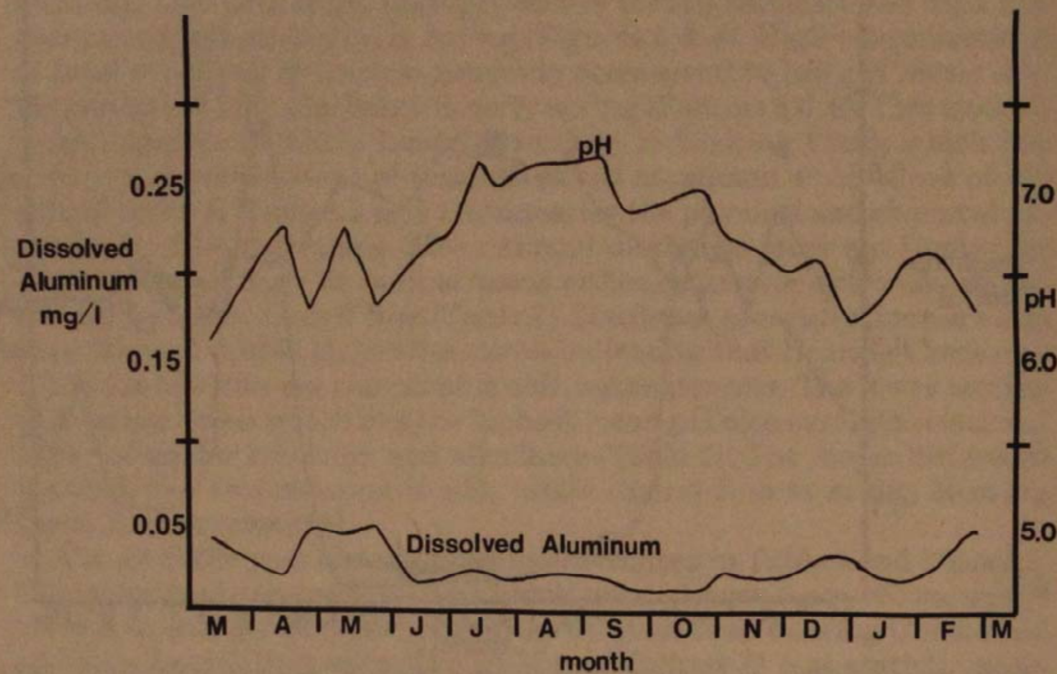


FIGURE 6. Total Dissolved Aluminum Concentrations and pH Fluctuations, lower Roaring Creek (March, 1983 to March, 1984).

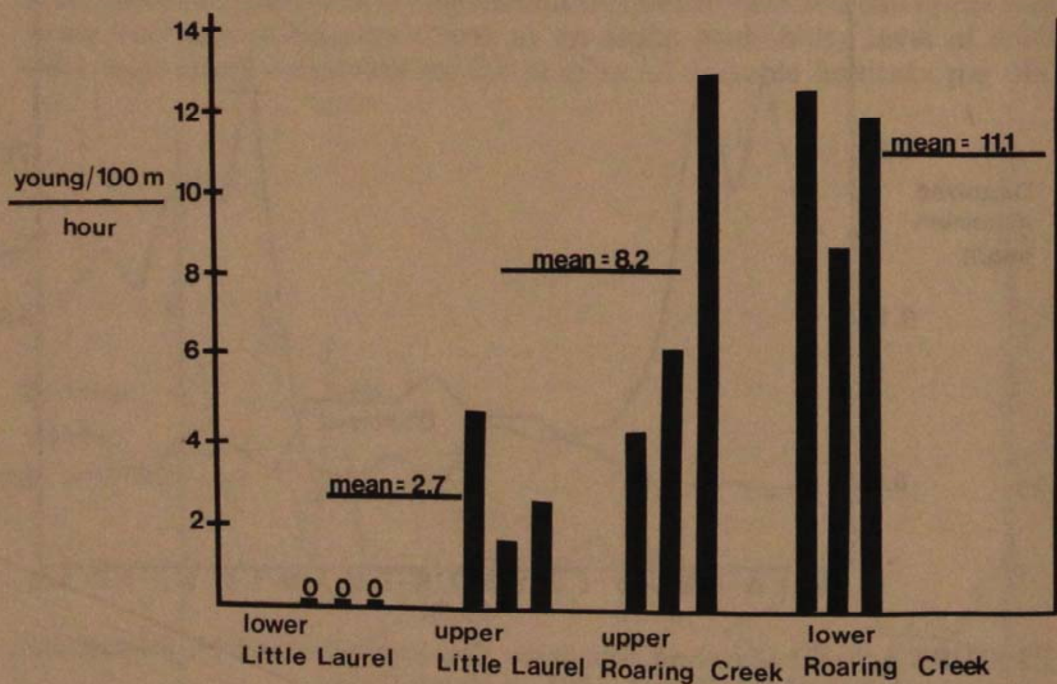


FIGURE 7. Young of the Year (age 0 brook trout) Observations (May-June, 1983).

Table 1. Physical Characteristics of Roaring Creek and Little Laurel (March, 1983-March, 1984)

	Discharge (m^3/s)		Temperature (°C)	
Section	Range	Mean	Range	Mean
upper RC	0.003-.27	0.079	0.2-17.0	8.4
lower RC	0.011-.59	0.175	0.1-17.0	8.9
upper LLR	0.0005-.23	0.068	0.0-19.5	9.6
lower LLR	0.010-.61	0.165	0.2-20.2	10.0

RC: Roaring Creek LLR: Little Laurel Run

Table 2. Chemical Characteristics of Roaring Creek and Little Laurel Run (March, 1983-March, 1984)

	Total Hardness (mg/1)		Total Alkalinity (mg/1)	
Section	Range	Mean	Range	Mean
upper RC	10.7-16.5	13.4	1.6-3.7	2.3
lower RC	12.7-20.1	16.2	2.9-5.8	4.2
upper LLR	10.3-16.7	13.4	1.0-2.0	1.5
lower LLR	10.0-17.0	12.8	0.8-1.6	1.3
	Total Dissolved Aluminum (mg/1)		pH	
upper RC	0.02-.13	0.06	5.6-6.6	6.0
lower RC	0.01-.05	0.03	6.1-7.2	6.7
upper LLR	0.04-.22	0.11	5.0-5.8	5.4
lower LLR	0.04-.31	0.16	4.9-5.7	5.2

RC: Roaring Creek LLR: Little Laurel Run

number of young observed per 100 meters of stream length per hour between both sections of Roaring Creek although there is a large difference in the number of suitable habitats (Table 3). Furthermore, there is a significant difference between the number of young observed per 100 meters stream length between upper Roaring Creek and upper Little Laurel Run even though there is nearly the same amount of habitat per 100 meters of stream length (Table 3).

The population estimates and catch data of Table 4 show an order of magnitude difference in the density of brook trout between Roaring Creek and Little Laurel Run. The population density of Roaring Creek is substantially greater. Scarcity of young trout and the absence of many length classes is evident in the Little Laurel Run population (Figure 8). This population seems to consist of a low density of large trout (greater than 130 mm total length) with a very low frequency of small trout. The Roaring Creek population shows complete representation of all length classes and abundant numbers of small trout (Figure 9).

Table 3. Young of Year (age 0 brook trout) Observations (May-June, 1983)

Section	*Range: # young/100 m per hour*	*# of days surveyed*	*Mean: # young/100 m per hour*
upper RC	4.2-12.6	3	8.2
lower RC	9.4-12.6	3	11.1
upper LLR	1.6- 4.9	3	2.7
lower LLR	———	3	0

Section	*Range: # of suitable habitats/100 m*	*Mean: # of suitable habitats/100 m*
upper RC	14.5-19.5	17.0
lower RC	21.0-27.5	23.0
upper LLR	16.0-21.5	17.8
lower LLR	16.5-18.0	17.6

RC: Roaring Creek LLR: Little Laurel Run

Table 4. Catch Data and Petersen Population Estimates (August-September, 1983)

Stream	*Total # of brook trout caught once (during 2 sampling runs)*	*# age 0 brook trout caught once (during 2 sampling runs)*
Roaring Creek	181	68
Little Laurel Run	21	4

Stream	*Population Estimate (No./400 m)*[a]	*Population Estimate (No./100 m)*
Roaring Creek	291 (± 54)[b]	73
Little Laurel Run	26 (± 9)[b]	7

[a]Combined upper and lower sections of Roaring Creek, and Little Laurel Run.
[b]95% confidence interval (Everhart and Youngs, 1981).

Discussion

The physical characteristics of Roaring Creek and Little Laurel Run are nearly identical except for the slightly higher water temperatures and greater seasonal fluctuations of discharge at Little Laurel Run. Baseflow water levels are higher in Roaring Creek than at Little Laurel Run indicating that it has a greater proportion of groundwater recharge which would be one reason for its higher alkalinity and pH (Norton, 1982). The Roaring Creek watershed also contains Greenbrier limestone which has a greater buffering capacity than the Pottsville sandstone of

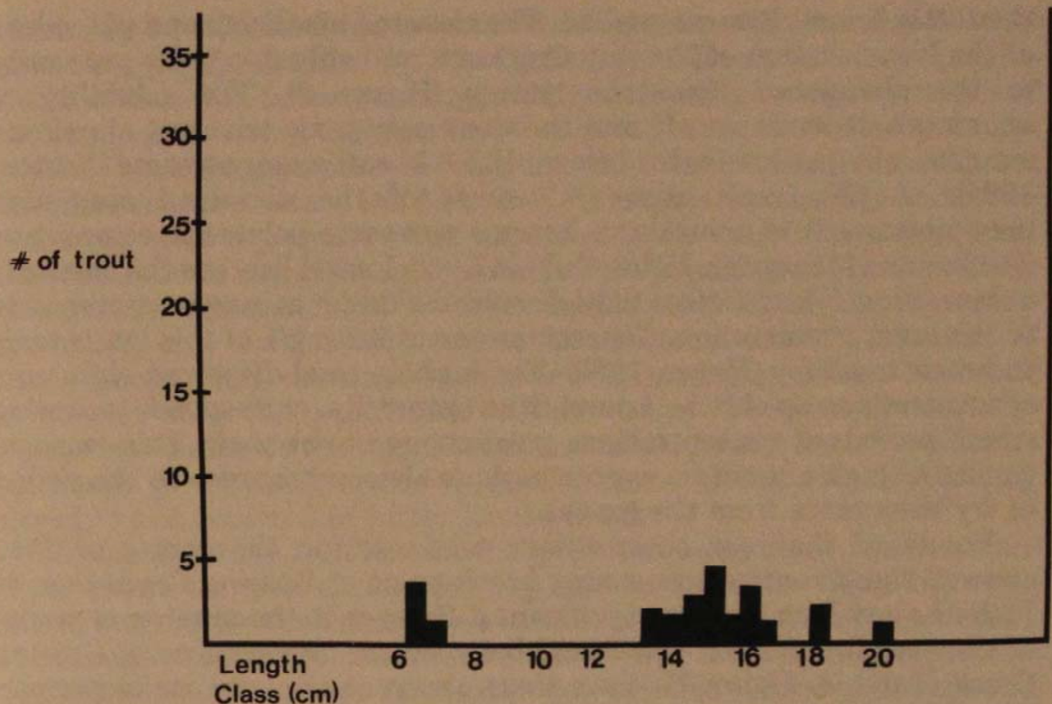


FIGURE 8. Length-Frequency Distribution, Little Laurel Run Brook Trout Population (August-September, 1983).

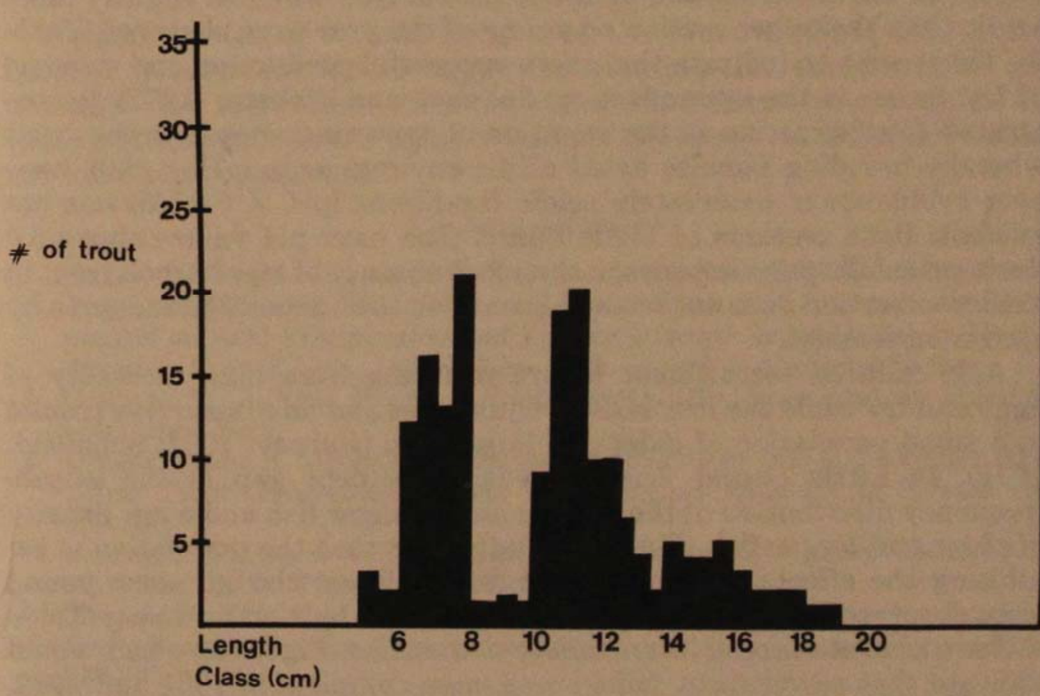


FIGURE 9. Length-Frequency Distribution, Roaring Creek Brook Trout Population (August-September, 1983).

the Little Laurel Run watershed. The elevated alkalinity and pH values of the lower section of Roaring Creek are probably due to its proximity to the abandoned limestone quarry (Figure 2). The solubility of aluminum depends on pH and the extremely toxic trivalent aluminum ion generally predominates below pH 5.5 in soft water streams (Norton, 1982); at pH levels above 5.5 most of the dissolved aluminum precipitates out of solution to become non-toxic polymeric compounds (Decker and Menendez, 1974). Only in Little Laurel Run are the mean pH values below 5.5, therefore total dissolved aluminum may consist mostly of the toxic trivalent ion. Concentrations of 0.2 mg/1 of this ion is toxic to brook trout fry (Baker, 1982). The highest total dissolved aluminum concentrations in Little Laurel Run generally correspond to spring runoff periods at concentrations great enough to be toxic. This seasonal timing of high aluminum concentrations also corresponds to the period of fry emergence from the gravel.

Young of the year observations made during the spring of 1983 showed significantly more young brook trout at Roaring Creek than at Little Laurel Run, but no significant difference in the number of young of the year brook trout was found between the two sections of Roaring Creek (Table 3, Figure 7). Since these observations were made comparable by expressing the data on a per unit effort basis (# of young/100 m stream length/hour), it would seem that the Little Laurel Run population has a substantially lower density of age 0 brook trout than Roaring Creek. In the lower section of Little Laurel Run which is slightly more acidic than the upper section no young of the year were observed (Table 3). This seems to indicate that more successful production and survival of fry occurs in the upper section. Johnson and Webster (1977) demonstrated discrimination in the selection of spawning sites in brook trout whereby breeding females avoid acidic environments (pH < 5.0), however avoidance of moderately acidic conditions (pH $\times$ 5.0-5.5) was not evident. Both sections of Little Laurel Run have pH values above 5.0 during the fall spawning season therefore absence of age 0 brook trout in the lower section does not seem to be related to avoidance of that area by spawning females.

Acid induced recruitment failure resulting from high mortality of eggs and fry while the less sensitive juveniles and adults survive results in a small population of older and larger fish (Harvey, 1982; Schofield, 1976). In Little Laurel Run there is an evident gap in the length-frequency distribution of the smaller and younger fish and a low density of older and larger fish (Figure 8), indicating that the population is exhibiting the effects of reproductive failure. Even though some young were observed (Table 3, Figure 7) and collected by electrofishing (Table 4) there is an absence of intermediate size classes (Figure 8), which would indicate that recruitment failure was more complete in 1981 and 1982. Obviously some reproduction did occur in 1983 to explain the presence of young fish (age 0) although they were mostly confined to the less acidic upper section of Little Laurel Run (Table 3). Since these young have now passed the most sensitive stage in their life history their chances of survival may be enhanced due to reduced competition for resources because of the low population density. The Little Laurel Run brook trout population may therefore be maintaining itself by depending on reproduction and recruitment occurring during a few favorable years rather than annually.

Since both streams possess relatively the same physical but different chemical characteristics, the differences in population density and structure seem to be due to the acidic nature of Little Laurel Run. Reproduction seems to be marginal and sporadic. This population is in the vulnerable position of depending on a few favorable years for any significant reproduction and recruitment to occur. Little Laurel Creek, a tributary of Little Laurel Run, does not have a brook trout population. No brook trout were observed or collected in this stream. Temperature and discharge are similar to the upper section of Little Laurel Run, however its pH range is 4.7 to 5.3 with an annual mean of 4.9. Extinction may already have occurred in Little Laurel Creek.

The Little Laurel Run brook trout population appears to be in a transition phase towards extinction, any further increases in acidification and it may suffer the same fate as the Little Laurel Creek population. The results of this study have warranted further investigation and a current study is underway to assess differences in survivorship of eggs and sac fry in the field between Little Laurel Run, Little Laurel Creek, and Roaring Creek.

Acknowledgments

I thank Professor Arnold Benson of the West Virginia University Biology Department for his suggestions during this study and for his critical review and comments of the manuscript. I am also grateful to all those who helped with the fieldwork without whose help this study could not have been completed.

Literature Cited

1. Baker, J. P. 1982. Effects on Fish of Metals Associated With Acidification. Pages 165-176 in Acid Rain/Fisheries, Proceedings of an International Symposium on Acid Precipitation and Fishery Impacts in Northeastern North America. Cornell Univ. Ithaca, New York. American Fisheries Society.
2. Conover, W. J. 1980. Practical Nonparametric Statistics, 2nd ed. Wiley & Sons, New York.
3. Decker, C. and R. Menendez. 1974. Acute Toxicity of Iron and Aluminum to Brook Trout. Proceedings of the West Virginia Academy of Science 46: 159-167.
4. Everhart, W. H. and W. D. Youngs. 1981. Principles of Fishery Science, 2nd ed. Cornell Univ. Press, Ithaca, New York.
5. Haines, T. A. 1981. Acid Precipitation and Its Consequences for Aquatic Ecosystems: A Review. Transactions of the American Fisheries Society 110: 669-707.
6. Harvey, H. H. 1982. Population Responses of Fishes in Acidified Waters. Pages 227-242 in Acid Rain/Fisheries, Proceedings of an International Symposium on Acid Precipitation and Fishery Impacts in Northeastern North America. Cornell Univ. Ithaca, New York. American Fisheries Society.

7. Henriksen, A. 1982. Susceptibility of Surface Waters to Acidification. Pages 103-121 in Acid Rain/Fisheries, Proceedings of an International Symposium on Acid Precipitation and Fishery Impacts in Northeastern North America. Cornell Univ. Ithaca, New York. American Fisheries Society.
8. Johnson, D. W. and D. A. Webster. 1977. Avoidance of Low pH in Selection of Spawning Sites by Brook Trout. Journal of the Fisheries Research Board of Canada 34:2215-2218.
9. Menendez, R. 1976. Chronic Effects of Reduced pH on Brook Trout. Journal of the Fisheries Research Board of Canada 33: 118-123.
10. Norton, S. A. 1982. The Effects of Acidification on the Chemistry of Ground and Surface Waters. Pages 93-102 in Acid Rain/Fisheries, Proceedings of an International Symposium on Acid Precipitation and Fishery Impacts in Northeastern North America. Cornell Univ. Ithaca, New York. American Fisheries Society.
11. Peterson, R. H., P. G. Daye, G. L. Lacroix, and E. T. Garside. 1982. Reproduction in Fish Experiencing Acid and Metal Stress. Pages 177-196 in Acid Rain/Fisheries, Proceedings of an International Symposium on Acid Precipitation and Fishery Impacts in Northeastern North America. Cornell Univ. Ithaca, New York. American Fisheries Society.
12. Schofield, C. L. 1976. Acid Precipitation: Effects on Fish. Ambio 5: 228-230.
13. Trojnar, J. R. 1977. Egg Hatchability and Tolerance of Brook Trout Fry at Low pH. Journal of the Fisheries Research Board of Canada 34: 574-579.

Progress Report: West Virginia Department of Natural Resources Freshwater Mussel (Naiad) Population Inventory

John E. Schmidt, *Aquatic Biologist*
West Virginia Department of Natural Resources
Division of Water Resources
1201 Greenbrier Street
Charleston, West Virginia 25311

and

Michael A. Zeto, *Aquatic Biologist*
West Virginia Department of Natural Resources
Division of Water Resources
350 North Vance Drive
Beckley, West Virginia 25801

Abstract

To date, ten major streams and three river basins within West Virginia have been investigated for freshwater mussel (naiad) populations. Three additional streams have been investigated, but no living naiads have been collected. The majority of this work has been conducted with Marshall University and the U.S. Fish and Wildlife Service. Sampling has been ongoing since mid-1980, and sampling techniques have included bank collection, water scopes, snorkeling and brailing.

A total of 49 naiad species plus the asiatic clam (Corbicula sp.) have been collected thus far. This number is expected to increase to approximately 60 as streams are investigated more thoroughly and additional streams are sampled.

PROGRESS REPORT: West Virginia Department of Natural Resources Freshwater Mussel (Naiad) Population Inventory.

Introduction

The West Virginia Department of Natural Resources, Division of Water Resources has been surveying freshwater mussel (or naiad) populations throughout the state since 1980. The purpose of this inventory is to determine what naiad species reside in the state and locate viable, reproducing populations of naiads. Eventually, a network of stations will be set up to monitor ambient water quality using naiads. These stations will be revisited every 5-10 years to determine changes in naiad populations, or a number of selected naiad species will be removed to analyze their shells and soft parts for metals and pesticides on a yearly basis.

Materials and Methods

Initial sampling consisted of reconnaissance on selected streams as part of 303(e) basin planning performed by members of our Planning Branch. All locations where naiads were found are noted. In addition, reports from citizens and other DNR employees aided in locating naiads.

At each station the banks were first walked looking for washed up shells and shell middens (shell piles left by muskrats and raccoons). If the water was shallow, the stream bottom was searched for naiads by wading with a water scope. In deeper water a mussel brail was used. Snorkeling was also employed at both shallow and deep water locations. For each station a record was kept of the number of live, freshly dead, and relic naiads collected. Representative specimens are kept from each station. Very few live naiads were kept if suitable, freshly-dead shells were available. All collected naiads were bagged and labeled for species and location and returned to the lab for cleaning and species verification.

Results and Discussion

Between 1980 and the present, ten major streams and three river basins were investigated and were found to have naiad populations (Table 1). Additionally, the Coal/Little Coal rivers, the Shenandoah River, and Opequon Creek have been superficially investigated but no living naiads have yet been collected. Each has naiad populations that

Table 1. Naiad Species Collected by the Freshwater Mussel (Naiad) Inventory

SPECIES	BIG SANDY RIVER	BLUESTONE RIVER	ELK RIVER/BIG SANDY CREEK	GREENBRIER RIVER	KANAWHA RIVER	LITTLE COAL/COAL RIVERS	NEW RIVER/INDIAN CREEK	OHIO RIVER	OPEQUON CREEK	POTTS CREEK	SHENANDOAH RIVER	SOUTH BRANCH POTOMAC RIVER	TUG FORK RIVER	HUGHES RIVER BASIN	LITTLE KANAWHA RIVER BASIN	MONONGAHELA RIVER BASIN	TOTALS
1. *Anodonta cataracta*												X					1
2. *Anodonta g. grandis*							X	X					X	X	X	X	6
3. *Anodonta imbecillis*								X									1
4. *Anodontoides ferussacianus*															X		1
5. *Strophitus u. undulatus*					X			X		X		X	X	X	X	X	8
6. *Alasmidonta varicosa*											X	X					2
7. *Alasmidonta marginata*		X		X													2
8. *Simpsonaias ambigua*																X	1
9. *Lasmigona complanata*								X					X	X			3
10. *Lasmigona costata*	X		X		X								X	X	X	X	7

11. *Megalonaias nervosa*								X									1
12. *Tritogonia verrucosa*		X		X			X						X	X	X	X	7
13. *Quadrula metanevra*								X									1
14. *Quadrula nodulata*								X									1
15. *Quadrula pustulosa*			X		X			X					X		X		5
16. *Quadrula quadrula*								X					X		X		3
17. *Amblema p. plicata*			X		X			X					X	X	X	X	7
18. *Fusconaia flava*			X					X					X	X	X	X	6
19. *Fusconaia maculata*			X		X								X				3
20. *Cyclonaias tuberculata*		X		X	X		X								X		5
21. *Plethobasus cyphyus*								X									1
22. *Pleurobema clava*														X	X	X	3
23. *Pleurobema cordatum*								X									1
24. *Pleurobema sintoxia*			X		X									X	X	X	5
25. *Elliptio complanata*									X		X	X					3
26. *Elliptio crassidens*								X					X				2
27. *Elliptio dilatata*		X	X	X	X		X							X	X	X	8
28. *Canthyria collina*										X							1
29. *Ptychobranchus fasciolaris*			X		X									X	X	X	5
30. *Obliquaria reflexa*					X			X									2
31. *Cyprogenia stegaria*					X												1
32. *Actinonais lig. carinata*	X	X	X	X	X		X	X					X	X	X		10
33. *Obovaria subrotunda*	X		X		X	X		X						X	X	X	8
34. *Truncilla donaciformes*								X									1
35. *Truncilla truncata*															X		1
36. *Leptodea fragilis*	X				X			X					X	X			5
37. *Potamilus alatus*	X							X					X	X	X		5
38. *Potamilus ohiensis*	X							X									2
39. *Toxolasma parvus*								X									1
40. *Liguimia recta*								X									1
41. *Villosa i. iris*		X					X							X	X		4
42. *Villosa lienosa*															X		1
43. *Lampsilis abrupta*					X												1

Table 1.—*(Continued)*

SPECIES	*BIG SANDY RIVER*	*BLUESTONE RIVER*	*ELK RIVER/BIG SANDY CREEK*	*GREENBRIER RIVER*	*KANAWHA RIVER*	*LITTLE COAL/COAL RIVERS*	*NEW RIVER/INDIAN CREEK*	*OHIO RIVER*	*OPEQUON CREEK*	*POTTS CREEK*	*SHENANDOAH RIVER*	*SOUTH BRANCH POTOMAC RIVER*	*TUG FORK RIVER*	*HUGHES RIVER BASIN*	*LITTLE KANAWHA RIVER BASIN*	*MONONGAHELA RIVER BASIN*	*TOTALS*
44. *Lampsilis cariosa*											X						1
45. *Lampsilis fasciola*		X	X	X	X		X								X		6
46. *Lampsilis radiata luteola*			X		X	X							X	X	X	X	7
47. *Lampsilis teres* form *teres*			X														1
48. *Lampsilis ventricosa*		X	X	X	X	X		X	X			X	X	X	X	X	12
49. *Epioblasma triquetra*														X	X	X	3
50. *Corbicula* sp.	X	X	X	X	X	X	X	X			X		X	X	X	X	13
TOTALS	7	9	16	8	19	4	8	24	2	2	4	5	17	20	25	16	

are low in numbers and/or are difficult to sample. Further sampling will be done this summer and fall on the Shenandoah River and Opequon Creek.

In the Monongahela River basin, five tributary streams to the Monongahela River (Hackers Creek, Buffalo Creek, Dunkards Creek, Tenmile Creek, and West Fork River) have naiad populations. Of these, Dunkards Creek had the most diverse fauna with 12 naiad species. The Monongahela River itself was found to be void of unionids.

Five tributaries to the Hughes River (North Fork, Bonds Creek, South Fork, Spruce Creek, Goose Creek) and the mainstem of the Hughes River had naiad populations. The North Fork was the richest with 16 naiad species. In the Little Kanawha River basin, seven tributaries (excluding the Hughes River) and the mainstem had naiad populations. The tributaries surveyed were Reedy Creek, Henry Fork, West Fork, Steer Creek, Cedar Creek, and Leading Creek. Leading Creek had the most diverse fauna with 13 naiad species. Both the Hughes River and Little Kanawha River basins were surveyed in cooperation with Marshall University.

Eighteen naiad species have been collected in the Kanawha River mainstem from Kanawha Falls to Alloy. One species, *Anodonta grandis*, was collected from the Nitro-St. Albans area. The upper section has been investigated on several occasions by this division, assisting the U.S. Fish and Wildlife Service in their attempt to find two endangered species (Schmidt and Zeto 1983, Clarke 1982). The pink mucket pearly mussel (*Lampsilis abrupta* (=*orbiculata*), a federally endangered species, was collected by Dr. Arthur Clarke near Kanawha Falls during his survey for the U.S. Fish and Wildlife Service. Although Clarke (1982) reported collecting only 23 species, as many as 27 species have been reported in the reach (Stansbery 1980). This is probably the richest naiad population in the state, with the exception of the Ohio River.

A comparative study of naiad populations in two streams in the same physiographic area but in different drainage basins was conducted on Potts Creek and Indian Creek in Monroe County in the spring 1983. Potts Creek, which flows east into the James River (Atlantic drainage), yielded only two species, *Stroplutus u. undulatus* and *Canthyria collina*. Both species were very abundant. Indian Creek, which flows west into the New River (Mississippi drainage) had a total of six naiads collected from four locations. The results of this study will be published in the fall of 1984.

The Greenbrier River has been partially investigated. So far, eight naiad species have been recorded. The New River has received considerable attention upstream and downstream of Bluestone Reservoir with a total of four and five naiad species collected, respectively.

The Bluestone River was investigated in the fall of 1983, along with the New River (above Bluestone) and the lower portion of Indian Creek in a joint effort with the U.S. Fish and Wildlife Service. Nine naiad species were collected from the Bluestone River.

Further surveys are planned this year for the Potomac River drainage in West Virginia. Thus far, two segments of the South Branch near Romney have been investigated. A total of five naiad species have been collected from this river, which contains both Mississippian fauna and Atlantic Slope fauna. Naiads from one location, the South Branch near Springfield, have been used for tissue analysis for pesticides.

The Elk River has been surveyed by a number of investigators (Taylor and Hughart, 1981; D. H. Stansbery, pers. comm.). It is hoped that our work and further investigation will complement their findings. Our work has only added one new name, *Lampsilis teres* form *teres*, to the species list which currently lists 18 species.

The Ohio River was investigated primarily by the U.S. Fish and Wildlife Service, during the summer of 1982. The Department's participation on the Ohio River was limited to brailing around selected Ohio River islands and identification of collected specimens. The U.S. Fish and Wildlife Service kindly provided us with a complete species list when the project was finished. A total of 24 species were reported, (W. Tolin, pers. comm.).

Results of the Tug Fork and Big Sandy River naiad investigations were also the work of the U.S. Fish and Wildlife Service's Elkins Office. Our involvement consisted of providing positive identification for collected specimens and draft report review. A total of 7 and 17 naiad species were collected from the Big Sandy River and Tug Fork, respectively (W. Tolin, pers. comm.).

Conclusions

In summary, 49 naiad species plus the asiatic clam *Corbicula* sp. have been collected from the ten major streams and three river basins in West Virginia which have been surveyed for their naiad populations. The surveys of the major streams range from completion of initial reconnaissance with few specimens collected, to lacking publication of results. All three river basins surveys are finished and published (Zeto 1982; Schmidt, et al 1983). Future basins/streams to be surveyed or completed are the Shenandoah River, Opequon Creek, and the remainder of West Virginia's Potomac River basin.

Literature Cited

1. Clarke, A. H. 1982. Survey of the freshwater mussels of the upper Kanawha River (RM 91-95), Fayette County, West Virginia, with special reference to *Epioblasma torulosa torulosa* (Rafinesque) and *Lampsilis abrupta* (Say) (=*Lampsilis orbiculata* (Hildreth), of authors)). U.S. Fish and Wildlife Service Final Report No. 50181-0546-2. Ecosearch, Inc., Mattapoisett, MA.
2. Schmidt, J. E. and M. A. Zeto. 1983. A survey of the freshwater mussel fauna of the Kanawha River, September 1981-September 1982. West Virginia Academy of Science 55(2,3,4):72-75.
3. Schmidt, J. E., M. A. Zeto, and R. W. Taylor. 1983. A survey of the mussel fauna of the Little Kanawha River Basin. In Report of the Freshwater Mussels Workshop, October 1982. pp. 131-139. U.S. Army Engineer Waterways Experiment Station, CE Vicksburg, Mississippi.
4. Stansbery, D. H. 1980. The naiad mollusks of the Kanawha River below Kanawha Falls with special attention to endangered species (Bivalvia:

Unionida: Unionidae). Report to the Environmental Protection Agency, Philadelphia, PAS under EPA Project No. C-540383, 16 p.
5. Taylor, R. W. and R. C. Hughart. 1981. The freshwater naiads of Elk River, West Virginia with a comparison of earlier collections. The Nautilus 95(1): 21-25.
6. Zeto, M. A. 1982. Notes of the freshwater mussels (Unionidae) of the Upper Monongahela River Basin, West Virginia. The Nautilus 96(4): 127-129.

Toxicity to Fathead Minnows (*Pimephales promelas*) of Oil and Gas Well Drilling Wastewater Following Field Treatment

Donald G. Kain and John E. Schmidt
Biology Section
Division of Water Resources
West Virginia Department of Natural Resources
1201 Greenbrier Street
Charleston, West Virginia 25311

Abstract

Wastewater generated during the drilling phase of oil and gas production in West Virginia is typically acidic, with high concentrations of chlorides and metals. On-site treatment for metals and suspended solid removal and subsequent local disposal, via land application and/or metered stream discharge, has been proposed. Concerns over potential impacts to aquatic communities have led to intensive biological monitoring during experimental discharges. Laboratory (static) and instream acute toxicity tests with fathead minnows (*P. promelas*) have been conducted on selected sites.

Of 16 twenty-four hour static tests, 7 showed no measurable toxicity, 3 were considered mildly toxic (LC50 $>$ 75%), 2 moderately toxic (LC50 of 30-74%), and 4 highly toxic (LC50 $<$ 30%). The lowest LC50 calculated was 10.8%. Toxicity was not clearly shown in any of the 4 instream (during discharge) tests.

Discharge at each site was a one-time event and generally lasted 24-48 hours. Discharge rates were based on a maximum wastewater/streamwater ratio of 1/300. Based on the short durations and high dilution rates of the discharges, impacts on aquatic communities were felt to be negligible.

Introduction

Oil and gas exploration and production is a major industry in West Virginia. In 1983, 3,323 wells (oil and gas combined) were permitted in the state (West Virginia Office of Oil and Gas 1984). Most activities are focused in the western two-thirds of the state, although nearly every county is affected to some degree by the industry. Ritchie County alone had 767 wells permitted in 1983 (West Virginia Office of Oil and Gas 1984). More importantly, there is hardly a river or stream system in the state that has not felt the effects of the industry's activities.

Major environmental impacts from oil and gas drilling activities include erosion and subsequent stream siltation from site preparation and access road construction, along with streamwater contamination from wastewater generated during the drilling process. This discussion will focus on the latter concern.

A typical drilling scenario is as follows: After a site is selected, an access road is cleared so equipment can be brought to the site. The well site is then cleared and leveled, and an earthen pond, or pit, is constructed to collect and hold all wastewater associated with the drilling process. A large truck rig is driven to the site along with additional truckloads of long steel pipe and support equipment (generators, pumps, storage tanks, etc.). Following erection of a drilling tower, the pipe sections are fitted together to follow a rotary bit thousands of feet into the earth. Drilling often continues around the clock for several days.

During the drilling process, fluids and air are pumped to the bit for lubrication and to carry cuttings to the surface. These fluids typically consist of a detergent mixed with a corrosion inhibitor and water. After the desired depth is reached, the well is cased with steel and cement, and the oil or gas bearing strata is fractured, allowing movement of oil and/or gas into the well. Fracturing methods include underground explosion, sand injection, and stimulation with a variety of chemical compounds, either singly or in some combination. At this point the well is complete and will be connected to a collection system.

If the pit has served its purpose, it will have received a considerable volume of liquid during the drilling operation. Contents vary tremendously from site to site but typically include drilling and fracturing fluids, groundwater encountered in drilling, surface water, oil, drill cuttings, cement, and garbage. Pit water is generally acidic with high levels of chlorides and metals. This water must be disposed of prior to final site reclamation.

Existing regulations allow for on-site pit water disposal through evaporation, with subsequent filling, grading, and seeding of the pit area. This method is efficient and cost-effective where applicable, but unfortunately is unfeasible in most of West Virginia, since rainfall often exceeds evaporation rates. Untended pits are likely to overflow and/or develop leaks with time, releasing their contents into the nearest receiving stream, often in a single large slug. The effects on water quality and aquatic life can be devastating.

An alternative to evaporation is field treatment of pit water and local disposal via land application or metered stream discharge. As part of a program cooperatively developed by the West Virginia Department of Natural Resources, Division of Water Resources (DNR-DWR) and representatives from the oil and gas industry, experimental field treatments and discharges were initiated in 1983.

Treatments consisted of addition of hydrated lime ($Ca(OH)_2$) to raise pH to 8-10 units and reduce levels of dissolved metals. Stream discharge rates were calculated using a maximum wastewater/streamwater ratio of 1/300. Discharge rates were based on results of chemical analyses of untreated drilling pit wastes sampled during winter/spring 1983 and were designed to keep all parameters at or below their respective criteria in the state's water quality standard (Ellenburg 1984). The interim discharge program has been intensely monitored by the DNR-DWR and the oil and gas industry. Frequent field inspections (throughout the drilling and discharge process), incorporating water chemistry and biological sampling and observations, have been conducted.

Biological monitoring during the experimental discharge period has consisted of static (24-hr) and instream toxicity testing with juvenile fathead minnows (*Pimephales promelas*).

The objective of this report is to evaluate the toxicity of field-treated drilling pit waste to fathead minnows. A secondary objective is to assess the impact of actual discharges on resident aquatic communities.

Materials and Methods

Bioassay analyses were conducted at 16 well sites during 1983. Although chemical analyses were performed on wastewater throughout the drilling and treatment processes, biological monitoring focused only on post-field treated wastes.

Static 24-Hour Toxicity Tests

Samples were collected prior to, or during, discharge at the pit or the discharge pipe, placed on ice, and taken to the DNR-DWR laboratory in Charleston. All tests commenced within 24 hours of sample collection. Prior to testing, samples were warmed to room (testing) temperature (22-25°C). Adjustment of pH was performed with dilute HC1 as necessary to eliminate pH "shock" as a source of mortality. One liter solutions of pit water and laboratory dilution water (tapwater filtered through an organics removal cartridge) were prepared in duplicate. Concentrations (expressed as percent pit water by volume in filtered tapwater) used in each test were 0 (control), 10, 18, 32, 56, and 100 (pit water). Dissolved oxygen and pH levels were measured in each concentration at the beginning and end of each test. Fish ranged from 13 to 67 days old at the time of testing, with a typical age range of 10 days for a test group. Ten fish (5 per container) were exposed to each test concentration.

Stress and mortality were noted in each test concentration. LC50s were calculated by probit analysis in tests with more than one partial kill and by use of straight-line plot in all other cases.

Instream 24-Hour Toxicity Tests

Instream toxicity tests were conducted at selected sites during the experimental discharge program. Prior to stream discharge, fish were acclimated to stream temperature and placed in clear flow-thru test chambers (at 10 per container) anchored to the stream bottom. Two test chambers were located immediately above the discharge point, and two were placed 50-150 feet downstream to allow adequate mixing. Exposure time was 24 hours.

Results and Discussion

Toxicity measurements of drilling pit waste were determined through acute static toxicity tests. Instream toxicity tests were conducted to complement laboratory results.

Static 24-Hour Toxicity Tests

Of 16 samples, 9 exhibited measurable toxicity in laboratory tests with juvenile fathead minnows (Table 1). Of these, 3 were considered mildly toxic (LC50 > 75% pit water by volume), 2 moderately toxic (LC50 of 30-74%), and 4 highly toxic (LC50 < 30%). The lowest LC50 calculated was 10.8%.

Toxicity of several pit wastes tested was felt to be influenced by dissolved oxygen and/or pH levels. For example, sample 14 (LC50=22) was tested with no pH adjustments. Toxicity likely resulted from pH "shock" in this test as fish (reared in neutral pH water) were placed directly in solutions with pHs ranging from 10.0-11.65. Dissolved oxygen (DO) depletion was considered a contributor to toxicity of several samples. In two cases (samples 15 and 16), DO levels fell below 1.0 mg/1 in test solutions by the end of the 24-hour tests. Aeration in test chambers was employed only when DO levels were below 5.0 mg/1 at the beginning of a test.

Based on the worst case example (LC50=10.8%) from laboratory testing, one would not expect instream acute toxicity from the 24-48-hour discharges of pit waste investigated, particularly when one considers the maximum wastewater/streamwater ratio of 1/300 (approximately 30 times greater than the LC50 of the most toxic sample) required. Instream toxic effects of pH and DO variability in pit wastes were considered minimal, based on high dilution rates, rapid mixing, and natural instream reaeration.

Instream 24-Hour Toxicity Tests

Instream toxicity testing was employed at four discharge sites. Mortalities were recorded at only one site. At this site, however, fish died within 24 hours both above (15% mortality) and below (75% mortality) the discharge point. Mine drainage was felt to play a major role in impacting water quality at this site. No resident fish were observed in the stream during pre- and post-discharge inspections.

All test organisms survived 24-hour instream exposures below the remaining 3 discharge sites. No stress was noted in surviving fish.

In only one case could a direct comparison be made between samples tested by both laboratory and instream toxicity methods (i.e., laboratory test sample collected at discharge pipe during instream toxicity test). The LC50 collected from this laboratory test was 13%. No toxicity was demon-

Table 1. Summary of 24-Hour Static Toxicity Test Results on Field Treated Oil and Gas Drilling Wastes, 1983 (LC50s expressed as percent pit water by volume in filtered tapwater)

Degree of Toxicity	Sample No.*	Test Date	LC50	Comments
No Measurable Toxicity	1	7 June 83	N/A	No stress or mortality evident during test
	2	22 Dec 83	N/A	" "
	3	10 Aug 83, #1	N/A	" "
	4	10 Aug 83, #2	N/A	" "
	5	10 Aug 83, #3	N/A	" "
	6	25 Aug 83, #1	N/A	" "
	7	25 Aug 83, #2	N/A	Fish stressed in 56% and 100% concentrations; no mortality
Mildly Toxic	8	27 Oct 83	90	
	9	26 Oct 83	87	
	10	12 Aug 83	75	Exposure in 50 and 100% only: Total kill in 100%; all survived in 50%
Moderately Toxic	11	10 Nov 83	59.6	
	12	28 July 83	49	
Highly Toxic	13	19 Oct 83	22	
	14	30 June 83	22	No pH adjustments made; pH "shock" likely contributed to toxicity (sample pH = 11.65)
	15	29 Oct 83	13	Fish killed within 30 minutes in 32, 56 and 100% concentrations; DO depleted
	16	2 Nov 83	10.8	All fish in 56 and 100% concentrations succumbed within 90 minutes. DO depleted. Dry well; not stimulated; no field treatment

*Numbers assigned in order of increasing toxicity strated in the corresponding instream test. The wastewater/streamwater ratio was estimated at 1/1000 during this discharge event.

Acute toxicity testing was felt to be a useful and appropriate monitoring tool for assessing impacts of oil and gas drilling pit waste discharges (one-time, short-term events). The combined test (static and instream) results indicate that acute impacts to fish in receiving streams were negligible. Based on the large margins of safety between measured toxic concentrations (lab) and instream concentrations (factor of 30 or greater), acute toxicity to aquatic communities as a whole was not expected. However, additional toxicity tests employing additional species at various life stages would be needed to quantify effects on entire aquatic communities in receiving streams. Additional testing could also be useful as a component of toxicity reduction evaluations of more toxic pit wastes (i.e., isolating toxic constituents of the waste). Identification of toxic components may allow the industry to modify or refine drilling or treatment procedures to reduce toxicity.

Conclusion and Summary

Toxicity of oil and gas drilling pit wastes to fathead minnows is best characterized as highly variable. The most toxic sample examined ($LC50=10.8\%$) was not considered to pose an acute threat to fish in the receiving stream when discharged at the prescribed wastewater/streamwater ratio of 1/300. The nature of stream discharges (highly diluted and short in duration) was felt to minimize impacts to aquatic communities. Acute toxicity testing was felt to be an appropriate biological monitoring tool for one-time, short-term discharge events. However, testing with additional species (fish and invertebrates) at different life stages is recommended.

The data presented in this report are considered preliminary. Experimental discharges of drilling pit waste with chemical and biological monitoring are continuing. Final assessments of the effects of pit waste discharges will be based on all components of monitoring operations.

Acknowledgments

This project was the result of a coordinated effort between the West Virginia Department of Natural Resources, Division of Water Resources and representatives of the oil and gas industry. Industry participation was voluntary. Assistance and cooperation by industry representatives has been greatly appreciated.

The authors recognize that the results represented the culmination of the efforts of numerous staff members of the Division of Water Resources. In particular our fellow aquatic biologists were heavily involved in field inspections and laboratory analyses: Janice Fisher, Rob Gatewood, and Bill Kendall. Kathryn Ellenburg and Eli McCoy provided the background for the experimental design and were responsible for close coordination with the oil and gas industry. A special thanks is extended to Cherrie Sizemore for reviewing and typing the manuscript.

Literature Cited

1. Ellenburg, K. A. 1984. Personal Communication. West Virginia Department of Natural Resources, Division of Water Resources, Charleston, West Virginia.
2. West Virginia Office of Oil and Gas 1984. Statistical Report, 1983. State of West Virginia, Department of Mines, Oil and Gas Division, Charleston, West Virginia.

Psychology and Education Section

Reliability and Validity Findings on the Preliminary Diagnostic Questionnaire (PDQ)[1]

Richard J. Zawlocki, Ranjit K. Majumder, and Joseph B. Moriarty
West Virginia Rehabilitation Research and Training Center
West Virginia University
Morgantown, West Virginia 26506

Abstract

The Preliminary Diagnostic Questionnaire (PDQ) is an evaluation instrument designed to provide information on the functional capacities of disabled people in relation to their employability. Over 3,000 vocational rehabilitation (VR) clients have been administered the PDQ in at least 35 states. Several procedures have been used to assess the reliability and validity of the PDQ. Samples employed in these procedures were fairly representative of the general VR population. PDQ scales appear stable over time and exhibit a relatively high degree of internal consistency, i.e., significant test/retest and interitem reliability coefficients. Criterion-related validity of several relevant PDQ scales was demonstrated by significant correlation coefficients with certain Wechsler Adult Intelligence Scale (WAIS) scores. Examination of construct validity by a factor analysis procedure yielded three factors (cognitive functioning, motivational and emotional states, and physical functioning) with significantly high loadings. These factors were associated with the appropriate corresponding PDQ scales. Additional analyses are being conducted on the PDQ by staff of the West Virginia Rehabilitation Research and Training Center.

[1]This work was supported in part by grant no. G008300159 from the National Institute for Handicapped Research. We also wish to acknowledge the contributions of the staff of the Center in the collection and analysis of data. In particular, we would like to thank Dick Walls, Don McLaughlin, Elizabeth Minton, and Jinny Spann for their efforts and Janet Boyles for preparation of this manuscript.

Introduction

The Preliminary Diagnostic Questionnaire (PDQ) is an evluation instrument designed to provide useful information on the functional capacities of disabled people in relation to their employability (Moriarty, 1981). The eight scales are (a) work information (WINF), (b) preliminary estimate of learning (PEL), (c) learning (READ), (d) psychomotor (PSYMO), (e) estimate of personal independence (EPI), (f) work importance (WIMP), (g) internality (IE), and (h) emotional functioning (EMOT). On the WINF scale, items range from knowing about federal income tax guidelines to information about unions. Scores on this scale demonstrate the extent of clients' knowledge of specific work-related information usually acquired by actually working or being in employment situations. On the PEL scale, items assess such abilities as basic math skills, general or informal learning, and formal and academic skills. On the READ scale, items measure short term memory and reading skills thereby providing indications of visual impairments and learning disabilities. On the PSYMO scale, items evaluate various fine and gross motor skills and detect possible symptoms associated with visual and neurological disorders. On the EPI scale, items fall into three behavioral categories of daily living activities, mobility, and range of motion. On the WIMP scale, items assess the importance of work to clients and how much support they have from their friends and family. On the IE scale, items measure clients' perceptions or reports of their ability to control events in their lives. On the EMOT scale, items measure behaviors defining anxiety, aggression, depression, withdrawal/bizarreness, and drug addiction.

Any test or evaluation instrument such as the Preliminary Diagnostic Questionnaire (PDQ) represents a systematic attempt to gather information about people through careful observations of their performance under specific conditions. There is quite a bit of variation in the actual way this may be accomplished in different kinds of tests. Nevertheless, all tests must be designed to attain some acceptable level of two major criteria, reliability and validity, if they are to meet the needs of the users. The term users refers not only to persons giving the test but also to those who are taking it. The evaluation process and its outcome are usually significant events for both parties, and therefore it is important that the test measures whatever it is supposed to measure (validity) and in a dependable manner (reliability). Over 3,000 clients have been administered the PDQ, and several procedures have been used to evaluate its reliability and validity. Additional analyses of the reliability and validity as well as evaluation of the pragmatic utility of the PDQ are being conducted at the West Virginia Rehabilitation Research and Training Center as the information becomes available.

Sample

Several samples were used in attempts to assess the reliability and validity of the Preliminary Diagnostic Questionnaire (PDQ). The earliest sample to be used in studies systematically evaluating the PDQ consisted of residents of a rehabilitation facility. There were 151 clients receiving services at this state operated comprehensive rehabilitation center selected for inclusion in this study. These clients were in various phases of different service programs at the center and came from all parts of the state. Some of the other demographic characteristics of this facility sample include (a) 91 males (60.3%) versus 60 females (39.7%), (b) 137 whites (94.5%) and 8 blacks (5.5%), (c) an average age of 25.8 years (with a standard deviation of 10.96), and (d) a mean number of years of education at 10.6 (with a standard deviation of 2.19).

The second example was comprised of more than 986 rehabilitation clients who were given the PDQ by counselors seeking certification in the use of PDQ. These clients came from 21 states located primarily in the eastern half of the United States. Distributions of other demographic characteristics of this sample include (a) 593 males (60.3%) versus 390 females (39.7%), (b) 700 whites (73.9%) and 242 blacks (25.5%) and 6 other (0.6%), (c) a mean age of 31.1 years (with a standard deviation of 11.2), and (d) an average number of years of education at 11 (with a standard deviation of 2.4).

The third and final sample consisted of clients tested by persons from a local chapter of a learning disabilities association to evaluate various approaches in the assessment of learning disabilities.

A general sample of rehabilitation clients was chosen to serve as a baseline for a comparison with these research samples. This baseline sample of general rehabilitation clients consisted of a 5% sample of approximately 885,800 closed cases from the fiscal year 1981. This 5% sample consisted of 44,290 clients closed from rehabilitation program. These cases were randomly selected from a national data base maintained at the West Virginia Rehabilitation Research and Training Center. The relevant demographic characteristics of this baseline sample include (a) 25,998 males (58.7%) versus 18,292 females (41.3%), (b) 30,967 whites (77.2%) and 8,184 blacks (20.4%) and 953 other (2.4%), (c) an average age of 33.6 years (with a standard deviation of 13.8), and (d) a mean number of years of education of 10.8 (with a standard deviation of 2.7).

Several conclusions can be drawn regarding the representativeness and generalizability of the research findings. The first research sample and the R300 sample were fairly similar except that there are substantially fewer black clients and a considerably younger group of clients in the first research sample. A comparison of the demographic characteristics of the second research sample and the R300 sample indicates that they are very similar in nature. Thus, the first two research samples are fairly representative of the general VR population (based on the R300 or baseline sample).

Reliability

The test/retest reliability of the Preliminary Diagnostic Questionnaire (PDQ) scales was evaluated by using 28 cases out of the first sample. Thus, 28 clients in the state operated comprehensive rehabilitation facility were readministered the PDQ. The results of this retest were merged with the previous test data and then subjected to a Pearson product moment correlation procedure. The correlation coefficients produced in this process are the test/retest reliability coefficients for the PDQ scales listed in Table 1.

Table 1. Test/Retest Reliability Coefficients

PDQ Scale	Coefficient Value
Work Information (WINF)	.775
Preliminary Estimate of Learning (PEL)	.970
Psychomotor (PSYMO)	*
Reading (READ)	.793
Work Importance (WIMP)	.754
Estimate of Personal Independence (EPI)	*
Internality (IE)	.465
Emotional (EMOT)	.910
Anxiety	.745
Withdrawn	.767
Depression	.832
Anger	.745

*Not Available

No data are currently available to evaluate the test/retest reliability of the Psychomotor and Estimate of Personal Independence scales since the PDQ was in a relatively early stage of development, and therefore score algorithms had not been created for these scales. Examination of Table 1 indicates all of the flexibility coefficients are high with the exception of the Internality scale. Further statistical testing revealed significant differences ($p < \cdot.01$) between the reliability coefficients and zero. In the case of the Internality scale, it appears likely that changes of individuals' orientation scores were probably due to the effects of the institutional environment since many of them were relatively new arrivals upon first testing. Thus, the PDQ scales seem to be stable (with the possible exception of Internality), and scores derived from their application should not be expected to vary significantly over time as a consequence of their administration.

The interim reliability or internal consistency (i.e., the intercorrelation of items) in the PDQ scales was assessed by using a Cronbach coefficient alpha procedure (Cronbach, 1951). Reliability coefficients were calculated from the second research sample and are listed below in Table 2.

Inspection of Table 2 reveals that PDQ scales do have a relatively high degree of internal consistency. Thus, there appears to be a relationship among items of each scale in the PDQ, i.e., items in a scale seem to be measuring the same kind of trait or characteristic of clients for that scale.

Validity

The criterion-related validity of the Preliminary Diagnostic Questionnaire (PDQ) was evaluated by calculating validity coefficients and com-

Table 2. Cronbach Alpha Coefficients

PDQ Scale	Coefficient Value
Work Information (WINF)	.865
Preliminary Estimate of Learning (PEL)	.900
Psychomotor (PSYMO)	.708
Reading (READ)	.841
Work Importance (WIMP)	.692
Estimate of Personal Independence (EPI)	.871
Internality (IE)	.769
Emotional (EMOT)	.856

paring scores or outcomes for contrasted or different groups (Anastasi, 1976). Scores on two PDQ scales, Preliminary Estimate of Learning (PEL) and Psychomotor (PSYMO) were compared to the results on a generally accepted intelligence test, the Wechsler Adult Intelligence Scale or WAIS (Wechsler, 1958). The WAIS is a frequently used assessment device in clinical settings and often serves as a criterion for the validation of other intelligence tests. Thirty cases with WAIS Full, Verbal, and Performance scale scores were randomly selected from the second research sample and then subjected to a Pearson product moment correlation procedure. This produced correlation coefficients of .770, .868, and .440 between the PEL scale and WAIS Full, Verbal, and Performance scales respectively. It also produced correlation coefficients of .404, .313, and .444 between PSYMO scale and the WAIS Full, Verbal, and Performance scales respectively. All of these validity coefficients were significant except for the one between the PSYMO scale and the WAIS Verbal Scale. In addition, a Pearson product moment correlation procedure was performed using the third research sample and provided a validity coefficient of .696 between the PEL and WAIS Verbal scales. Thus, there are significant correlations between the PEL and PSYMO scales and the WAIS Full, Verbal, and Performance scales (with the exception of the PSYMO and WAIS Verbal scales) thereby indicating a degree of criterion-related validity for these PDQ scales.

In an attempt to provide further evaluation of the criterion-related validity of the PDQ scales, a group differentiation method (Brown, 1983) was employed in the following manner. The cases in the second research sample were stratified into groups based on indications of mental retardation in the primary and secondary disability codes of the clients. The three groups of this sample (moderately, mildly, and not mentally retarded classifications) were compared on each of the PDQ scales using a one way analysis of variance procedure. The results of this procedure showed that six PDQ scales (PEL, PSYMO, READ, IE, WIMP, & EMOT) had significant differences ($p < .01$ in their means. The contrasted group method was employed again except this time the groups were differentiated with respect to indications of mental illness based on disability codes. The second research sample was divided into two groups, mental illness versus no mental illness, and compared by using a one way analysis of variance procedure. This revealed significantly different means ($p < .01$) for three PDQ scales (EMOT, EPI, & PEL). Thus, criterion-related validity of several relevant PDQ scales was demonstrated by comparing the differential outcomes or scores of individuals classified into groups based on different disability codes (e.g., mental illness vs. no mental illness).

The construct validity of the PDQ was evaluated by performing a principal components analysis with a Varimax orthogonal rotation (Sarle & Sall, 1982) to increase the variance accounted for by the extracted factors. This factor analysis was carried out to determine if cognitive, physical, emotional, and motivational variables were the major contributors to the employability of disabled people. The second sample (of 986 VR clients) was used in this procedure. The results of this factor analysis are listed below in Table 3.

Table 3. PDQ Factor Loadings After Rotation

PDQ Scale	Factor 1	Factor 2	Factor 3
Work Information (WINF)	0.73268	0.16679	−0.21718
Preliminary Estimate of Learning (PEL)	0.86562	0.08114	−0.12865
Psychomotor (PSYMO)	0.65260	0.09018	0.22725
Reading (READ)	0.76716	0.10515	0.02193
Work Importance (WIMP)	−0.01907	0.82127	0.15847
Estimate of Personal Independence (EPI)	0.02186	0.02822	0.92383
Internality (IE)	0.36681	0.66500	0.12939
Emotional (EMOT)	0.06731	0.70220	−0.24406

Examination of Table 3 indicates that three factors emerged from this data. In Factor 1, the PEL, PSYMO, READ, and WIMP scales have high loadings ($p < .5$). These four scales were designed to measure some aspect of intellectual functioning or general knowledge level. Consequently, Factor 1 appears to be a cognitive functioning variable. In Factor 2, the WIMP, IE, and EMOT scales have high loadings ($p < .05$). The WIMP and IE scales were designed to measure motivation while the EMOT scale was devised to assess emotional states. It seems that Factor 2 represents a combination of motivational and emotional features of the individual, and that they are not separate factors. In Factor 3, the EPI scale is the only one with a high loading ($p < .5$). This scale was designed to measure the physical limitations of people in the areas of daily living activities, mobility, and range of motion. It appears as though Factor 3 represents the area of physical functioning. Thus, an examination of the construct validity of the PDQ revealed that three factors representing (a) cognitive functioning, (b) motivational and emotional states, and (c) physical functioning were each associated with the appropriate corresponding PDQ scales.

Conclusions

The Preliminary Diagnostic Questionnaire (PDQ) is an evaluation instrument designed to provide useful information on the functional capacities of handicapped people in relation to their employability. Several procedures have been used to assess the reliability and validity of the PDQ. The samples employed in these procedures were fairly representative of the general vocational rehabilitation (VR) population (based on the baseline sample of VR clients nationwide).

Test/retest and interitem reliability of the PDQ was shown to be significant by the coefficients obtained from these procedures. Thus, PDQ scales appear to be stable over time and to exhibit a relatively high degree of internal consistency (i.e., a strong relationship among items of each scale).

The criterion-related validity of several relevant scales of the PDQ was demonstrated by the significant correlation coefficients obtained with Wechsler Adult Intelligence Scale (WAIS) scores. This was accomplished by comparing PDQ scale scores with WAIS scale scores for a randomly selected VR client sample and for another sample of VR clients classified into groups according to different disability codes. Thus, there is a significant relationship between the outcomes on certain relevant WAIS and PDQ scales.

The construct validity of the PDQ was examined by using a factor analysis procedure. The results of this analysis indicated three factors representing cognitive functioning, motivational and emotional states, and physical functioning with significantly high loadings. These factors were associated with the appropriate corresponding PDQ scales. Thus, the PDQ scales contribute to three conceptually discrete constructs.

The PDQ, therefore, appears to be a relatively stable and valid functional assessment instrument for vocational rehabilitation settings. In addition, further analyses and cross validation of the PDQ will be carried out at the WV Rehabilitation Research and Training Center as more data become available.

References

1. Anastasi, A. 1976. Psychological testing. New York: Macmillan.
2. Brown, F. G. 1983. Principles of educational and psychological testing. New York: Holt, Rinehart, and Winston.
3. Cronbach, L. J. 1951. Coefficient alpha and the internal structure of tests. *Psychometrika, 16,* 297-334.
4. Moriarty, J. B. 1981. Preliminary diagnostic questionnaire. Dunbar, WV: West Virginia Rehabilitation Research and Training Center.
5. Sarle, W. S. & Sall, J. P. 1982. The factor procedure. In A. A. Ray (Ed.), *SAS User's Guide: Statistics* (309-345). Cary, NC: SAS Institute.
6. Wechsler, D. 1958. The measurement and appraisal of adult intelligence. Baltimore: Williams and Wilkins.

A Laboratory Course on Lasers for the Advanced Undergraduate Student

Joseph E. Wiest
West Virginia Wesleyan College
Buckhannon, West Virginia 26201

Abstract

While the development of lasers has been rapid and extensive and the laser has opened up new opportunities for research in the sciences, few undergraduate institutions offer courses on lasers. I have developed a laboratory course on lasers at West Virginia Wesleyan College which leads students to explore the optical background, the design, the parameter measurements, and the applications of lasers. The course is a one-semester course that meets for 3 hours each week; it has been taught for three years now. The laboratory has been designed at a reasonable cost, using a combination of in-house built equipment and commercially-bought equipment. The group of lasers that is used consists of the helium-neon laser, the ruby laser, the nitrogen laser, the solid-state diode laser, and two different types of tunable dye lasers. The experiments designed for the course are entitled: The Monochromator and Optical Spectra, The Helium-neon Laser and Quantum Optics, The Ruby Laser and Non-Linear Optics, The Diode Laser and Fiber Optics, The Nitrogen Laser: Design and Parameter Measurements, The Flashlamp-Pumped Tunable Dye Laser: Design and Characteristics, and The Laser-Pumped Tunable Dye Laser and Atomic Excitation.

I. Introduction

The laser and the transistor can be ranked as the two most significant developments in physics in the past 30 years. Although the theory and applications of the transistor are presented in good detail in several science and engineering departments in the undergraduate schools, laser theory and applications are generally taught only superficially. The laser was regarded in the popular mind as a laboratory curiosity for the first few years after its discovery; but, today, the laser finds applications in scientific research, routine medical procedures, various technologies, and in industrial processes. One of the largest growth industries in the past five years in the United States has been the laser and electro-optics industry. It has become increasingly important for our students to learn the theory, design, and applications of the major kinds of lasers.

II. The Course

Working towards that end, a laboratory course on lasers for juniors and seniors has been developed at West Virginia Wesleyan College. The course meets three hours per week for one semester each year; there is a prerequisite of a course in modern physics. Begun in 1981, the course has undergone further development each year. Cost has been a major consideration in developing the laboratory and has dictated building equipment wherever possible. Seven experiments have been developed for the course thus far, and an eighth one is currently under development. The course begins with an experiment to relate atomic spectra to energy levels, and ends with an experiment in using the tunable dye laser. There is only one formal lecture in the class, on the first day, when an overview of each experiment is presented and laboratory procedure and safety are discussed. The remainder of the course consists of informal discussions between instructor and students as the experiments are being performed. Students work in pairs; grades are based upon written reports.

III. The Experiments

A. *The Monochromator and Atomic Spectra*

In the first experiment of the course, students are asked to use a .35 meter McPherson Scanning Monochromator to measure intensity versus wavelength spectral curves for sodium, mercury, nitrogen, hydrogen, helium, and neon. They are then asked to relate their results to the known energy levels of the atoms and to consider transition permissibility and probability. Figure 1 shows a typical spectral curve measurement for three different entrance slit widths, for the sodium doublet. The atomic energy level diagram for sodium is given in reference 1.

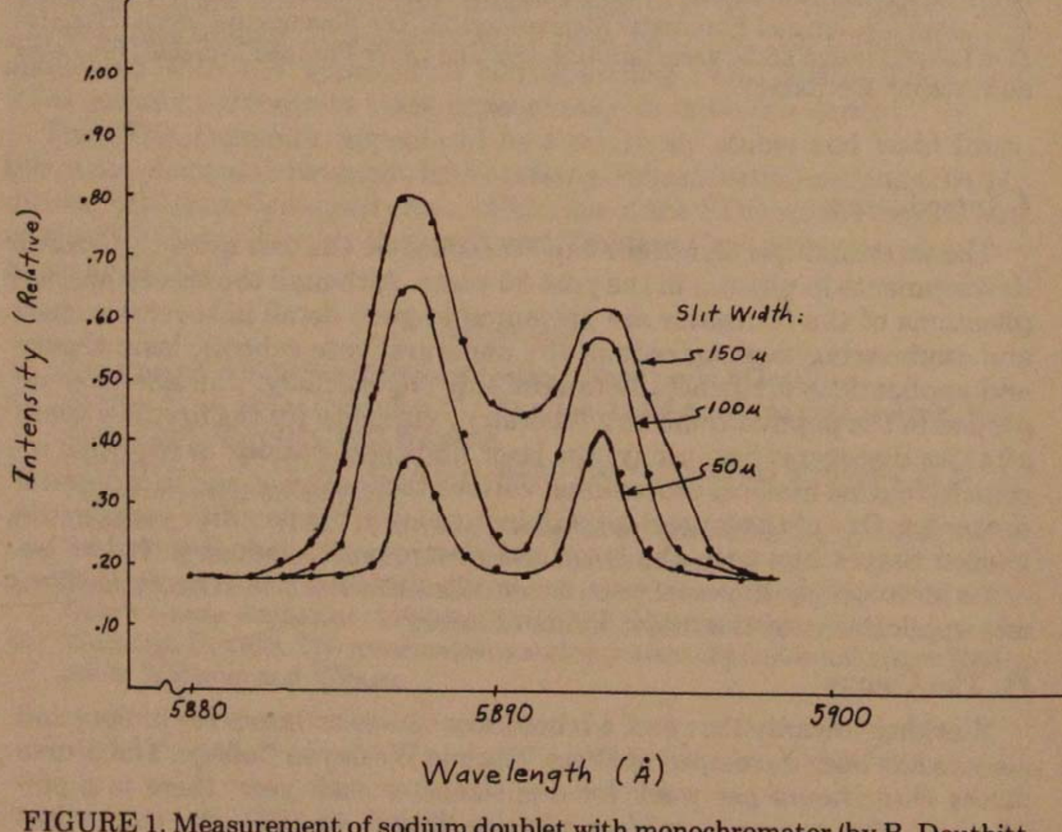


FIGURE 1. Measurement of sodium doublet with monochromator (by B. Douthitt, Class of 1982).

B. *The Helium-Neon Laser and Quantum Optics*

In the second experiment, the student is reintroduced to the most widely known laser—the helium-neon laser—and is asked to consider the design of the laser by comparing the interior of a defunct laser with the schematic of reference 2. The wavelength of the visible beam is then measured and related to the energy level diagram of reference 3. Using a photodiode array (4) and an oscilloscope, the student can now measure the gaussian intensity profile of the laser beam (see Figure 2). Two applications are now introduced: the Kerr Effect (5) and the Acousto-Optic Effect (6).

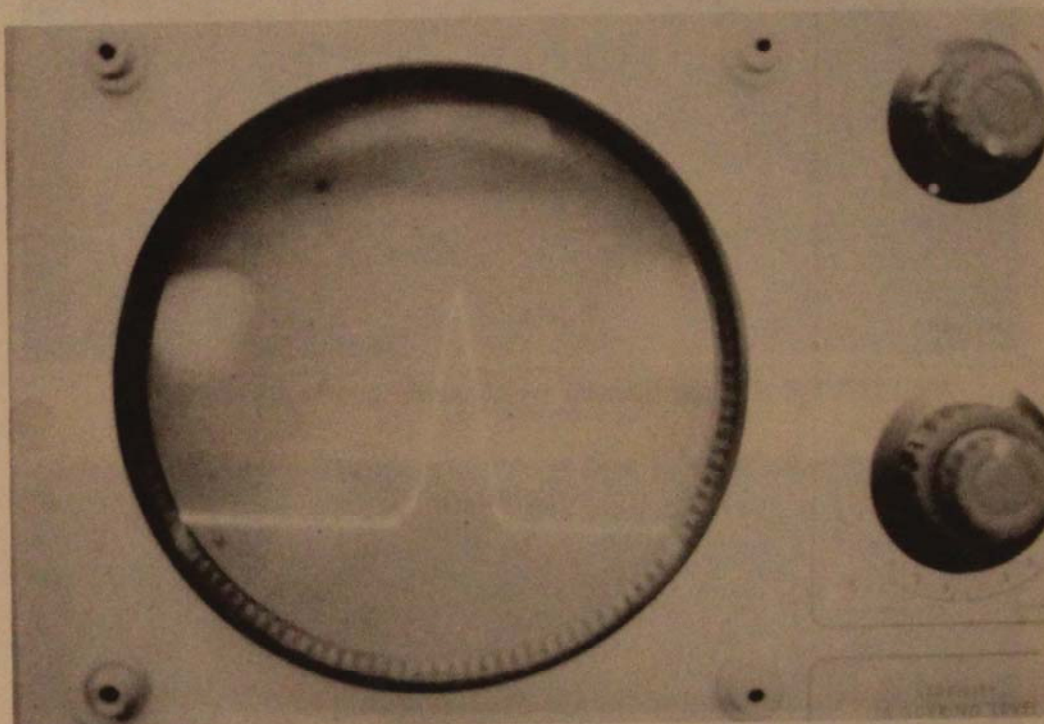


FIGURE 2. Profile of the He-Ne laser beam measured with photodiode array.

The experimental arrangement for the Kerr Effect is shown in Figure 3: a cell of nitrobenzene is mounted between two crossed polarizers with a photodiode detector beyond the second polarizer. We built our own Kerr cell, as shown in Figure 4. As voltage is increased on the terminals of the cell, the nitrobenzene becomes birefringent and acts as a waveplate to turn the plane-polarized light into an elliptically-polarized wave with an increasing horizontal semi-axis, thereby allowing more light to pass through the horizontal optical axis of the second polarizer. Thus, a light valve is created. A typical measurement is shown in Figure 5.

The Acousto-Optic Effect, shown schematically in Figure 6, uses an ultrasonic wave, at a frequency of nearly 40 MHz here, to diffract a light wave from the laser. The diffraction equation that applies here is $\lambda s (\sin \Theta - \sin \Phi) = \ell \lambda_L$, where λs is the ultrasonic wavelength, λ_L is the light wavelength, and $\ell = 0, 1, 2, \ldots$ (7). We purchased the acoustomodulator (8) but

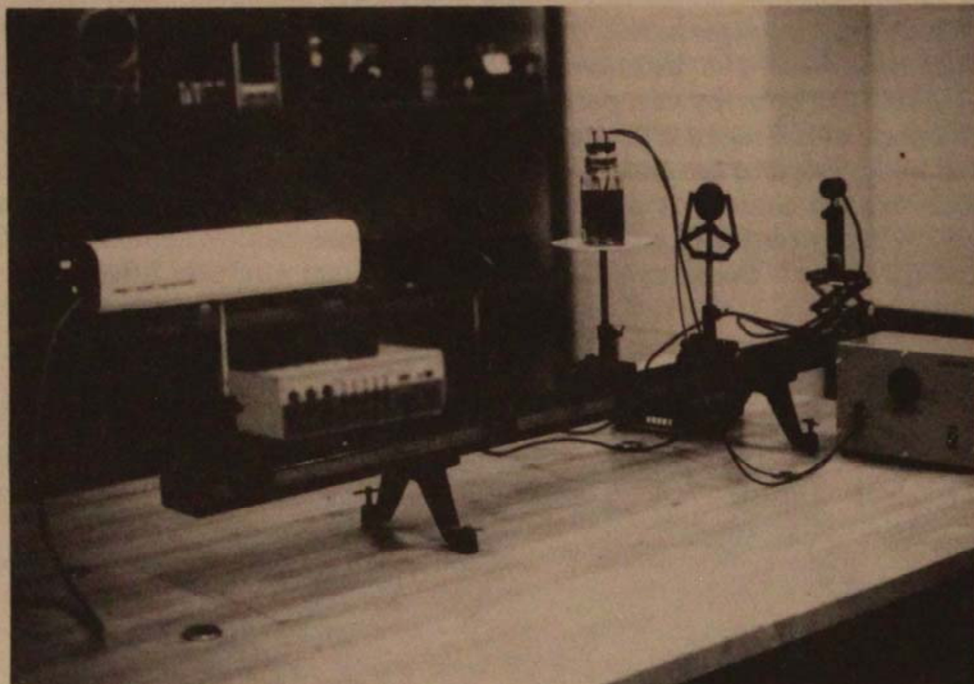


FIGURE 3. Experimental arrangement for the Kerr Effect.

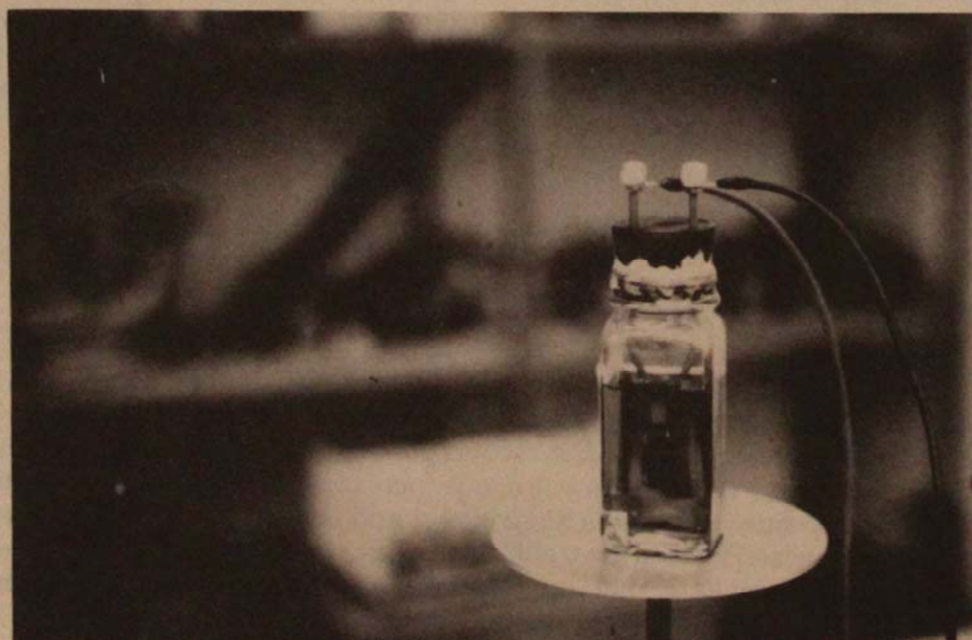


FIGURE 4. The Kerr cell.

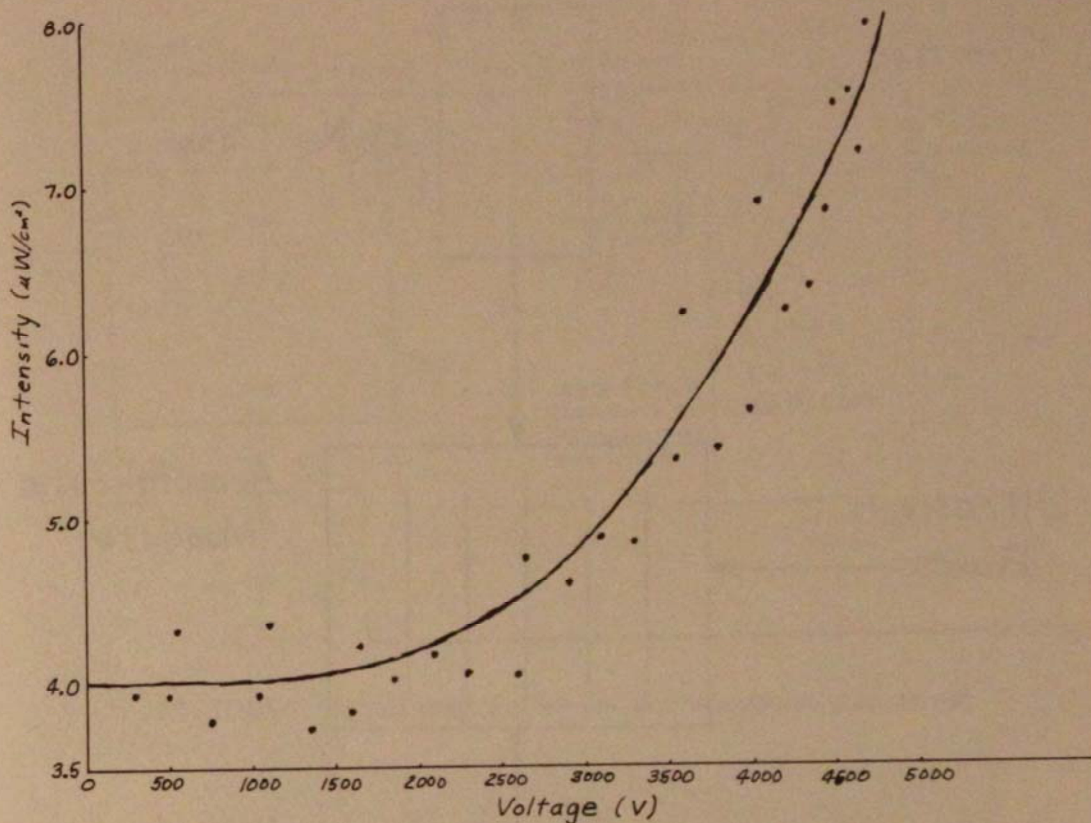


FIGURE 5. Intensity versus voltage for the Kerr Effect (by B. Longacre, Class of 1983).

built our own driver, using the circuit (9) shown in Figure 7. A typical diffraction pattern is shown in Figure 8. The Acousto-Optic Effect is used in light steering for printing and in signal processing (10).

C. *The Ruby Laser and Non-Linear Optics*

The third experiment uses a pulsed ruby laser which we built according to the circuit diagram of reference 11, using a ¼″ x 1″ synthetic ruby rod (12). An elliptical cylinder, of degreased aluminum foil, with the ruby rod at its center and two flashlamps at its foci form the head of the laser, as shown in Figure 9. The ruby rod was plated with aluminum on both ends, at approximately 100% and 80% reflectivities, and then coated with a thin layer of silicon oxide for durability (13). The head is housed in an aluminum cylinder that is mounted on top of a metal cabinet containing the electronics. Following a discussion of the optical and circuit designs, the student pair is asked to use a diffraction grating to measure the wavelength of the beam and then to correlate the 6943 Å line with the energy level diagram of the chromium ion in $A1_20_3$ as given in reference 14. Next, the phenomenon of frequency doubling (15) is introduced, using a crystal of KH_2PO_4. We grew our own crystal, beginning with a saturated solution at an elevated temperature, growing small seed crystals first, and then using the seed crystals to grow large crystals. Frequency doubling, which uses the second harmonic of a wave, was known for many years in radio

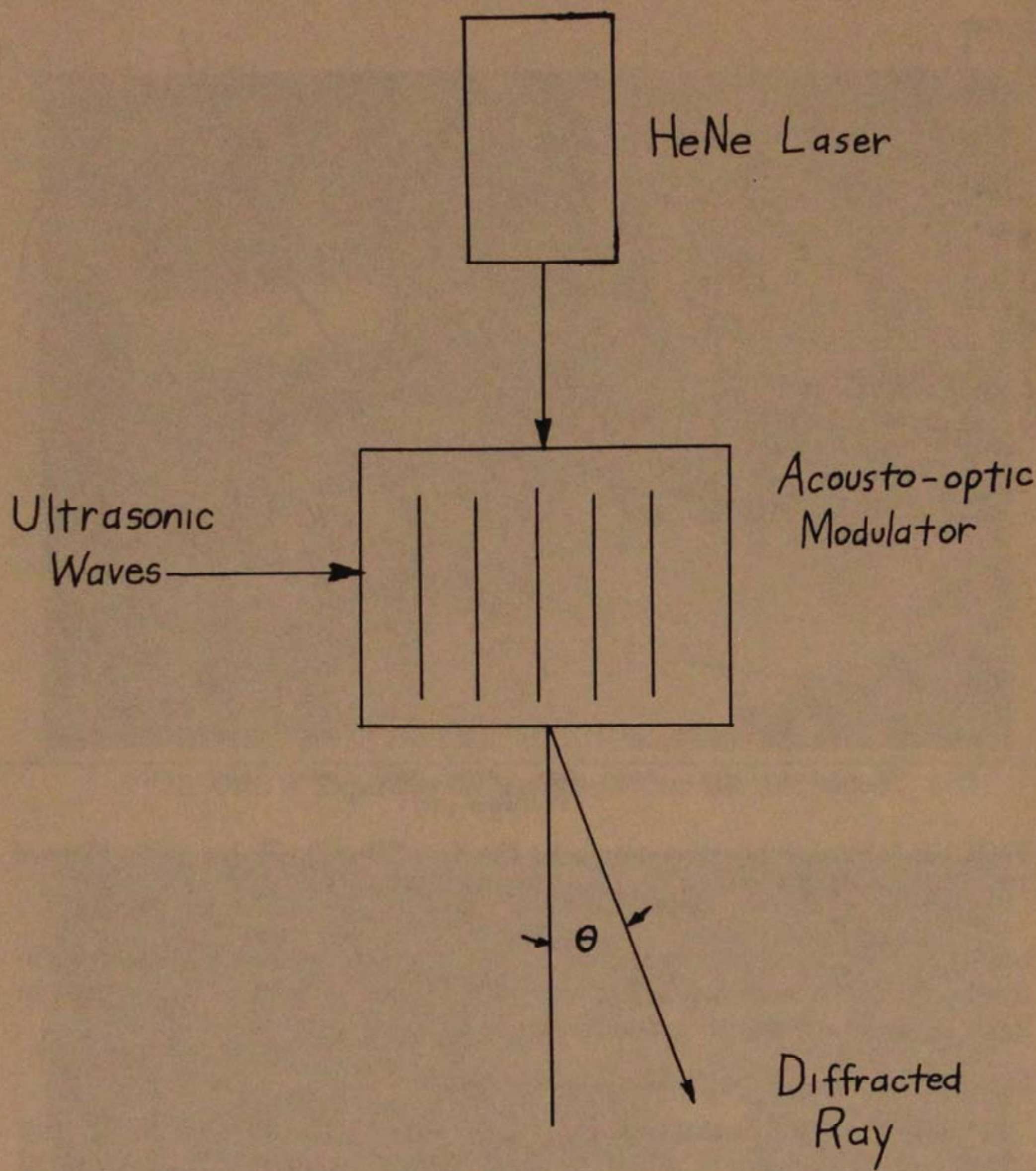


FIGURE 6. Schematic of the Acousto-Optic Effect experiment.

(and, in fact, was used in the circuit of Figure 7 to double the third overtone of the 6.37 MHz oscillator to 38.22 MHz) but was demonstrated for light only after the ruby laser was developed in 1960. A very intense beam is needed to shift an electron from one atom to another in the crystal, thereby creating ions which can vibrate in harmonics of the laser frequency. KH_2PO_4, which is a briefringent crystal, transmits the red 6943 Å line in the o-wave and produces the second harmonic blue line at 3472 Å in the e-wave. Using a grating and a photodiode light detector, the students can measure the wavelength and intensity of the blue line and, after measuring the initial red line intensity, can calculate the production efficiency of frequency doubling (which is a few percent here).

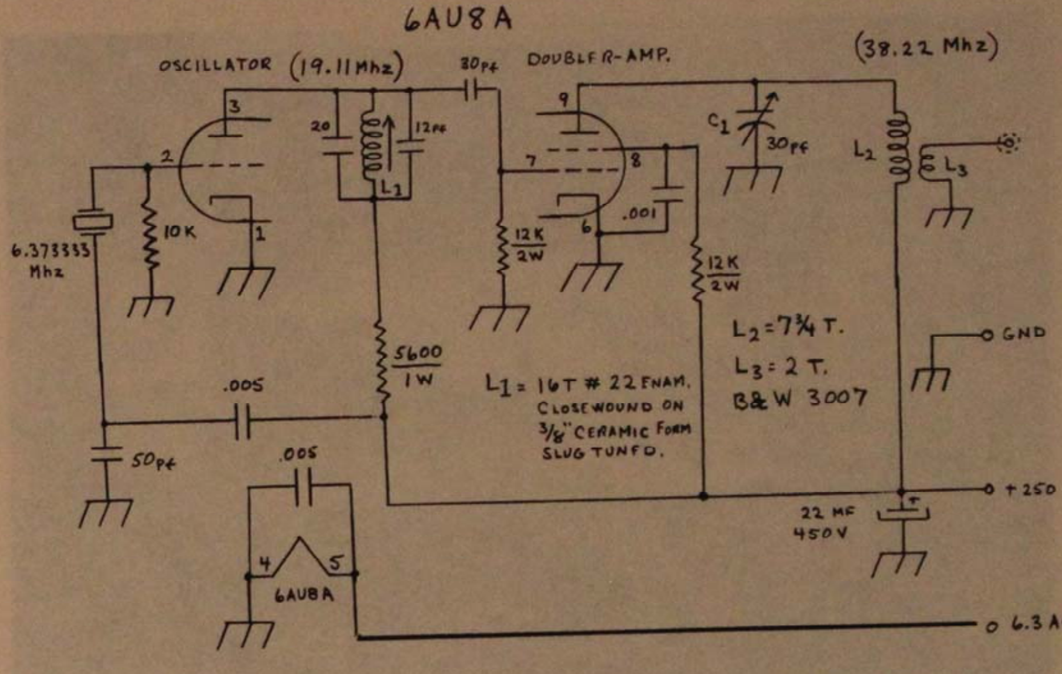


FIGURE 7. Circuit diagram for the acousto-modulator driver.

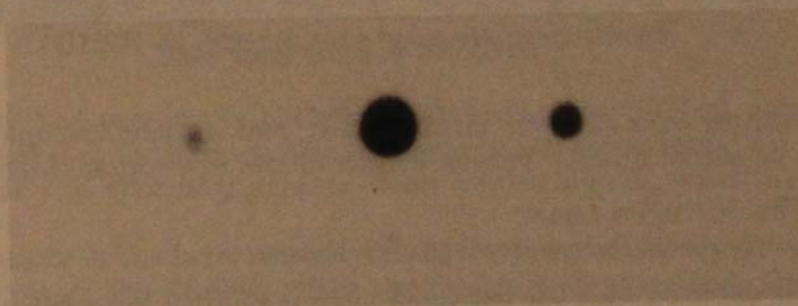


FIGURE 8. Diffraction pattern of He-Ne laser beam due to Acousto-Optic Effect.

D. *The Solid-State Diode and Fiber Optics*

Students have generally read popular reports of fiber-optic transmission of audio and video signals and are eager to do this experiment. The laser used in the experiment is a double heterojunction of AlGaAs, using parallel partially reflecting faces perpendicular to the junction to form a Fabry-Perot cavity which amplifies the light emitted by electrons and holes dropping between energy bands in n- and p- type materials (16). In size, the diode laser is about 5 mm x 6 mm, mounted in a metal cylinder with a window to transmit the 940 nm beam. With a forward current of 50 ma, the laser beam is typically 1.6 mW in power (17). The pair of students is asked to use a suitable photodiode for infrared light and to measure intensity versus distance and angle in air. Then, intensity versus length in the glass fibers is measured. Results are found to be in agreement with the manufacturer's curves which are shown in reference 17. The students are then asked to use a signal generator,

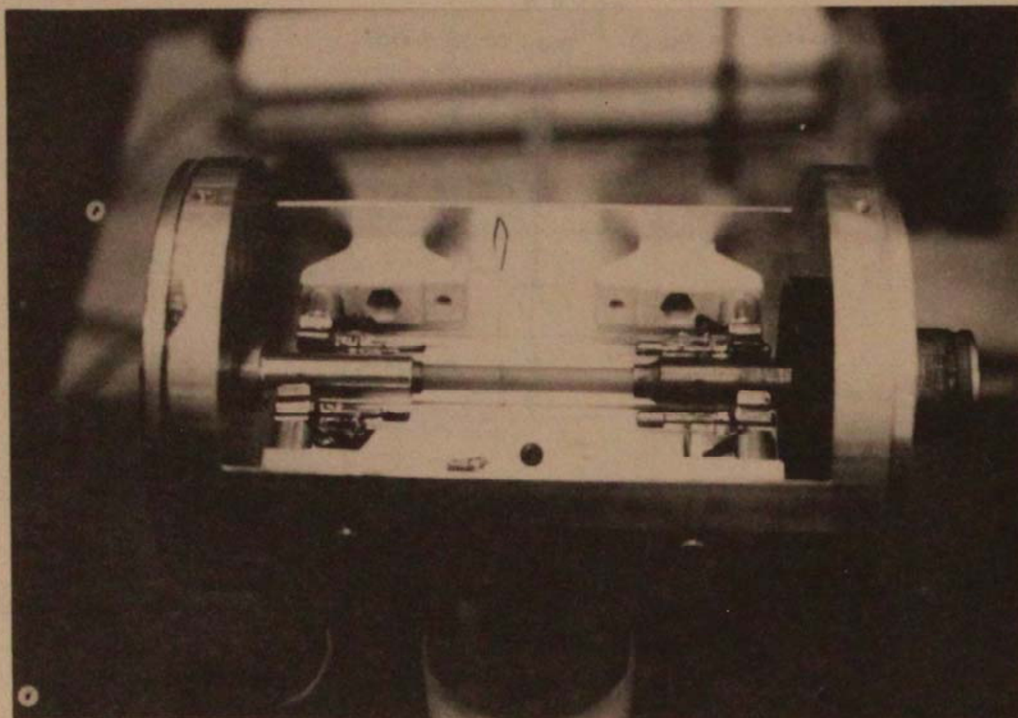


FIGURE 9. Ruby laser head.

transmitter and receiver circuits (18), and an oscilloscope in order to observe signal quality versus length of the fiber-optic cable.

E. *The Nitrogen Laser: Design and Parameter Measurements*

It is debated that the nitrogen laser is really a laser since the beam is not coherent. However, the device is an excellent source of radiation at 3371 Å and also serves as an excellent pump for tunable lasers. The nitrogen laser is relatively easy to build, using the Blumlein design as we did. As shown in Figure 10, the laser consists of two parallel sheets of copper foil separated by a thin dielectric. The top sheet is separated into two parts, connected to a gap running the entire length of a lucite chamber containing nitrogen gas. A 20,000-volt power supply and a spark-gap switch are also required and can be easily built. We built our power supply from a 5,000-volt transformer at 5 ma and a voltage quadrupler circuit. The spark-gap switch can be built of copper or brass in the form of a c-clamp (19). Several modifications that give improvement in beam quality and intensity but still use the same basic Blumlein design have been published in the literature (20-23). The device works as a large parallel plate capacitor, with the power supply initially charging the top half-sheets (equally) and the bottom sheet. The two half-sheets are interconnected through an inductor. The voltage is raised until the spark-gap switch fires. At this point, a circular wave moves out from the spark-gap switch towards the gap in the lucite chamber. Subsequently, a discharge

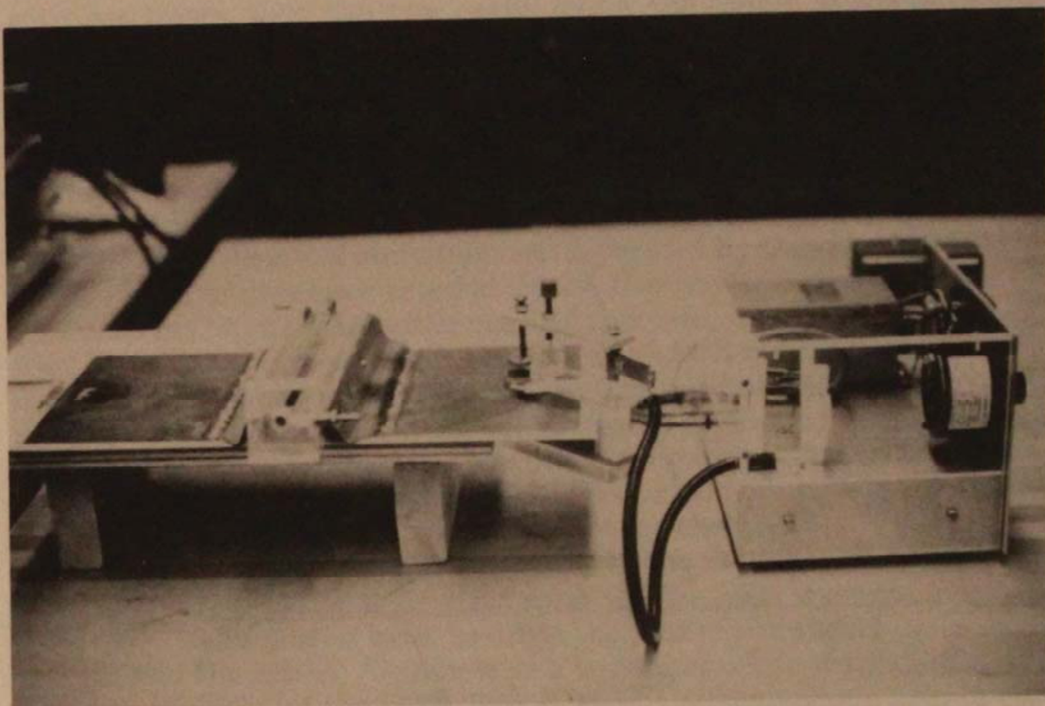


FIGURE 10. The nitrogen laser, Blumlein design.

occurs across the gap in the chamber, producing the 3371 Å nitrogen laser beam parallel to the gap. The nitrogen is self-quenching in a short time, so that the charging process soon begins again, resulting in a pulsed laser.

Since all parts of the laser are laid out in the open, students can easily follow the flow of the design. After the design is understood, the students are asked to use a grating to measure the wavelength of the nitrogen laser and to relate the 3371 Å line to the energy level diagram of the nitrogen molecule (24). Then, they are asked to measure intensity versus gas pressure for a fixed voltage. A photodiode with a high efficiency in the untraviolet region and with a sapphire or quartz window is needed here (25). After determining the optimum pressure, the curve of intensity versus voltage is measured. Typical results are shown in Figures 11 and 12. A front surfaced mirror is then set up behind the nitrogen beam and adjusted to be perpendicular to the beam. Although mirrors are not needed to cause lasing in nitrogen, contrary to other lasers, the addition of a back mirror will increase the intensity about 25%. Next, the students are directed to pass the laser beam into a small bottle of rhodamine dye solution and to observe the super-radiance as a bright yellow beam is produced within the orange dye solution (rhodamine dye in ethanol or methanol). The analysis of this phenomenon (26) becomes part of their written report.

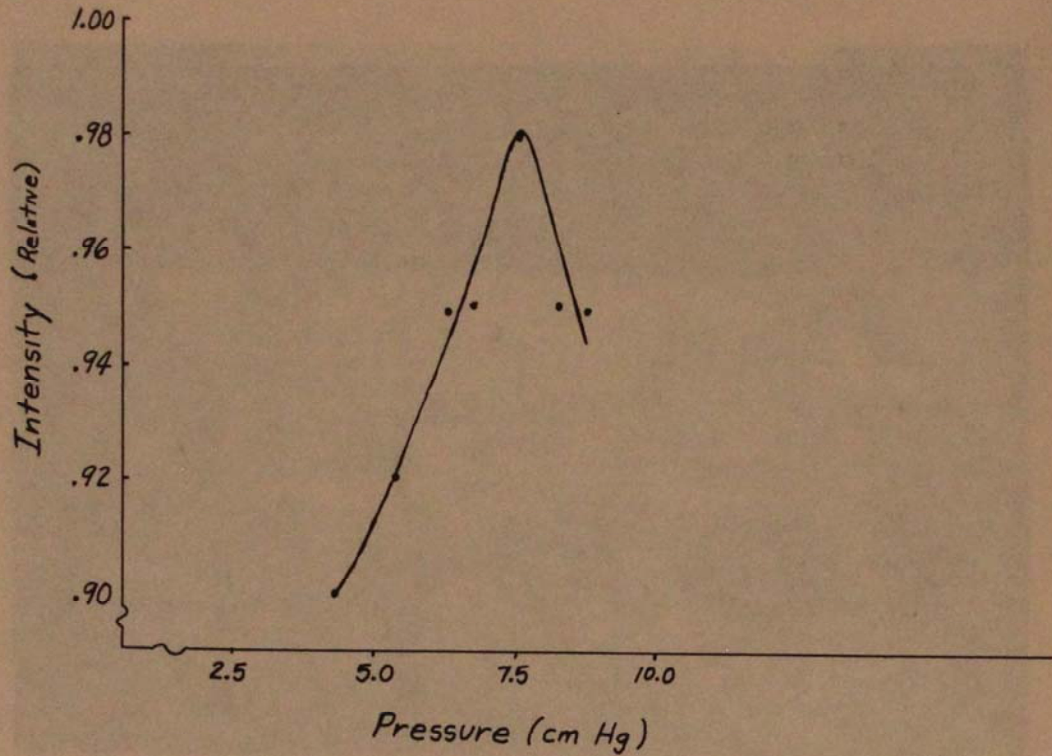


FIGURE 11. Intensity versus pressure for the nitrogen laser (by J. Puddington, Class of 1983).

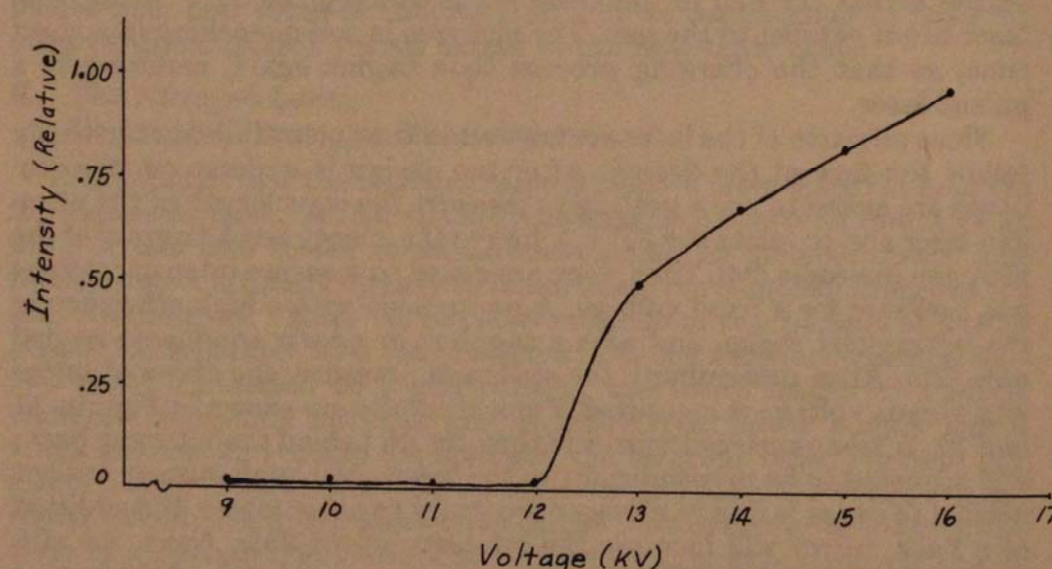


FIGURE 12. Intensity versus voltage for the nitrogen laser (by J. Puddington, Class of 1983).

F. *The Flashlamp-Pumped Tunable Dye Laser: Design and Characteristics*

At this point, students begin getting into more complex laser systems. However, having already gained an understanding of the ruby and nitrogen lasers, they can now easily follow the design of the flashlamp-pumped tunable dye laser. We built our laser system following the circuit design given in reference 27, finding it to be a much more complex and tedious task than the nitrogen laser construction but still a reasonable one if a small machine shop is available. The laser was built in a modular fashion to optimize student understanding. One of the most important components of the system is an energy storage capacitor which we built of 40 sheets of aluminum foil separated by thin sheets of Mylar, to give a .25 uf capacitor rated at 13 kv. Our power supply consists of a 15 kv, 30 ma, sign transformer coupled to a bridge rectifier. A spark-gap that is controlled by a trigger transformer—SCR circuit is also needed, to regulate the pulsing rate of the laser. The head of the laser consists of an elliptical cylinder with a xenon flashtube at one focus and a quartz dye tube at the other focus. The optical geometry consists of the laser head, an 80% reflection mirror, a prism for tuning, and a 100% reflection mirror. The flashtube has a water jacket for cooling.

After the system has been explained to the students, they are asked to sketch an operational flow diagram for the laser system. They can then use a helium-neon laser to align the two mirrors, each on a tripod mount, and the prism. A pinhole in a square of white cardboard that is taped to the head of the helium-neon laser is a tremendous help in comparing the emitted and reflected beams and, thereby, facilitating alignment. The laser is now ready to be started-up, flowing water through the water jacket of the flashtube, turning on the pump for the dye solution, turning on the power supply for SCR circuit, and finally raising the high voltage to 10,000 volts. We measure the voltage with a Heathkit high-voltage probe. The students are asked to measure intensity and wavelength versus angle of the rear 100% mirror for rhodamine dye. A grating and a photodiode detector are the tools used here to measure the characteristics of the bright yellow beam which varies from a slightly greenish-yellow to an orangish-yellow as the laser is tuned by rotating the rear 100% mirror. Results are found to be in agreement with the dye manufacturer's curves which are given in reference 28.

G. *The Laser-Pumped Tunable Dye Laser and Atomic Excitation*

Our laser-pumped system is a commercial NRG (29) system consisting of a nitrogen laser that pumps a dye cell in the Hansch (30) design to produce a final beam of about 500 nJ per pulse. The cylindrical lens serves to focus the rectangular nitrogen beam to a line image on the front surface of the dye. The reflection grating is rotated to select different lasing wavelengths. The telescope and the etalon have the function of increasing the resolution of the beam.

After the students understand the design of the system, they are directed to calibrate the micrometer that rotates the tuning grating in units of angstroms by using an external grating. We use a Coumarin 460 dye (31) solution that produces hues of blue light. The students are then asked to measure intensity versus wavelength for the dye which yields a curve in agreement with the dye manufacturer's data given in reference 31. The students are now prepared to study the laser beam passing through a small cylindrical cell with quartz windows in each end, containing hydrogen (32). Tuning through the wavelengths of the dye and measuring the intensity of the beam at each wavelength after passing through the cell, the students can plot the absorption curve of hydrogen. The experiment is repeated with helium. They are asked to compare the wavelengths of the dips in the curves with the spectra given in reference 33.

The technique of beam amplification (34) is useful for students to learn. By placing a partially reflecting mirror at 45° between the nitrogen laser and the cylindrical lens and extracting 20% to 50% of the nitrogen beam to reflect off a 100% front-faced mirror that directs the nitrogen beam into a second cylindrical lens and dye cell that is in the path of the first dye laser beam, students can measure the dye laser beam intensity before and after the second dye cell and calculate the amplification factor.

H. *Laser Spectroscopy*

We are presently building a laser spectroscopy system, see Figure 13, to allow students to do experiments in high resolution spectroscopy. We wish to show students the effect that the doppler shift due to the motion of atoms has on resolution and methods of eliminating the doppler shift such as polarization spectroscopy and two photon absorption (35). We

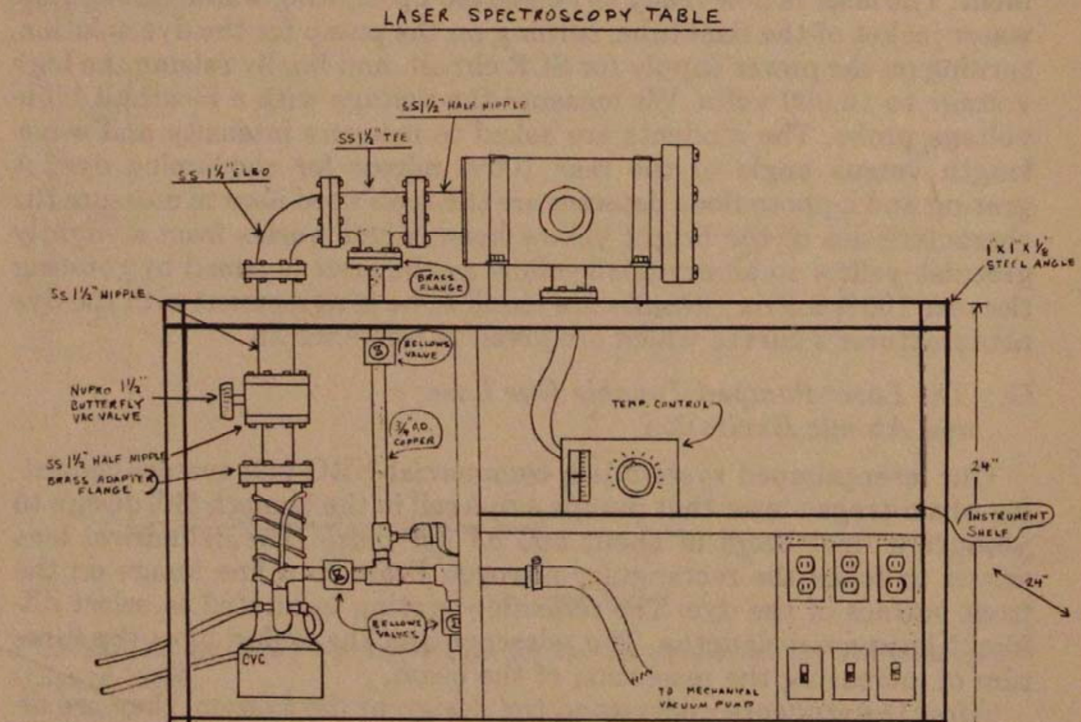


FIGURE 13. Chamber and vacuum system for laser spectroscopy.

are also interested in developing the methods of double—and triple—step energy level excitation where two lasers of different wavelengths pass beams through elements in vapor form. Finally, we wish to develop the method of resonance ionization spectroscopy which allows single-atom counting by lasers (36).

IV. Course Evaluation

The course has been taught for three years now. Students have shown great interest in the lasers and have expressed appreciation of the contemporary nature of the course. Students have used their knowledge gained in the course to do senior research projects, which is required of all of our majors, such as devising a laser method of measuring the speed of a gas. A few students have gone on to work in the electro-optics industry, and others have gone on to graduate schools to major in a laser-related area or have used lasers as tools in their research.

V. Acknowledgments

I wish to thank the NALCO Foundation, the Corning Foundation, and the Andrew W. Mellon Foundation for support in developing this laboratory. I wish to thank Dr. G.S. Hurst and his research group at Oak Ridge National Laboratory for their gracious hospitality during the summer of 1981 when I greatly improved my background in lasers. I also wish to thank Dean Kenneth Welliver of Wesleyan for his support, and my colleagues Dave Sheppard and Jai Dahiya for helpful discussions. Finally, I wish to thank Arnold Sayre of our department for building the lasers and associated equipment.

Bibliography

1. S. Baskin and J. Stoner, Jr., *Atomic Energy-level and Grotian Diagrams* (North Holland Publishing Co., Amsterdam, 1978), Vol. 1, revised ed.
2. J. Moore, C. Davis, and M. Coplan, *Building Scientific Apparatus* (Addison-Wesley Publishing Co., London, 1983).
3. F. Jenkins and H. White, *Fundamentals of Optics* (McGraw-Hill Book Co., New York, 1976), fourth ed., p. 640.
4. B. Turman, The Physics Teacher, 18, 420 (1980).
5. R. Ditchburn, *Light* (Academic Press, London, 1976), third edition.
6. P. Debye and F. W. Sears, Proc. Nat. Acad. Sci., 18, 409 (1932).
7. M. Born and E. Wolf, *Principles of Optics* (Pergamon Press, Oxford, 1975), fifth ed.
8. Andersen Laboratories, Inc., Bloomfield, Ct.
9. Designed by Arnold Sayre of our department.
10. R. Kingslake and B. Thompson, *Applied Optics and Optical Engineering* (Academic Press, New York, 1980), Vol. VI.
11. R. Benney, *Popular Science,* 62 (Nov., 1964).
12. Linde Co., Crystal Prod., Div., E. Chicago, Ind.
13. Evap. Metal Films, Inc., Ithaca, N.Y.
14. R. Kingslake and B. Thompson, *Applied Optics and Optical Engineering* (Academic Press, New York, 1980), Vol. VI.
15. F. Jenkins and H. White, *Fundamentals of Optics* (McGraw-Hill Book Co., Inc., New York, 1976), fourth ed.
16. R. Kingslake and B. Thompson, *Applied Optics and Optical Engineering* (Academic Press, New York, 1980), Vol. VI.

17. Specification sheet on MFOE 200, no. 11592-1, Motorola, Inc. (1978).
18. Motorola Semiconductor Products, Inc., *Basic Experimental Fiber Optic Systems,* Phoenix, AZ (1978).
19. J. Small, Sci. Am., 230, 122(74).
20. I. Nagata and Y. Kimura, Journal of Physics E, 6, 1193 (1973).
21. A. Schwab and F. Hollinger, IEE J. Quantum Electron., QE-12, 183 (1976).
22. C. Wang, Rev. Sci. Instr., 47, 92 (1976).
23. C. Sam, Appl. Phys. Letters, 29, 505 (1976).
24. G. Barrow, *Molecular Spectroscopy* (McGraw-Hill Book Co., Inc., New York, 1962), p. 237.
25. Hanamatsu Corp., Middlesex, N.J.
26. R. H. Dicke, Phys. Rev. 93, 99 (1954).
27. A. Alfrey, Am. J. Phys., 49(8), 776 (1981).
28. Exciton Chemical Corp. catalog (1983). See also P. Sorokin, J. Lankard, V. Moruzzi, and E. Hammond, Chem. Phys., 48, 4726 (1968).
29. National Research Group, Inc., Madison, Wis.
30. T. Hansch, *Dye Lasers* (Springer-Verlag, Heidelberg, 1973), sec. 4.2c.
31. Exciton Chemical Corp., Dayton, Ohio.
32. T. Hansch, A. Schawlow, and G. Series, Sci. Am., 240, 94 (1979).
33. S. Baskin and J. Stoner, Jr., *Atomic Energy-level and Grotian Diagrams* (North Holland Publishing Co., Amsterdam, 1978), vol. 1, resided ed.
34. A. Corney, *Atomic and Laser Spectroscopy* (Clarendon Press, Oxford, 1977), p. 396.
35. T. Hansch, A. Schawlow, and G. Series, Sci. Am., 240, 94 (1979).
36. G. Hurst, M. Nayfeh, and J. Young, Phys. Rev. A, 15, 2283 (1977).

Engineering Section

Influence of Ultrasound on Material Processing—Some observations

Harold V. Fairbanks
Department of Chemical Engineering
West Virginia University
Morgantown, West Virginia 26506

Abstract

The purpose of this paper is to report the effects produced when ultrasonic energy is introduced into various processes. The major unit operation areas covered by the processes studied include: crystallization, heat transfer, and mass transfer. Results of the changes produced by the addition of ultrasonic energy into the systems are given for each specific process investigated. Brief explanations of the mechanisms thought to be responsible for the observed changes are presented. It was found that ultrasonic energy may effect a change in either the processing rates, the processing temperature, or the microstructure of the product. This paper covers two decades of work in this area of ultrasonic research at West Virginia University.

Introduction

The influence of adding ultrasound during the processing of materials may be considered catalytic. That is, the sonic radiation increases the rate for a given process to reach equilibrium. The influence of this catalytic effect by sonic radiation is quite significant when the normal rate toward equilibrium is very slow. The mechanism by which ultrasound produces the catalytic effect differs with the various process systems.

This paper summarizes the major results of several exploratory studies which made use of ultrasound during processing of materials at West Virginia University. Ultrasound having a frequency of 20 kHz with sound intensities up to 170 dB was introduced into processes which included both metallic and non-metallic materials.

For metals, the areas studied include: solidification, recrystallization, heat treating, heat transfer and drilling of metals. For non-metals the areas studied include: molding of polymer powders, filtration, drying of temperature sensitive materials, and the effect of ultrasound on the adherence of molten glass to heated metal.

Metals and Alloys

Solidification studies were made using aluminum, nickel, gray cast iron, and nodular cast iron. The introduction of ultrasound during solidification produced grain refinement in both aluminum and nickel.[1] See Figure 1.

With gray cast iron two effects were noted: (1) the graphite flakes produced were smaller, (2) the graphite flakes were more homogeneously distributed throughout the metal.[2] See Figure 2. For nodular cast iron insonation substantially reduced the size of the graphite nodular.[3] It was also found that alloy additions to the melt significantly influenced the product produced.

The catalytic effect of ultrasonic energy is seen here in the increased grain refinement and homogeneity of the resulting microstructure of the metal produced during solidification. This catalytic effect was brought about by: (1) an increase in heat transfer promoted by the ultrasonic energy,[9] and (2) an increase in the atomic diffusion rate caused by the induced ultrasonic vibrations.[2] Both of these factors will increase the rate of nucleation during solidification (See Figure 3). This nucleation increase results in an increased refined grain structure, smaller particles of precipitated graphite, and a more homogeneous metal microstructure.

Recrystallization studies included the polymorphic transformation in steel and reheating of cold worked metals. Insonation during polymorphic transformation of steel aided in the promotion of smaller ferrite grains but increased the thickness of the lamellar layers making up the pearlite.[4] Figures 4 and 5 show the resulting microstructure in steel.

Insonation during the recrystallization of cold worked metals generally refined the grain size and lowered the temperature required for recrystallization.[5] Figure 6 shows the influence of ultrasound on the removal of the twinning structure in magnesium during recrystallization along with some grain refinement. With uranium, it was found that a more randomized crystal orientation among the grains was also produced.[6]

The reasons for the catalytic effect of the ultrasonic energy addition to recrystallization processes were primarily due to the increase in rate of nucleation, much the same as in solidification. However, it was noted that the thickness of the very thin lamellar plates of iron carbide and ferrite which form the pearlite structure in steel were made thicker by a major increase in the atomic diffusion rate caused by the introduction of ultrasonic energy into the system.

Heating treating studies included precipitation hardening for aluminum, and tempering of steel.

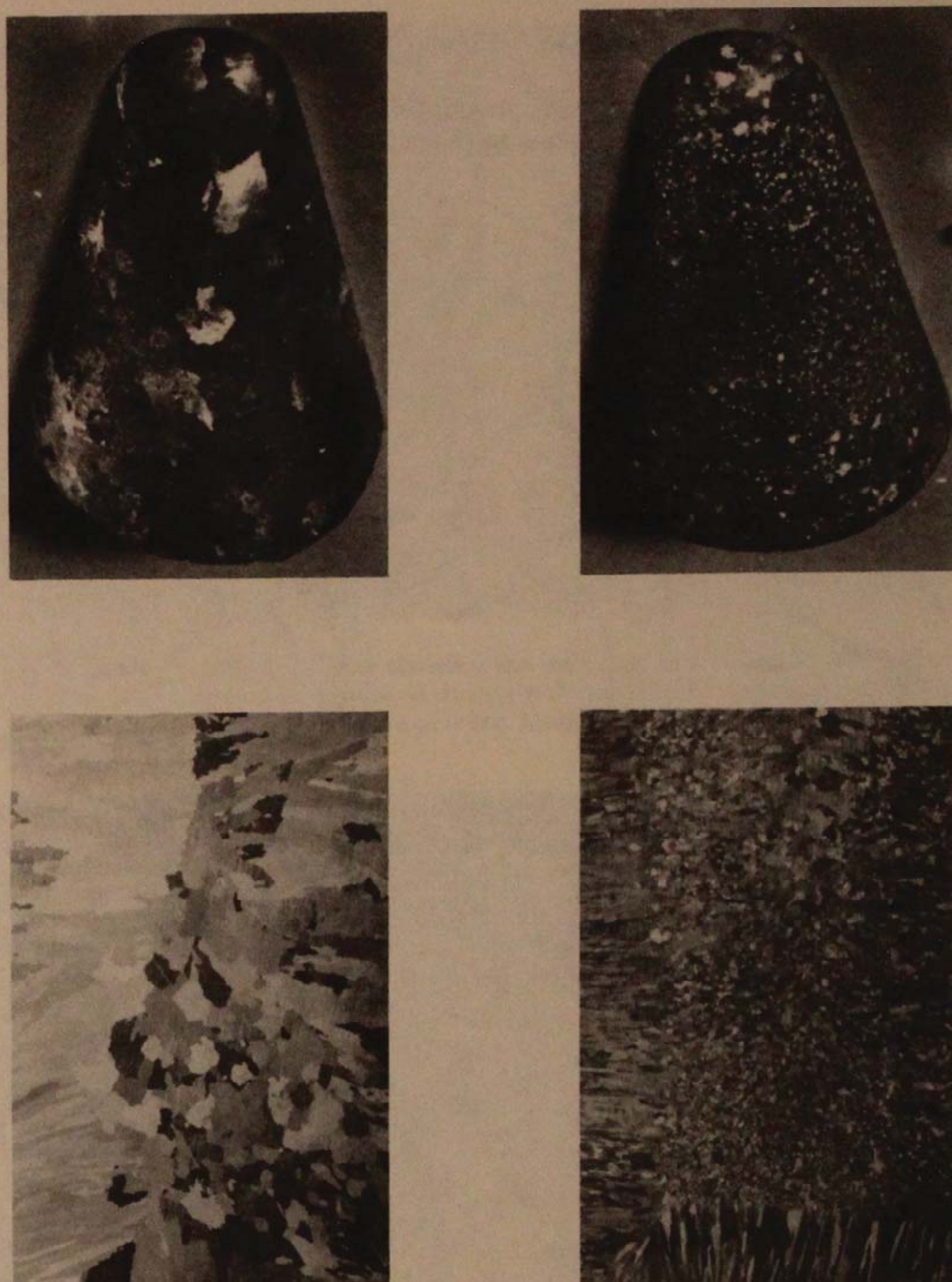


FIGURE 1. Photographs showing the influence of ultrasonic on refinement of grain size during solidification. Top photos show crystal structure on surface of small aluminum cones. Bottom photos show crystal structure on cross-section of small nickel ingots.

Insonation during solution treatment of aluminum alloy appeared to produce a more homogeneous solid solution. Insonation during the precipitation stage aided the rate of precipitation. However, only a slight increase in hardness remained.[7] Figure 7 presents the experimental results.

In tempering of martensite, insonation retarded the decomposition rate of martensite, thus decreasing the rate for softening of the alloy.[8] It

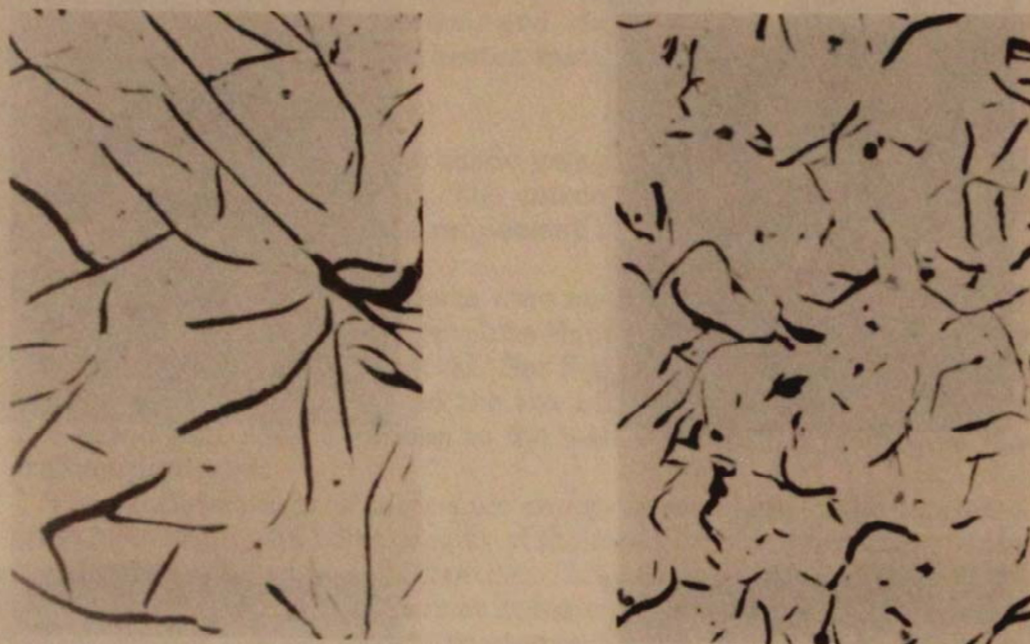


FIGURE 2. Photomicrographs (25X) showing the influence of ultrasound on the graphite size formation and distribution during solidification of the iron.

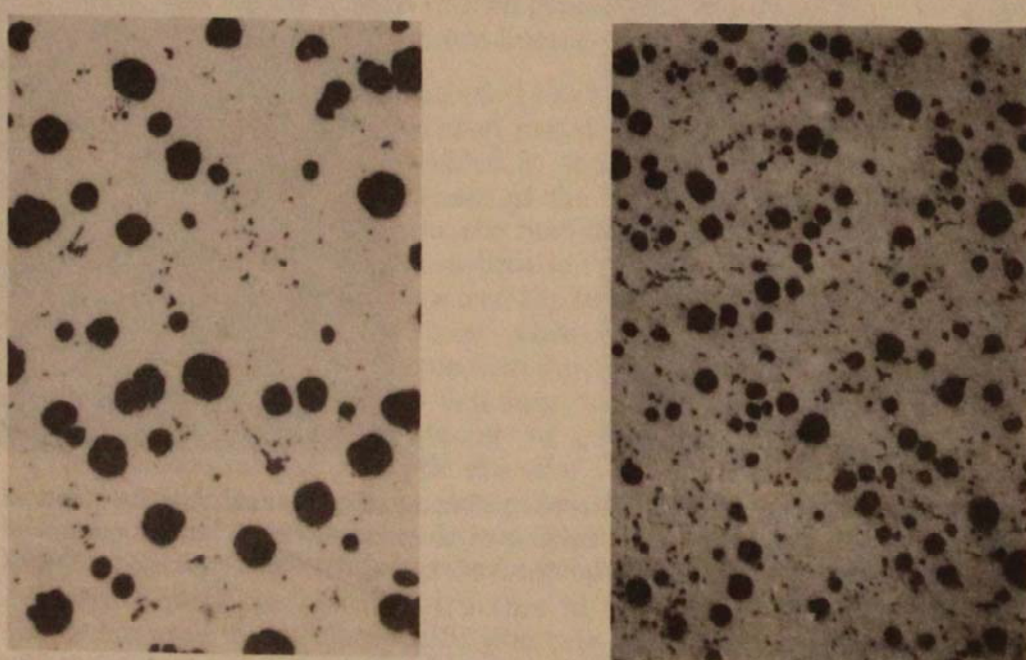


FIGURE 3. Photomicrographs (50X) showing the influence of ultrasound on the size and distribution of the graphite nodulars formed during solidification of the iron.

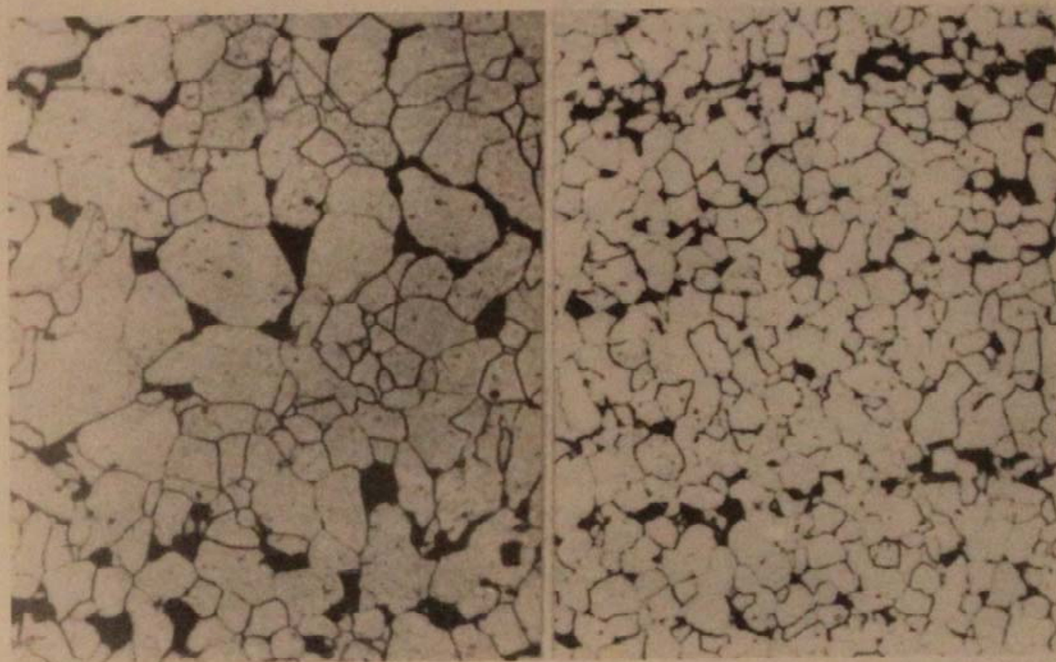


FIGURE 4. Photomicrographs showing the influence of insonating low carbon steel upon the grain size produced during polymorphic transformation. White grains are ferrite, black grains are pearlite. Magnification is 100X. Right sample ultrasonically treated.

FIGURE 5. Photomicrographs showing the influence of insonating high carbon steel upon the lamellar layer thickness of the ferric and iron carbide produced during polymorphic transformation. Magnification is 1000X. Right sample ultrasonically treated.

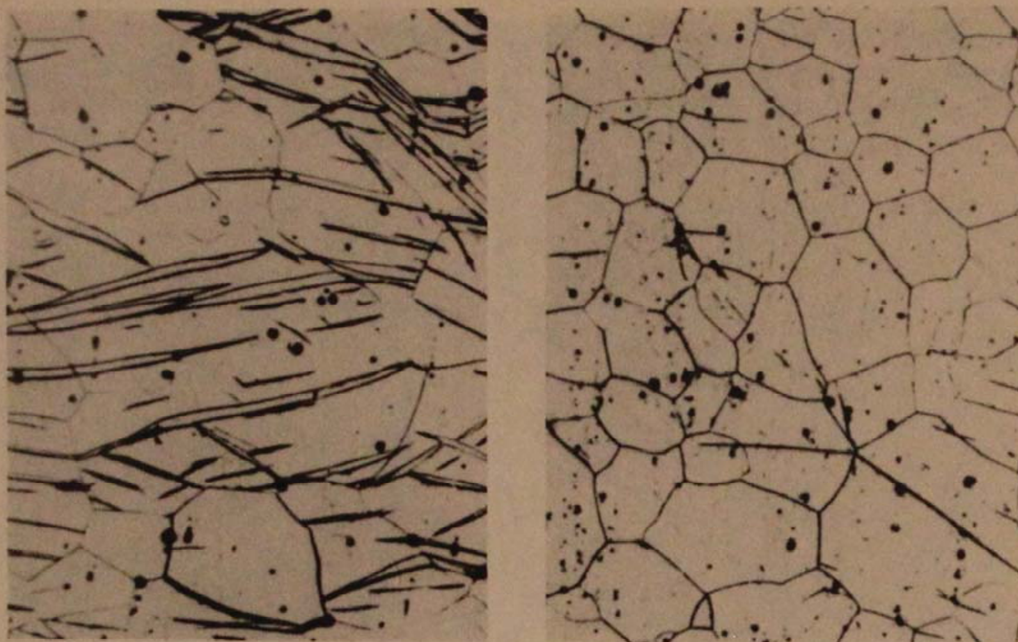


FIGURE 6. Photomicrographs show the removal of mechanical twins in magnesium by insonation of specimen which were mechanically deformed 12%. Both samples were heated to 500°C for 30 minutes. Magnification is 100X.

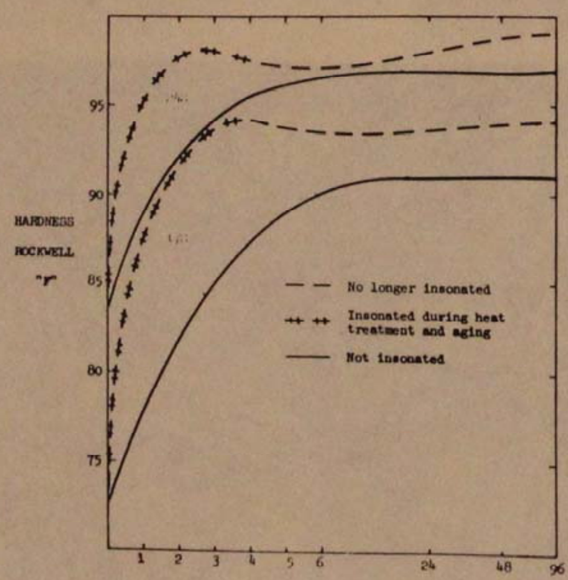


FIGURE 7. Curves showing the effect of insonation in two heat treatable aluminum alloys upon the resulting hardness obtained.

was also noted that the introduction of ultrasound produced a more homogeneous temper structure as shown in the photomicrographs in Figure 8.

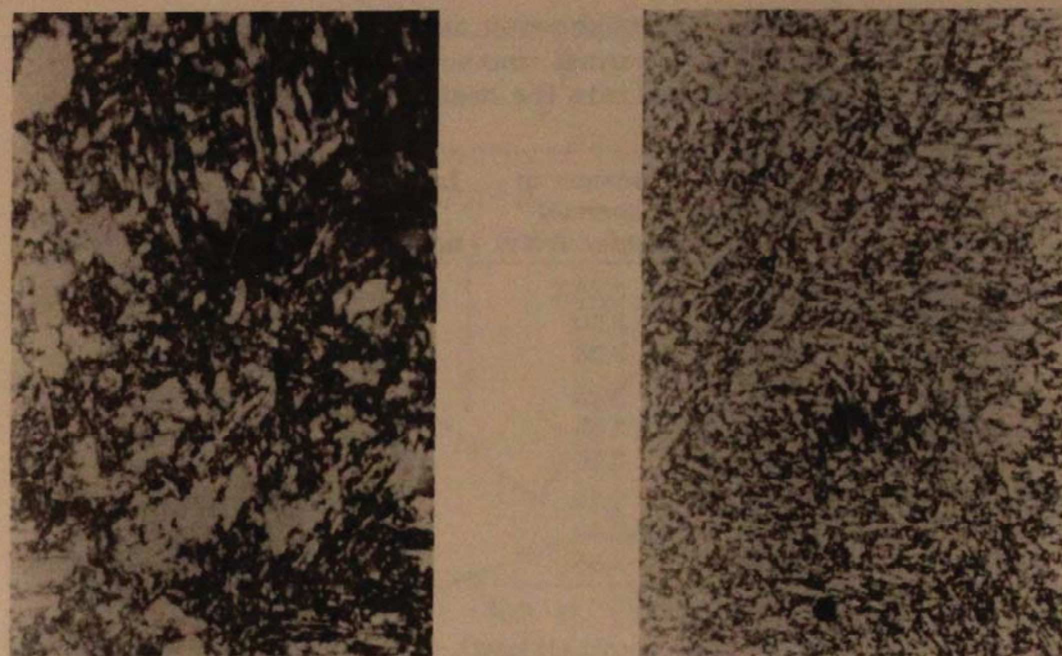


FIGURE 8. Photomicrographs comparing the resulting microstructures for a mild steel sample (right) which has been insonated during tempering at 650°C with a reference sample (left). Magnification is 650X.

In the tempering of martensite steel, it was postulated that the ultrasonic vibrations initially cause some relaxation of peak stress points by small atomic readjustments within the metal. Next, the ultrasonic energy causes an increase in the nucleation rate for the iron carbide which diffuses out of the matrix in the solid state. This effect in turn produces a more homogeneous microstructure.

Heat conduction studies included the following metals: (1) steel which has a body-centered cubic crystal structure (2) aluminum which has a face-centered cubic crystal structure, and (3) magnesium which has a hexagonal crystal structure. The application of ultrasound increased the conduction rate approximately three to three and one-half times. See Table 1. Neither the crystal structure or direction of applying the ultrasound into the metal test rods made very little difference in the results.[9] However, the higher temperatures for the hot end of the rods gave lower increases for the thermal conductivity due to ultrasonic energy absorption.

Figure 9 shows an unsteady state curve for magnesium with ultrasound being introduced for a few minutes and then being shut off for a few minutes. This Figure dramatically illustrates the effect of insonation on temperature rise along the magnesium rod. It also shows that steady state for this system was attained in approximately 40 minutes.

The addition of ultrasonic energy into a metal rod increased the rate of heat convection from the metal rod surface into the surrounding air due to the vibrational disturbance of the static air filter located on the surface of the metal rod. However, a good explanation for the catalytic

Table 1. Summary of results showing numerical increase for thermal conductivity and thermal convection when ultrasound was introduced into the heat transfer system

	Furnace temp. °C	*Increase in thermal conductivity*	*Increase in thermal convection*	*Crystal Structure*
Magnesium*	550	3.25X	4X	Hexagonal
Magnesium	500	3.50	4X	Hexagonal
Magnesium	450	3.25	4X	Hexagonal
Aluminum**	550	3.45	4	Face-centered cubic
Aluminum	500	3.55	4	Face-centered cubic
Aluminum	450	3.50	4	Face-centered cubic
Steel**	700	2.25	4	Body-centered cubic
Steel	650	2.50	4	Body-centered cubic
Steel	600	3.55	4	Body-centered cubic

* ¾-inch diameter rods, 2 wavelengths in length. One end threaded and screwed into the sonic transducer horn; other end of the rod placed in temperature controlled furnace.
** ½-inch diameter rods.

effect for ultrasonic energy to promote an increased rate of heat conduction in a metal rod appears to be lacking.

Drilling studies included insonated machine drilling of steel, aluminum, brass, cast iron, and stainless steel. It was found that the metals which were work hardened due to the ultrasonic vibrations gave improved drilling.[10] That is, the cutting speed increased, tool life increased, and the drilled hole had a smoother surface. Figure 10 shows the difference in aluminum chip formation when ultrasound was applied during drilling.

Non-metallic

Polymer molding studies included both thermosetting and thermoplastic polymer powders. It was found that by use of a small amount of pressure along with ultrasound, solid cylinders could be produced from the polymer powders without the addition of heat. It was also found that thermoplastic powder could be fused and extruded through a small orifice by using ultrasound with a small amount of pressure. Figure 11 shows the equipment in operation.

The catalytic effect of the ultrasonic energy when added to the compressed plastic particles was due to the heat produced by the friction of the polymer particles rubbing against each other. The ultrasonic vibrations produced this rubbing action and moved through the polymer mass as each particle fused with its neighbors.

Filtration studies included the separation of particles 1-40 micron in size from both an oil and water slurry. When the normal filtration rate was very slow, insonation of the process was able to increase the flow rate as much as ten times. It was noted that Biot's equation, $F_m > \pi u/4d^2$

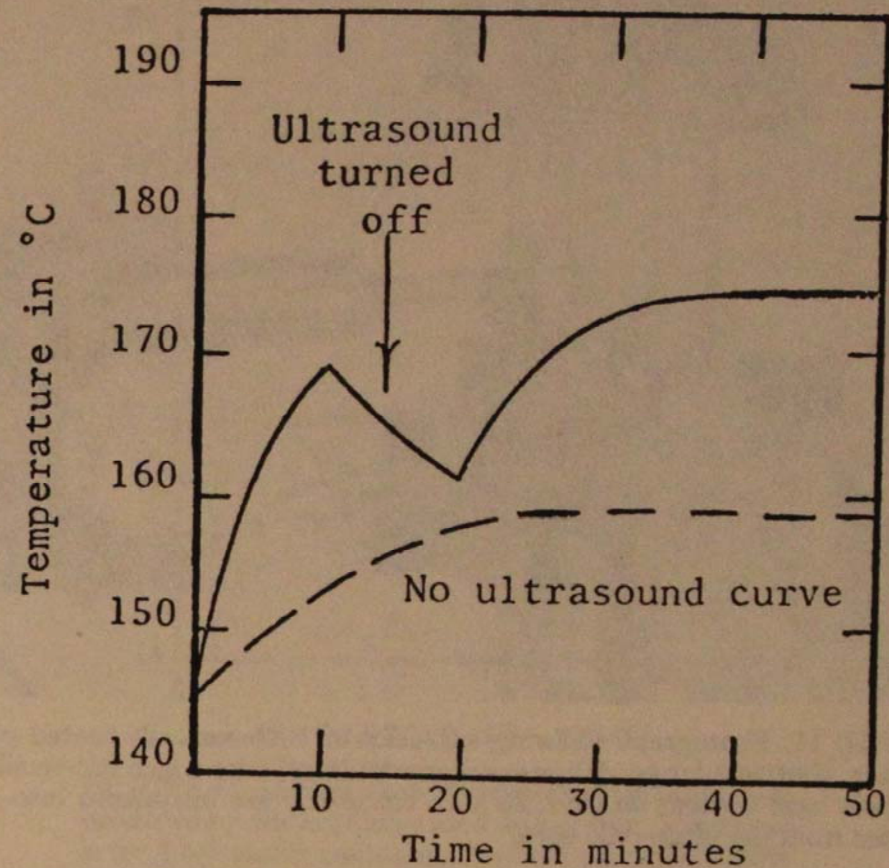


FIGURE 9. Unsteady state temperature curves showing the effect of introducing ultrasound in a magnesium bar. The lower dashed curve is for no sound added. Both curves continue to a steady state condition.

FIGURE 10. Photograph showing the change from spirals to small chips when ultrasound was applied during mechanical drilling of aluminum.

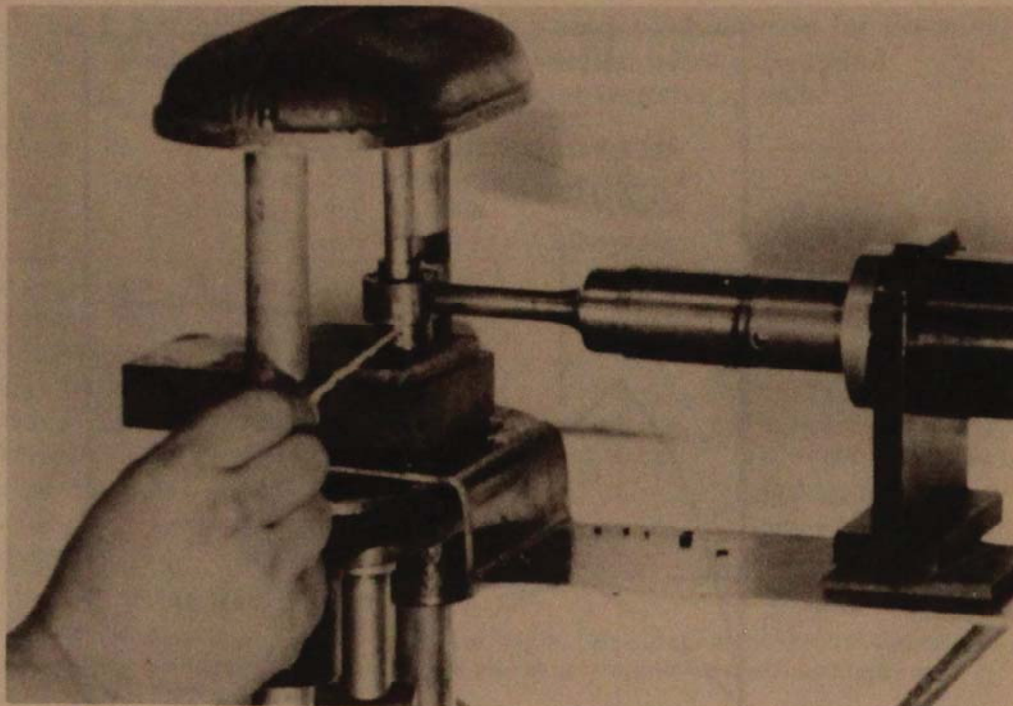


FIGURE 11. Photograph showing extrusion of ultrasonically-heated polymer powders. Vertical plunger compresses powder in cylinder which has small extrusion hole near bottom on side. 20 kHz vibrations are introduced into wall of cylinder from the ultrasonic horn.

must be maintained for insonation to have an effect. F_m is the sound frequency in cycles per second, u is the kinematic viscosity in aqueous centimeters per second, and d is the filter channel diameters in cm. Insonation reduces the fluid flow friction by producing a plug type flow instead of the normal viscous type fluid flow. It was also found that insonation at 20 kHz coagulated the particles in the 2-6 micron size.[12] Figure 12 shows the influence of ultrasonic intensity in increasing filtration rate for two different types of slurries. Figure 13 shows flow rate stimulation produced by the introduction of ultrasound into fluids diffusing through porous media.

The catalytic effect of ultrasonic energy when added to a filtration process or to a fluid moving through a porous media is due to attenuation of the ultrasonic energy at density discontinuities. In this case, the solid-liquid interfaces of the capillaries in the porous media or filter bed are effected. This attenuation of ultrasonic energy reduced the friction of the liquid flowing adjacent to the side walls of the capillaries, thereby producing the plug type of liquid flow.

Drying studies were made using polymer powders and pulverized coal, both being temperature sensitive material. Insonation was found to both increase the drying rate during the constant drying rate period, and to extend the constant drying rate period to a lower moisture content level.[13]

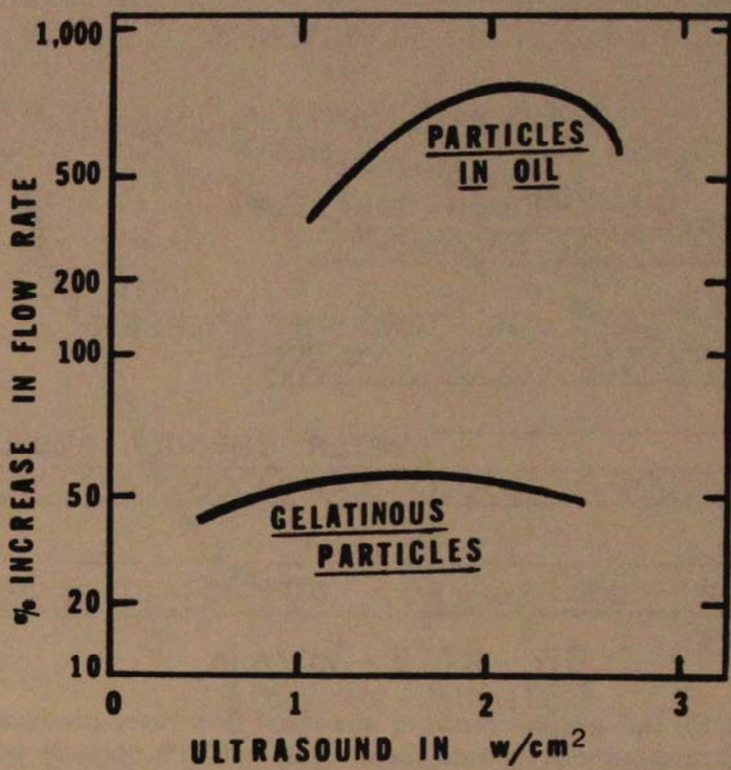


FIGURE 12. Curves showing increased filtration rate produced by adding ultrasound into system. Top curve is for 7.5% slurry containing 1-40 μm particles in 30W motor oil. Bottom curve is filtration of neutralized mine water drainage.

Figure 14 compares drying rate curves with and without ultrasound. The increase in drying rate is considered to be due to the increased turbulence of the air caused by the sound waves at the evaporation surface. The extended constant drying rate period is considered to be due to the increased fluid flow rate to the evaporation surface caused by the ultrasound. Figure 15 compares normal oven drying of powdered coal with and without ultrasound added.

Adherence of glass to metal studies showed that insonation increased the temperature required for adherence.[14] The experimentation simulated the process of molding a glass bottle in a metal mold. Figure 16 compares the molten glass adherence time to heated metal with and without ultrasound being introduced into the metal. Figure 17 shows the difference in oxide pick-up by the glass surface during contact with a stainless steel surface, with and without ultrasound.

It was hypothesized that the ultrasonic energy introduced into the heated metal specimen not only vibrated the metal surface but increased the heat loss at the metal surface, thereby requiring a higher metal temperature to produce the adherence of molten glass to the heated metal surface.

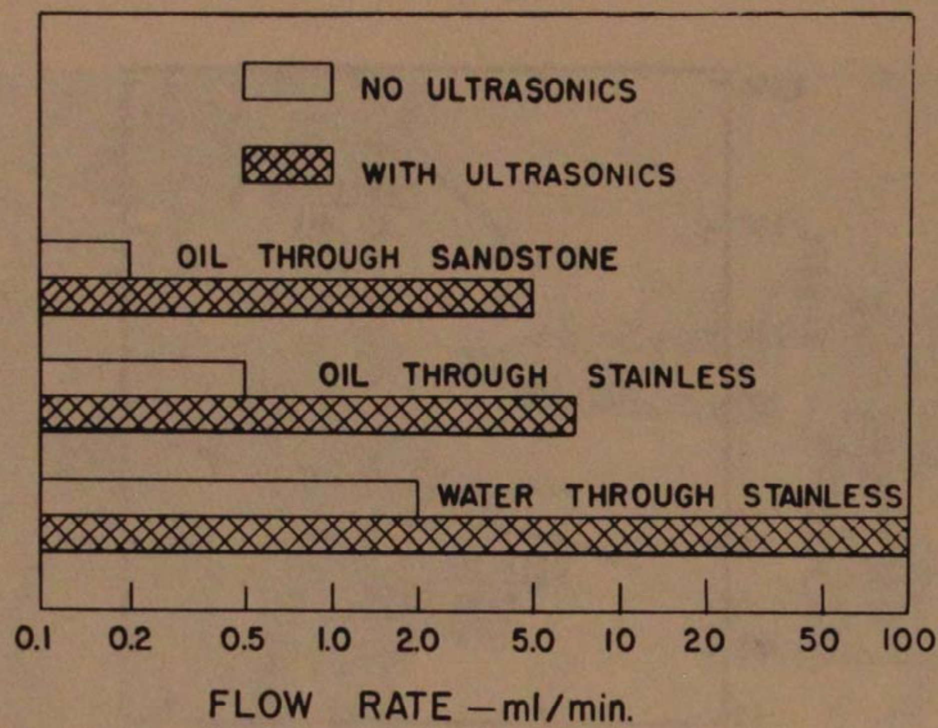


FIGURE 13. Bar graphs showing increased flow rates produced when adding ultrasound into system. Sandstone had 20% porosity with flow channels of 10-50 μm in size, stainless steel filter had 42% porosity with flow channels of 20-180 μm in size.

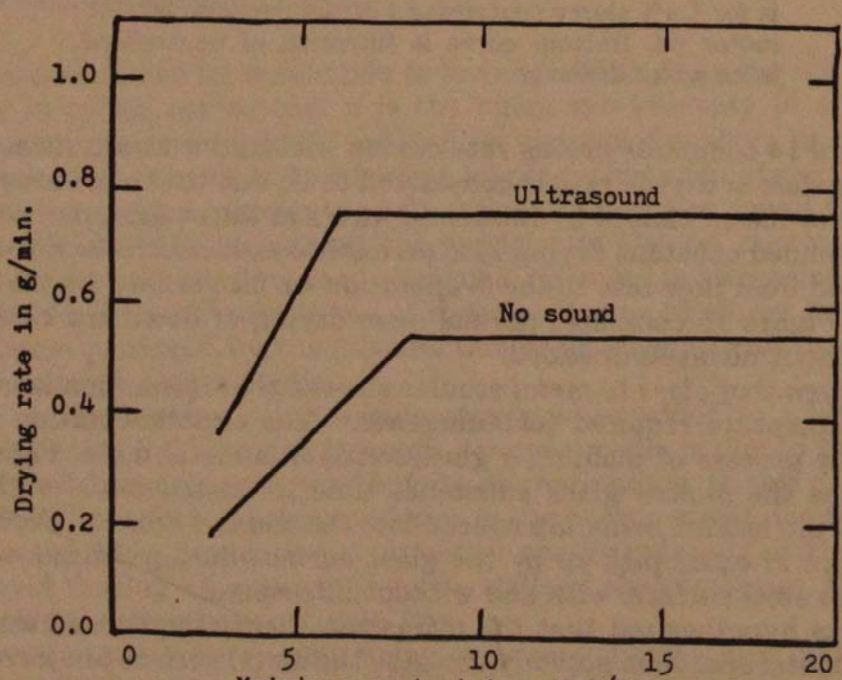


FIGURE 14. Typical drying rate curves showing the effect of airborne ultrasound being introduced above the evaporation surface.

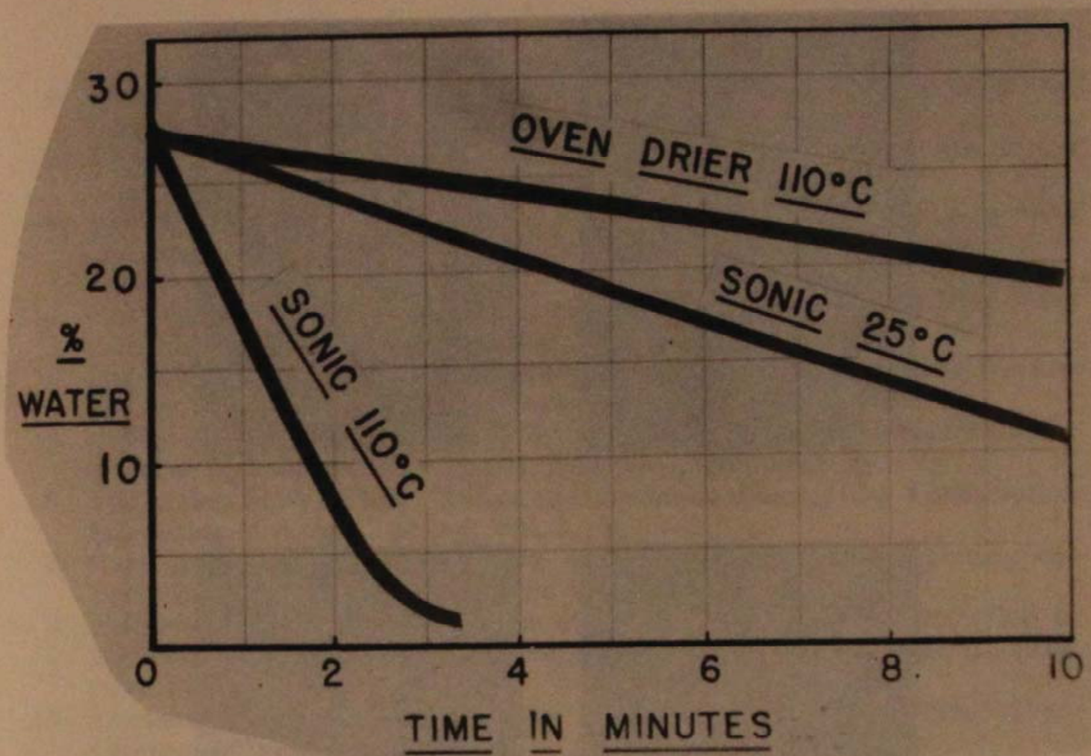


FIGURE 15. Drying of powdered coal layer 0.6 cm in thickness in drying oven with and without ultrasound.

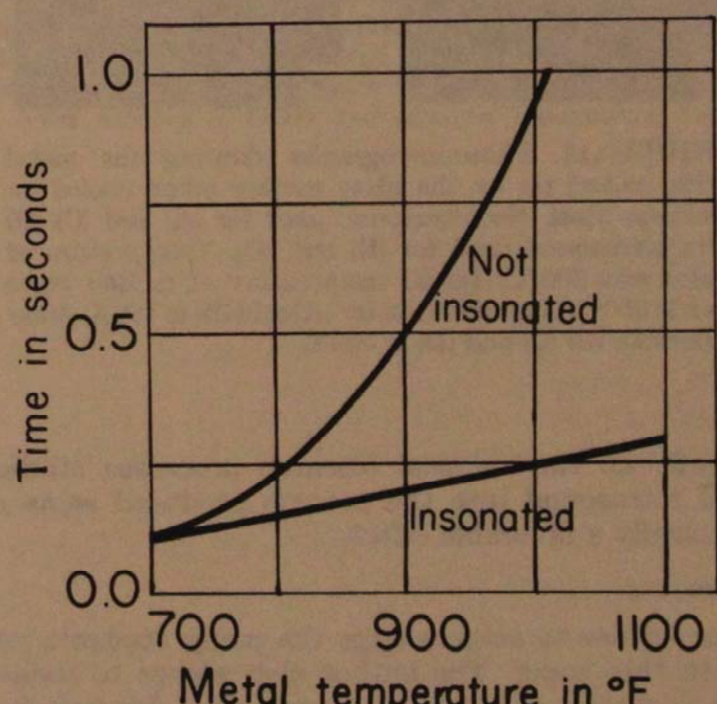


FIGURE 16. Adherence curves showing the influence of ultrasonics on the retention time of molten glass beads on the heated cast metal surface.

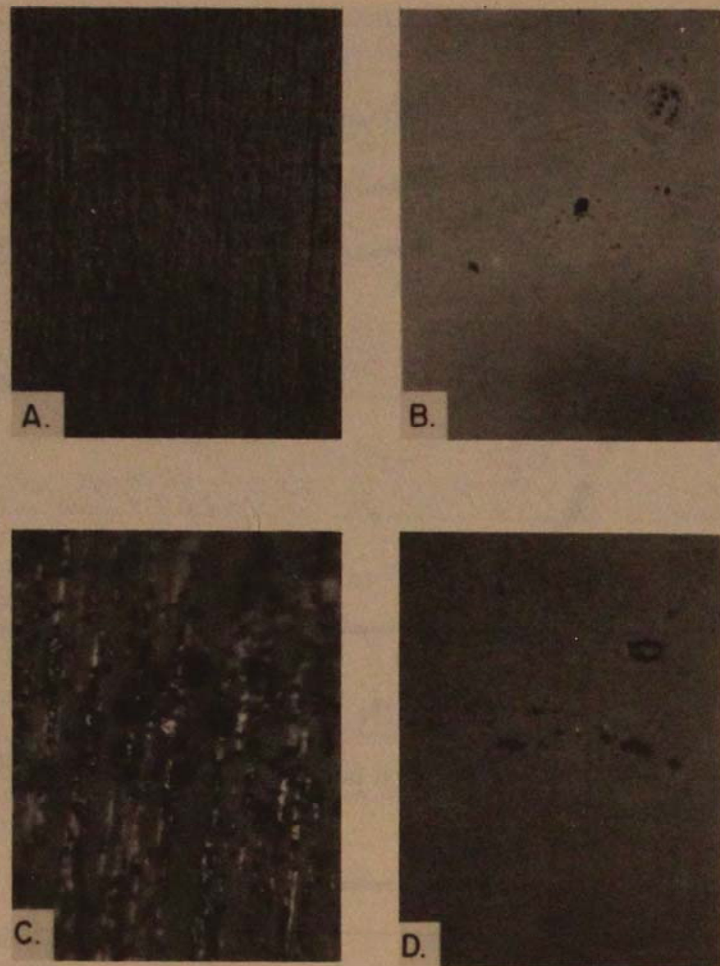


FIGURE 17. Photomicrographs showing the metal oxide picked up by the glass surface when cooled on stainless steel. No ultrasound used for (A) and (C). 20 kHz ultrasound used for (B) and (D). Temperature of metal was 500°C. Initial temperature of molten glass was 1100°C. Magnification for (A) and (B) is 100X. Magnification for (C) and (D) is 500X.

Conclusions

In practically all the material research processes studied, the introduction of ultrasound into the process produced some significant change and usually a favorable effect.

Acknowledgments

The author wishes to acknowledge the many students whose work contributed to this paper. The author also wishes to thank Branson Sonic Power Company of Danbury, Connecticut, for supplying the instrumentation, and the Coal Research Bureau of West Virginia University and the National Science Foundation for their financial aid.

References

1. Mankins, W. L. 1963. "Effects of Ultrasonics on Nickel During Solidification," *Thesis,* West Virginia University.
2. Lee, W. K. 1966. "Ultrasonic Treatment of Alloys to Produce Dispersion Strengthening," *Thesis,* West Virginia University.
3. Fairbanks, H. V. and Dakan, J. F. 1974. "The Effects of Adding Ultrasound During the Production of Nodular Cast Iron," *IEEE Proc. Ultrasonic Symposium,* pp. 664-666.
4. Fairbanks, H. V. and Dewez, F. J. 1957. "Effects of Acoustical Waves on the Annealing of Steel," *J. Acoust. Soc. Am.,* Vol. 29, pp. 588-592.
5. Liu, C.Y. 1963. "Effects of Insonation During the Annealing of Cold Worked Metals," *Thesis,* West Virginia University.
6. Culley, G. E. 1963. "The Effect of Ultrasonic Energy Upon Uranium During a Phase Transformation," Thesis, West Virginia University.
7. Fairbanks, H. V. 1962. "Effect of Insonation During the Precipitation Hardening of Alloys," *Sound,* Vol. 1, pp. 35-39.
8. Caplinger, W. H. 1962. "Effects of Ultrasonic Insonation During the Tempering of Steels," *Thesis,* West Virginia University.
9. Fairbanks, H. V. 1983. Influence of Ultrasound on Heat Conduction in Metals," *16th International Thermal Conductivity Conf.,* Chicago, IL, 1979, publ. Plenum Press, pp. 409-416.
10. Fairbanks, H. V. 1978. "Ultrasonic Assistance in Drilling Metals," *Proc. Ultrasonic Int'l.,* pp. 107-109.
11. Fairbanks, H. V. 1974. "Applying Ultrasonics to the Molding of Plastic Powders," *Ultrasonics,* pp. 22-24.
12. Fairbanks, H. V. 1974. "Behavior of Fine Particles in Sonic-Assisted Filgration," *Proc. Int'l Conf. on Fine Particles,* Electrochem. Soc., pp. 336-343.
13. Fairbanks, H. V. 1976. "Ultrasonic Assisted Drying: Advantages and Limitations," *Proc. West Pharmacol. Soc.,* pp. 483-487.
14. Fairbanks, H. V. 1967. "Influence of Ultrasonics Upon the Surface of Glass," *Sym. Surface of Glass and Modern Treatments,* Luxemburg, pp. 1-14.

Mining and Geology Section

Characteristic Small Spores of the Coalburg Coal (Upper Pottsville, Pennsylvanian) in West Virginia

Cortland F. Eble
West Virginia Geological and Economic Survey
Morgantown, West Virginia 26505

and

William H. Gillespie
West Virginia University and
United States Geological Survey
Charleston, West Virginia 25314

Abstract

A palynological analysis of the Coalburg coal from eleven localities in Kanawha, Fayette, Boone, Mingo, and Wayne Counties, West Virginia has shown the small spore flora to contain 125 species in 42 genera. *Lycospora* and *Laevigatosporites* are the two most common genera, although various species of *Punctatisporites, Densosporites, Radiizonates, Granulatisporites*, and *Florinites* also occur frequently. Twenty-two additional forms were not specifically identified, either because they were imperfectly preserved or so few were observed that identification at the specific level was thought to be unwise. It is probable that all twenty-two represent morphological or preservational variations of those specifically identified.

Dictyotriletes bireticulatus is restricted to the lower part of the bed at location two where the sample was taken in vertical increments instead of a full-channel sample, as was done at the other locations. This, plus the apparent beginning of the range of *Torispora securis* in the younger Stockton coal and the ending of the range of *Ahrensisporites guerickei*, var. *ornatus* in the older Winifrede coal may indicate that these spores will be stratigraphically useful in separating the generally closely associated beds.

The overall small spore assemblage indicates a probable upper Westphalian C age based on European stratigraphic nomenclature, and an upper Atokan-lower Desmoinesian age according to Illinois Basin zonations.

Introduction

This description of the small spore flora of the Coalburg coal in West Virginia is a continuation of the work initiated by Cross [2] and expanded by Schemel [10] and Clendening [1], among others. Such palynological studies have proven to be of great value in the stratigraphic correlation of coal beds [6,7,8,11].

This particular stratigraphic interval was selected for study because, historically, the Coalburg coal has been hard to identify specifically in areas where the older Winifrede coal and the associated Winifrede marine zone or the younger Stockton coal and the associated Kanawha Black Flint are absent. Another reason for choosing this interval is that a prior report [4] has indicated that these units are part of, or in close proximity to, a conspicuous megaflora change.

Materials and Methods

The Coalburg coal is the middle-member of the "Kanawha Splints," a trade name for the, in ascending order, Winifrede, Coalburg, and Stockton coals, all of which occur near the top of the Kanawha Formation (Figure 1). The trade name emphasizes their hard, blocky appearance, even though all three beds often contain alternating layers of "splint" and "bright" coal.

Eleven samples were collected from seven locations (Figure 2). Six of these samples were collected as full-channel samples representing the total vertical extent of the coal. The seventh (location 2) was collected in five "bench" increments, each bounded by shaley layers, to check on spore asemblage variation, if any, in different portions of the bed. Sample location two is the Harewood section of the Proposed Pennsylvanian System Stratotype [3]. It was chosen as a substitute type location because the original type location at Coalburg, West Virginia, is no longer available for surface collection.

The samples were cleaned, ground to -20 mesh size, thoroughly mixed and riffled. Four grams of the coal were then oxidized in Schultzes solution [5,10], digested in 5% potassium hydroxide, washed several times and screened through a 210μ mesh sieve. The resulting "fine" residues ($< 210\mu$) were concentrated in an acidified, saturated solution of zinc chloride and mounted on cover glasses in polyvinyl alcohol. After the solution dried, the cover glasses were attached to standard microscope slides with Permount.

A total of 400 spores were counted from each maceration, 200 from each of two slides [12]. The uncounted portion of each slide was additionally scanned in order to record any species not encountered in the statistical count.

Photographs were taken through a Nikon Labophot microscope with a Nikon M-35-S camera using Kodak plus-X panchromatic film. The maceration residues, slides, film negatives, and extra coal are stored at the West Virginia Geological and Economic Survey, Morgantown, West Virginia.

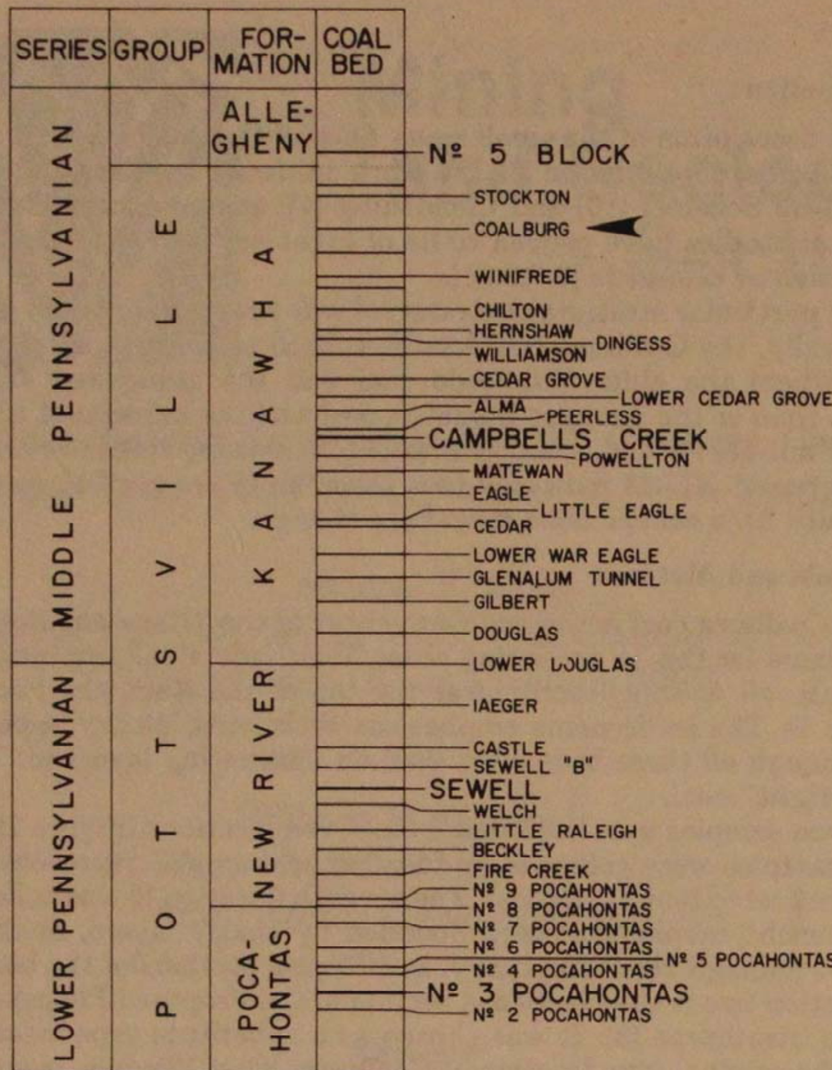


FIGURE 1. Generalized Stratigraphic Column Showing the Position of the Coalburg Coal near the top of the Kanawha Formation.

Results

One hundred twenty-five species of small spores in 42 genera were identified during the study. Figures 3 and 4 show the distribution of the more common small spore genera. Twenty-two other forms were found, but it was not possible to make specific identifications because of poor preservation and/or single spore occurrences. It is highly probable that these forms are preservational variations of the 125 named species.

The following list includes all spores identified during this study along with pertinent comments (note: all photographs are magnified approximately 350x unless otherwise indicated):

Genus *Leiotriletes* (Naumova) Potonie and Kremp 1954

L. adnatus (Kosanke) Potonie and Kremp 1955 (Plate 1, Figure 1; $30x31\mu$)

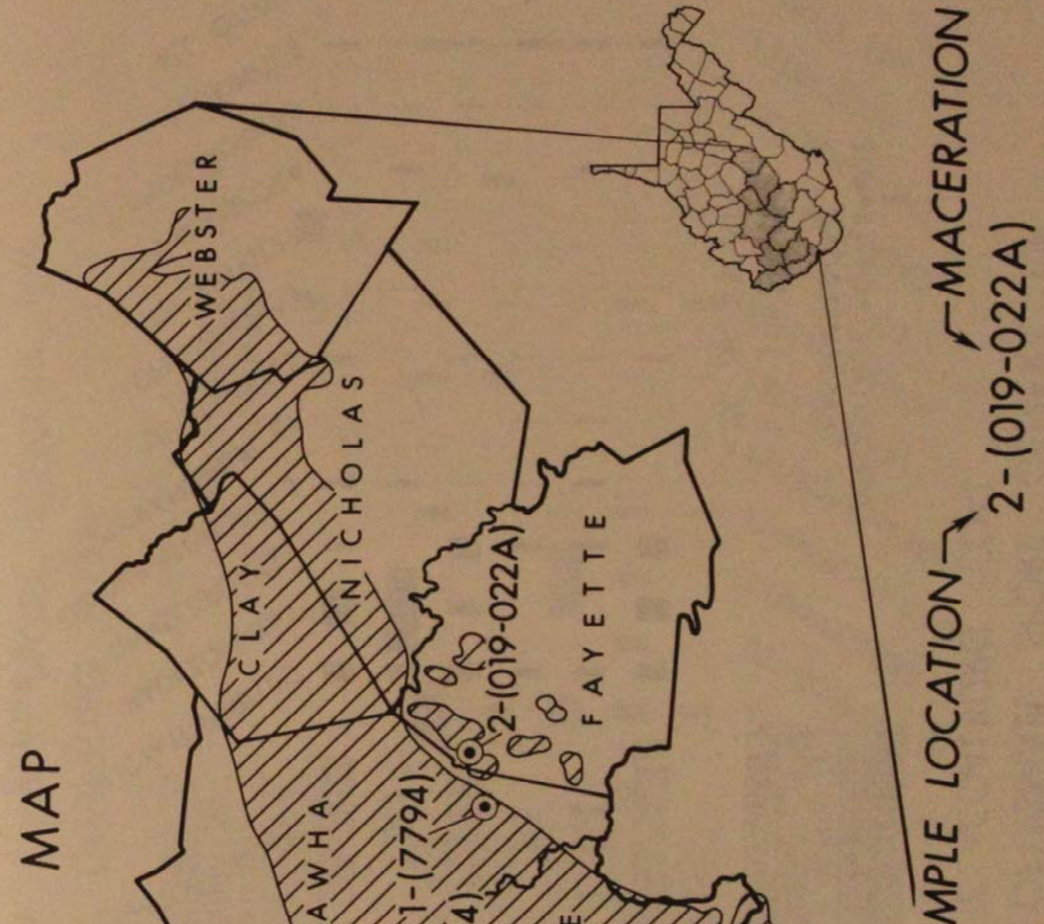


FIGURE 2. Sample Location Map

DISTRIBUTION OF SMALL SPORE GENERA OF THE COALBURG COAL

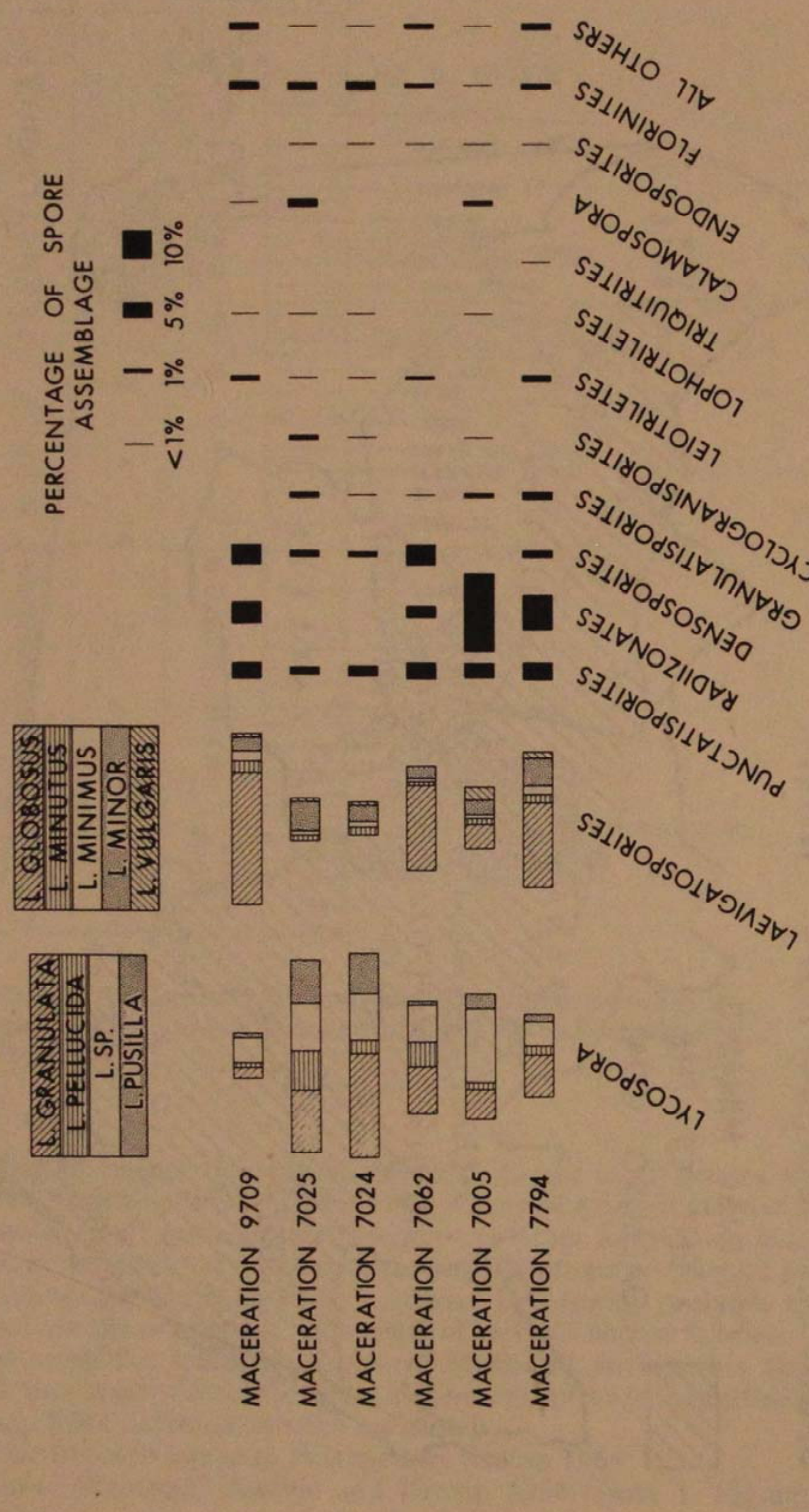


FIGURE 3

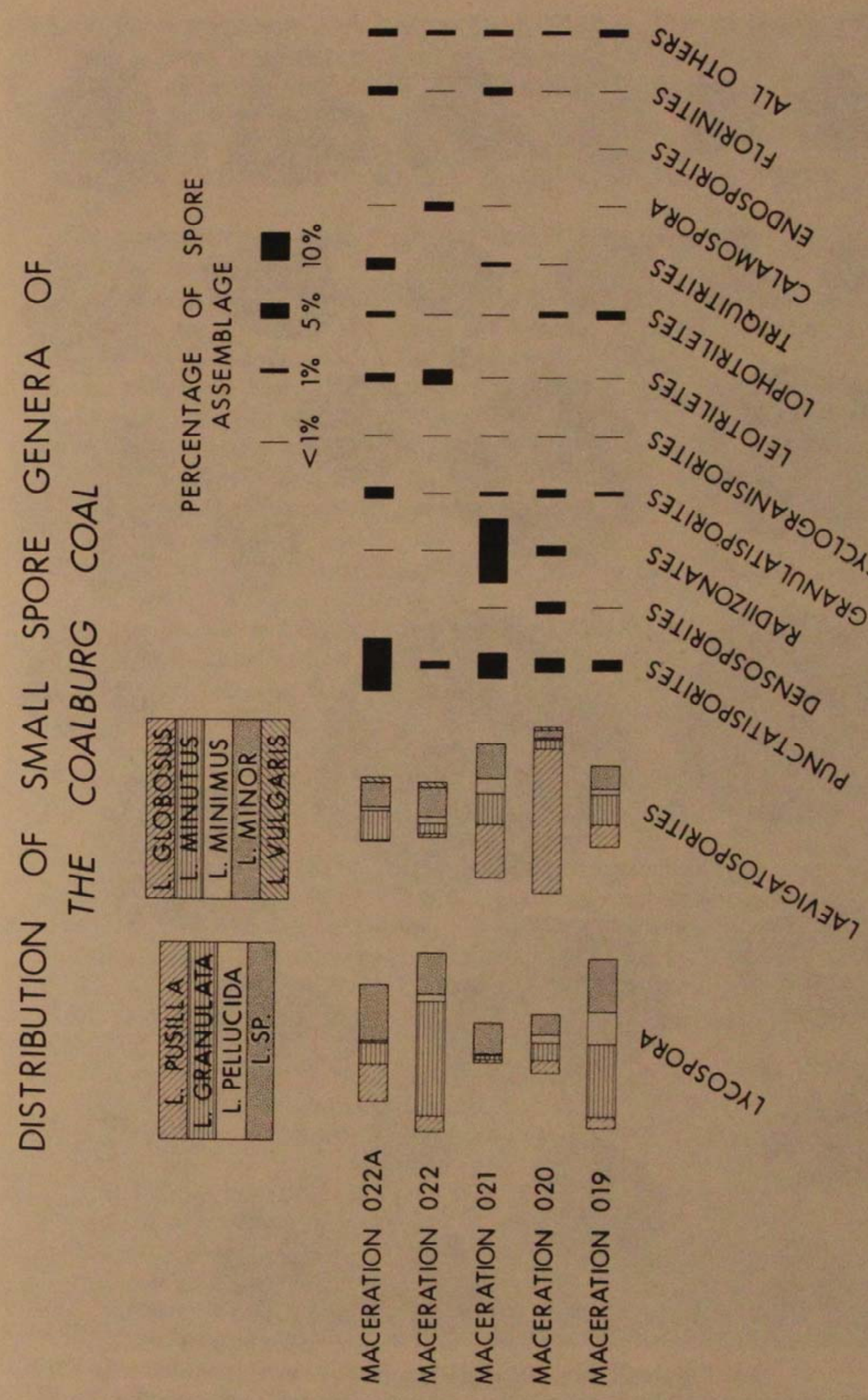

DISTRIBUTION OF SMALL SPORE GENERA OF
THE COALBURG COAL
L. PUSILLA
L. GRANULATA
L. PELLUCIDA
L. SP.
L. GLOBOSUS
L. MINUTUS
L. MINIMUS
L. MINOR
L. VULGARIS
PERCENTAGE OF SPORE
ASSEMBLAGE
<1%
1%
5%
10%
MACERATION 022A
MACERATION 022
MACERATION 021
MACERATION 020
MACERATION 019
LYCOSPORA
LAEVIGATOSPORITES
PUNCTATISPORITES
DENSOSPORITES
RADIIZONATES
GRANULATISPORITES
CYCLOGRANISPORITES
LEIOTRILETES
LOPHOTRILETES
TRIQUITRITES
CALAMOSPORA
ENDOSPORITES
FLORINITES
ALL OTHERS

FIGURE 4


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
24
21
23
25
27
29
22
28
30
31
26

PLATE 1

L. gulaferus Potonie and Kremp 1954 (Plate 1, Fig. 2; 28x26μ). This is the most frequently occurring species of this genus.

L. levis (Kosanke) Potonie and Kremp 1955 (Plate 1, Fig. 5; 46.8x42μ, Fig. 6; 46.4x47.2μ)

L. cf. *parvus* Guennel 1958 (Plate 1, Fig. 7; 24x18.4μ)

L. cf. *priddyi* (Berry) Potonie and Kremp 1955 (Plate 1, Fig. 3; 33.6x 34μ)

L. cf. *sphaerotriangulus* (Loose) Potonie and Kremp 1954 (Plate 1, Fig. 4; 36x40μ)

L. sp. (Plate 1, Fig. 8; 26.4x24μ). This species is very similar to *L.* cf. *parvus* except that the sides are rather strongly concave. It resembles *Leiotriletes sp. A* of Clendening 1974.

L. sp. (Plate 4, Fig. 22; 37x39μ). This species may be a poorly preserved example of *L.* cf. *sphaerotriangulus.*

Genus *Punctatisporites* (Ibrahim) Potonie and Kremp 1954

P. minutus Kosanke 1950 (Plate 1, Fig. 9; 25.6x24μ). This species is consistently represented. Forms as small as 16μ have been included in this taxon.

P. cf. *nitidus* Hoffmeister, Staplin, and Malloy 1955 (Plate 1, Fig. 12; 48.8x40.8μ)

P. cf. *obesus* (Loose) Potonie and Kremp 1955 (Plate 1, Fig. 14; 106.5x) 103.4μ) (magnification 210x)

P. cf. *pseudolevatus* Hoffmeister, Staplin, and Malloy 1955 (Plate 1, Fig. 11; 42x36.6μ). This species occurs persistently, but is rarely of statistical importance.

P. punctatus Ibrahim 1933 (Plate 1, Fig. 13; 72x60μ)

P. sp. (Plate 1, Fig. 10; 31.5x28μ). Only a few specimens were observed.

P. sp. (Plate 1, Fig. 15; 37.6x36μ). Only one specimen was observed.

P. sp. (Plate 1, Fig. 17; 58.4x56.8μ). Only one specimen was seen.

Genus *Calamospora* Schopf, Wilson, and Bentall 1944

C. breviradiata Kosanke 1950 (Plate 1, Fig. 22; 46.2x42μ)

C. flexilis Kosanke 1950 (Plate 1, Fig. 24; 63.2x54.4μ)

C. cf. *microrugosa* (Ibrahim) Schopf, Wilson, and Bentall 1944 (Plate 1, Fig. 18; 76x72.4μ)

C. mutabilis (Loose) Schopf, Wilson, and Bentall 1944 (Plate 1, Fig. 23; 128x64.8μ) (magnification 210x)

C. pallida (Loose) Schopf, Wilson, and Bentall 1944 (Plate 1, Fig. 21; 50x44.2μ)

C. parva Guennel 1958 (Plate 1, Fig. 26; 31.2x34.4μ)

C. pedata Kosanke 1950 (Plate 1, Fig. 25; 64x36μ)

C. cf. *perrugosa* (Loose) Schopf, Wilson, and Bentall 1944 (Plate 1, Fig. 19; 111.2x95.2μ)

C. straminea Wilson and Kosanke 1944 (Plate 1, Fig. 16; 35.2x28μ, Fig. 20; 49.6x41.6μ)

Genus *Granulatisporites* (Ibrahim) Potonie and Kremp 1954

G. cf. *adnatoides* (Potonie and Kremp) Smith and Butterworth 1967 (Plate 2, Fig. 1; 44.6x44μ)

G. granulatus Ibrahim 1933 (Plate 1; Fig. 31; 36x34.6μ). This form occurs frequently, but is not of statistical importance.

G. micrograniifer Ibrahim 1933 (Plate 1, Fig. 29; 30x28μ)

G. pallidus Kosanke 1950 (Plate 2, Fig. 2; 40x35.2μ)

G. cf. *parvus* (Ibrahim) Potonie and Kremp 1955 (Plate 1, Fig. 27; 40x32μ, Fig. 28; 53.4x44μ). This is the most frequently occurring species of this genus.

G. piroformis Loose 1934 (Plate 1, Fig. 30; 27.2x23.2μ). This species occurs frequently.

Genus *Cyclogranisporites* Potonie and Kremp 1954

C. aureus (Loose) Potonie and Kremp 1955 (Plate 2, Fig. 6; 73.6x66.4μ). This species occurs frequently.

C. cf. *micaceous* Imgrund 1960 (Plate 2, Fig. 3; 56.5x54μ)

C. cf. *microgranus* Bharadwaj 1957 (Plate 2, Fig. 5; 79.6x66μ). This species occurs frequently.

C. cf. *minutus* Bharadwaj 1957 (Plate 5, Fig. 30; 50.4x38.4μ)

C. cf. *orbicularis* (Kosanke) Potonie and Kremp 1955 (Plate 2, Fig. 7; 40x36μ)

C. pergranulus Alpern 1959 (Plate 2, Fig. 8; 56x46μ)

C. provectus (Kosanke) Potonie and Kremp 1955 (Plate 2, Fig. 4; 68x64μ)

C. cf. *staplini* (Peppers) Peppers 1970 (Plate 2, Fig. 9; 60.8x53.6μ)

C. sp. (Plate 6, Fig. 17; 46.4x37.6μ). Occurs rarely.

Genus *Verrucosisporites* (Ibrahim) Smith and Butterworth 1967

V. cf. *compactus* Habib 1966 (Plate 2, Fig. 16; 42.4x36.8μ)

V. donarii Potonie and Kremp 1955 (Plate 2, Fig. 10; 68.8x64.8μ)

V. cf. *firmus* (Loose) Potonie and Kremp 1955 (Plate 2, Fig. 11; 60x 48.8μ)

V. cf. *microtuberosus* (Loose) Smith and Butterworth 1967 (Plate 2, Fig. 18; 70.6x62μ).

V. cf. *microverrucosus* Ibrahim 1933 (Plate 2, Fig. 15; 69x50.4μ)

V. sifati (Ibrahim) Smith and Butterworth 1967 (Plate 2, Fig. 12; 80x80μ)

V. verrucosus (Ibrahim) Ibrahim 1933 (Plate 2, Fig. 13; 72x47.6μ)

V. cf. *verus* (Potonie and Kremp) Smith et al 1964 (Plate 2, Fig. 14; 96x 76.6μ)

Genus *Schopfites* Kosanke 1950

S. dimorphus Kosanke 1950 (Plate 2, Fig. 19; 88x78.4μ). Only one specimen was observed.

Genus *Lophotriletes* (Naumova) Potonie and Kremp 1954

L. commissuralis (Kosanke) Potonie and Kremp 1955 (Plate 3, Fig. 1; 26.4x17.6μ). Occurs frequently.

L. cf. *copiosus* Peppers 1970 (Plate 3, Fig. 3; 46x44.4μ)

L. cf. *gibbosus* (Ibrahim) Potonie and Kremp 1954 (Plate 3, Fig. 4; 40x38.8μ)

L. cf. *granoornatus* Artuz 1957 (Plate 3, Fig. 5; 40.8x40μ)

L. microsaetosus (Loose) Potonie and Kremp 1955 (Plate 3, Fig. 7; 34x 34.6μ). This is the most frequently occurring species of this genus.

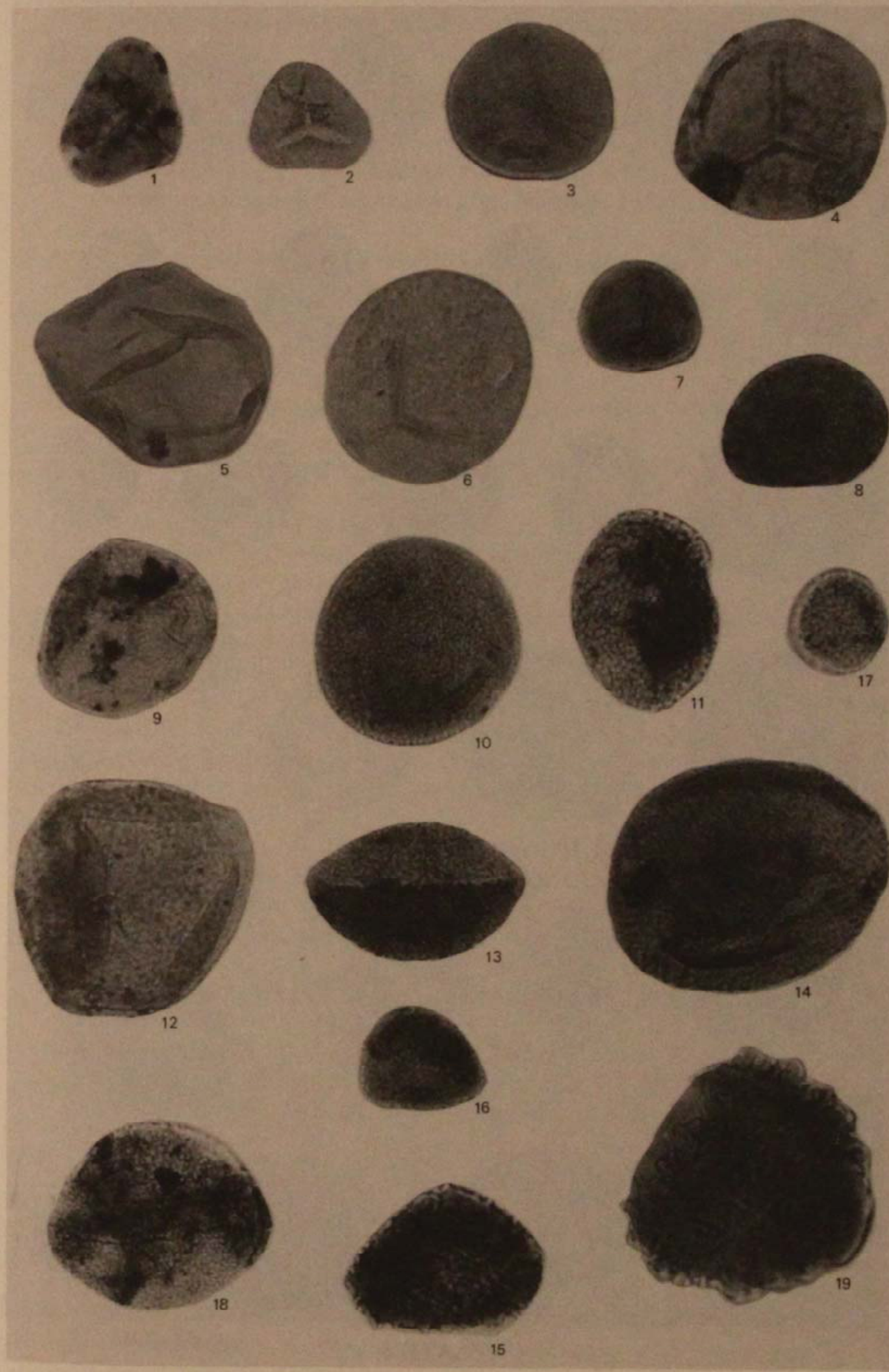


PLATE 2

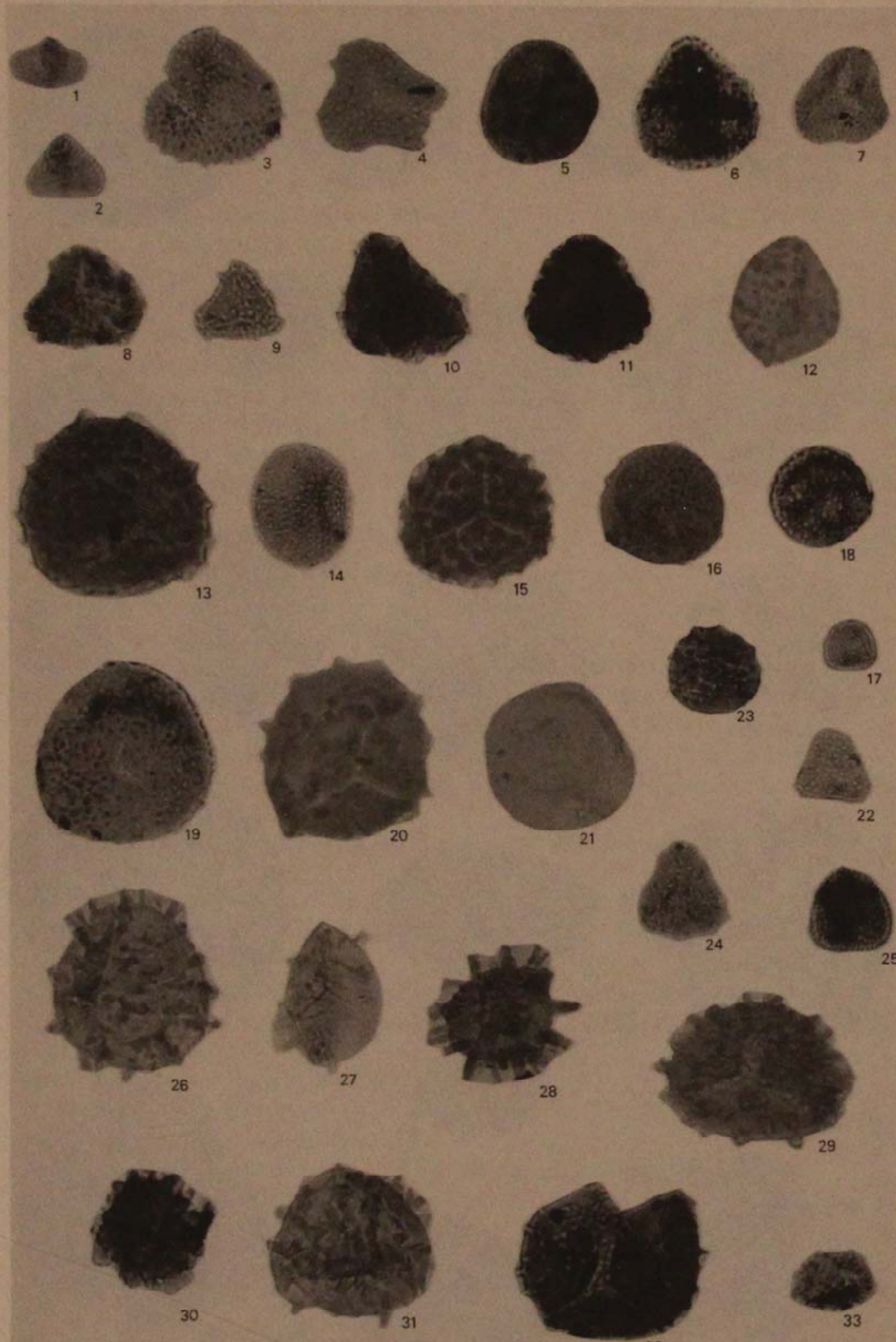

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
18
23
17
19
20
21
22
24
25
26
27
28
29
30
31
32
33

PLATE 3

L. mosaicus Potonie and Kremp 1955 (Plate 3, Fig. 8; 40.8x32μ)
L. cf. *rarispinosus* Peppers 1970 (Plate 3, Fig. 9; 28.8x25.6μ)
L. sp. (Plate 3, Fig. 10; 42x41.6μ). Only one specimen was seen.
L. sp. (Plate 3, Fig. 11; 42x42.2μ). Only one specimen was seen.
L. sp. (Plate 3, Fig. 6; 44x42μ, Fig. 25; 28x27.2μ). This species occurs rarely.

Genus *Anapiculatisporites* Potonie and Kremp 1954
A. spinosus (Kosanke) Potonie and Kremp 1955 (Plate 3, Fig. 2; 26x21.8μ)

Genus *Pustulatisporites* Potonie and Kremp 1954
P. cf. *crenatus* Guennel 1958 (Plate 3, Fig. 12; 40.8x37.6μ)

Genus *Apiculatisporis* Potonie and Kremp 1956
A. abditus (Loose) Potonie and Kremp 1955 (Plate 3, Fig. 13; 65.6x 60.8μ, Fig. 20; 60.5x56μ)
A. cf. *aculeatus* (Ibrahim) Smith and Butterworth 1967 (Plate 3, Fig. 14; 41.6x34.4μ)
A. cf. *imbricatus* (Kosanke) Potonie and Kremp 1955 (Plate 3, Fig. 15; 57.2x52μ)
A. lappites Peppers 1970 (Plate 3, Fig. 17; 16.8x16μ)
A. cf. *latigranifer* (Loose) Potonie and Kremp 1955 (Plate 3, Fig. 16; 42x42μ)
A. cf. *setulosus* (Kosanke) Potonie and Kremp 1955 (Plate 3, Fig. 19; 61.6x60μ)
A. sp. (Plate 3, Fig. 18; 35x34μ). Only one specimen was observed.
A. sp. (Plate 3, Fig. 23; 31.2x30μ). This species may be a morphological variation of *A.* cf. *imbricatus*. It is smaller, but otherwise similar.

Genus *Apiculatisporites* (Ibrahim) Smith and Butterworth 1967
A. cf. *spinulistratus* (Loose) Ibrahim 1933 (Plate 3, Fig. 21; 50.4x 50.4μ)

Genus *Acanthotriletes* (Naumova) Potonie and Kremp 1954
A. aculeolatus (Kosanke) Potonie and Kremp 1955 (Plate 3, Fig. 22; 27x25μ)
A. cf. *echinatus* (Knox) Potonie and Kremp 1955 (Plate 3, Fig. 33; 26x 19.2μ)
A. microspinosus (Ibrahim) Potonie and Kremp 1955 (Plate 3, Fig. 24; 31.2x26.4μ)

Genus *Raistrickia* Schopf, Wilson, and Bentall 1944
R. cf. *crinita* Kosanke 1950 (Plate 3, Fig. 32; 61.2x53.6μ)
R. cf. *fibrata* (Loose) Schopf, Wilson, and Bentall 1944 (Plate 3, Fig. 31; 60x58.2μ)
R. cf. *irregularis* Kosanke 1950 (Plate 3, Fig. 29; 60x47.2μ, Fig. 30; 40.8x 36.8μ)
R. cf. *lacerata* Peppers 1970 (Plate 3, Fig. 28; 40x35.2μ)
R. saetosa (Loose) Schopf, Wilson, and Bentall 1944 (Plate 3, Fig. 26; 60x68.4μ)
R. superba (Ibrahim) Schopf, Wilson, and Bentall 1944 (Plate 3, Fig. 27; 49.6x48.8μ)

Genus *Convolutispora* Hoffmeister, Staplin, and Malloy 1955

C. cf. *florida* Hoffmeister, Staplin, and Malloy 1955 (Plate 4, Fig. 1; 40x 36μ)

C. cf. *tessellata* Hoffmeister, Staplin, and Malloy 1955 (Plate 4, Fig. 2; 56x55μ)

C. sp. (Plate 4, Fig. 3; 44.8x37.6μ). Only one specimen was seen.

C. sp. (Plate 4, Fig. 4; 44x42μ). Only one specimen was observed.

C. sp. (Plate 4, Fig. 5; 66x61.6μ). Only one specimen was seen.

Genus *Spackmanites* Habib 1966

S. ellipticus (Loose) Habib 1966 (Plate 4, Fig. 10; 65.5x68μ)

Genus *Microreticulatisporites* (Knox) Potonie and Kremp 1954

M. nobilis (Wicher) Knox 1950 (Plate 4, Fig. 8; 32x31.2μ)

M. sulcatus (Wilson and Kosanke) Smith and Butterworth 1967 (Plate 4, Fig. 7; 42.4x40.8μ)

Genus *Dictyotriletes* (Naumova) Smith and Butterworth 1967

D. bireticulatus (Ibrahim) Smith and Butterworth 1967 (Plate 4, Fig. 17; 44x41.5μ). This species was observed to occur only in the bottom half of the coal at sample location 2. It occurs rarely.

D. cf. *distortus* Peppers 1970 (Plate 4, Fig. 6; 31.8x30.2μ)

D. falsus Potonie and Kremp 1955 (Plate 4, Fig. 18; 37.6x37.6μ)

D. cf. *muricatus* (Kosanke) Smith and Butterworth 1967 (Plate 4, Fig. 14; 74x62μ)

D. cf. *reticulocingulum* (Loose) Smith and Butterworth 1967 (Plate 4, Fig. 13; 46x43.4μ)

Genus *Camptotriletes* (Naumova) Potonie and Kremp 1954

C. cf. *bucculentus* (Loose) Potonie and Kremp 1955 (Plate 4, Fig. 11; 65.6x60μ)

C. cf. *corrugatus* (Ibrahim) Potonie and Kremp 1955 (Plate 4, Fig. 12; 54.4x50.4μ)

Genus *Triquitrites* (Wilson and Coe) Schopf, Wilson, and Bentall 1944

T. cf. *crassus* Kosanke 1950 (Plate 4, Fig. 16; 56x44μ)

T. sculptilis (Balme) Smith and Butterworth 1967 (Plate 4, Fig. 9; 27.8x 27.2μ). This is the most frequently occurring species of this genus.

T. cf. *protensus* Kosanke 1950 (Plate 4, Fig. 15; 41.6x40μ)

Genus *Reinschospora* Schopf, Wilson, and Bentall 1944

R. magnifica Kosanke 1950 (Plate 4, Fig. 19; 67.2x60μ)

Genus *Knoxisporites* (Potonie and Kremp) Neves and Playford 1961

K. cf. *triradiatus* Hoffmeister, Staplin, and Malloy 1955 (Plate 4, Fig. 20; 56x54μ, Fig. 23; 87.2x84μ)

Genus *Reticulatisporites* (Ibrahim) Neves 1964

R. cf. *lacunosus* Kosanke 1950 (Plate 6, Fig. 16; 83.6x72.4μ)

Genus *Savitrisporites* Bharadwaj 1955

S. nux (Butterworth and Williams) Smith and Butterworth 1967 (Plate 4, Fig. 21; 36x31.2μ)

Genus *Grumosisporites* Smith and Butterworth 1967

G. sp. (Plate 2, Fig. 17; 35.2x32.8μ). A recognizable intexine, the presence of which is characteristic of this genus, is evident in this single specimen.

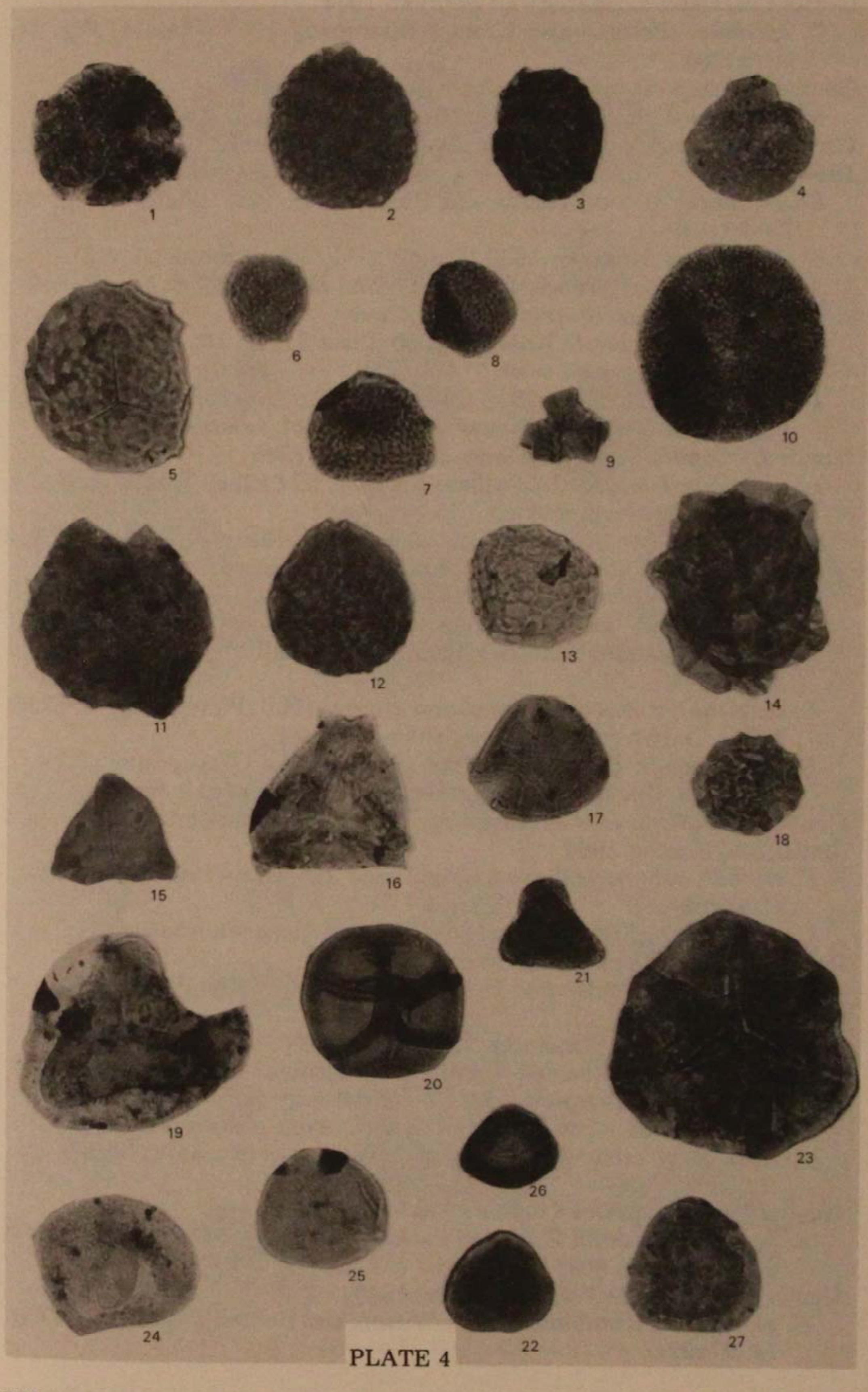


PLATE 4

Genus *Crassispora* (Bharadwaj) Sullivan 1964

C. kosankei (Potonie and Kremp) Bharadwaj 1957 (Plate 4, Fig. 24; 59.2x52μ)

Genus *Cappasporites* (Urban) Chadwick 1983

C. distortus (Urban) Chadwick 1983 (Plate 4, Fig. 25; 45.6x42.4μ)

Genus *Densosporites* (Berry) Butterworth, Jansonius, Smith, and Staplin 1964

D. annulatus (Loose) Smith and Butterworth 1967 (Plate 4, Fig. 26; 34x29.6μ)

D. cf. *lobatus* Kosanke 1950 (Plate 4, Fig. 27; 47.2x46.4μ). Although sporadic in occurrence, this species and *D. triangularis* are the most common representatives of this genus.

D. sphaerotriangularis Kosanke 1950 (Plate 5, Fig. 13; 48x46μ). Only a few specimens were seen.

D. triangularis Kosanke 1950 (Plate 5, Fig. 1; 39.6x34μ, Fig. 3; 48x46μ, Fig. 11; 43x42μ). See discussion under *D.* cf. *lobatus.*

Genus *Lycospora* Schopf, Wilson, and Bentall 1944

L. granulata Kosanke 1950 (Plate 5, Fig. 9; 29.6x22μ). This is generally the most common species of *Lycospora.*

L. micropapillata (Wilson and Coe) Schopf, Wilson and Bentall 1944 (Plate 5, Fig. 12; 24.8x24μ). This species occurs frequently.

L. pellucida (Wicher) Schopf, Wilson, and Bentall 1944 (Plate 5, Fig. 7; 32x30μ). This species is consistently represented.

L. pusilla (Ibrahim) Schopf, Wilson, and Bentall 1944 (Plate 5, Fig. 8; 25.4x22μ)

L. cf. *torquifer* (Loose) Potonie and Kremp 1956 (Plate 5, Fig. 6; 28.8x 27.2μ). Only a few specimens were observed.

L. sp. (Plate 5, Fig. 10; 22x20μ). This species is very similar to *L. granulata,* but is smaller (generally 17-26μ). It occurs frequently.

Genus *Cristatisporites* (Potonie and Kremp) Butterworth, Jansonius, Smith, and Staplin 1964

C. cf. *indignabundus* (Loose) Staplin and Jansonius 1964 (Plate 5, Fig. 4; 38.8x34.4μ)

C. sp. (Plate 5, Fig. 2; 49.6x44μ). Only one specimen was seen.

Genus *Cirratriradites* Wilson and Coe 1940

C. annulatus Kosanke and Brokaw (in Kosanke 1950) (Plate 5, Fig. 28; 81.6x76μ)

Genus *Radiizonates* Staplin and Jansonius 1964

R. cf. *difformis* (Kosanke) Staplin and Jansonius 1964 (Plate 5, Fig. 5; 44.8x36μ). This species occurs consistently, and sometimes abundantly. Some forms assigned to this taxon possess characteristics which may better align them with *R. rotatus* (Kosanke) Staplin and Jansonius 1964.

Genus *Spencerisporites* Chaloner 1951

S. radiatus (Ibrahim) Felix and Parks 1959 (Plate 5, Fig. 23; 311x276μ) (magnification 80x)

Genus *Endosporites* Wilson and Coe 1940

E. globiformis (Ibrahim) Schopf, Wilson, and Bentall 1944 (Plate 5, Fig. 14; 97x92μ)

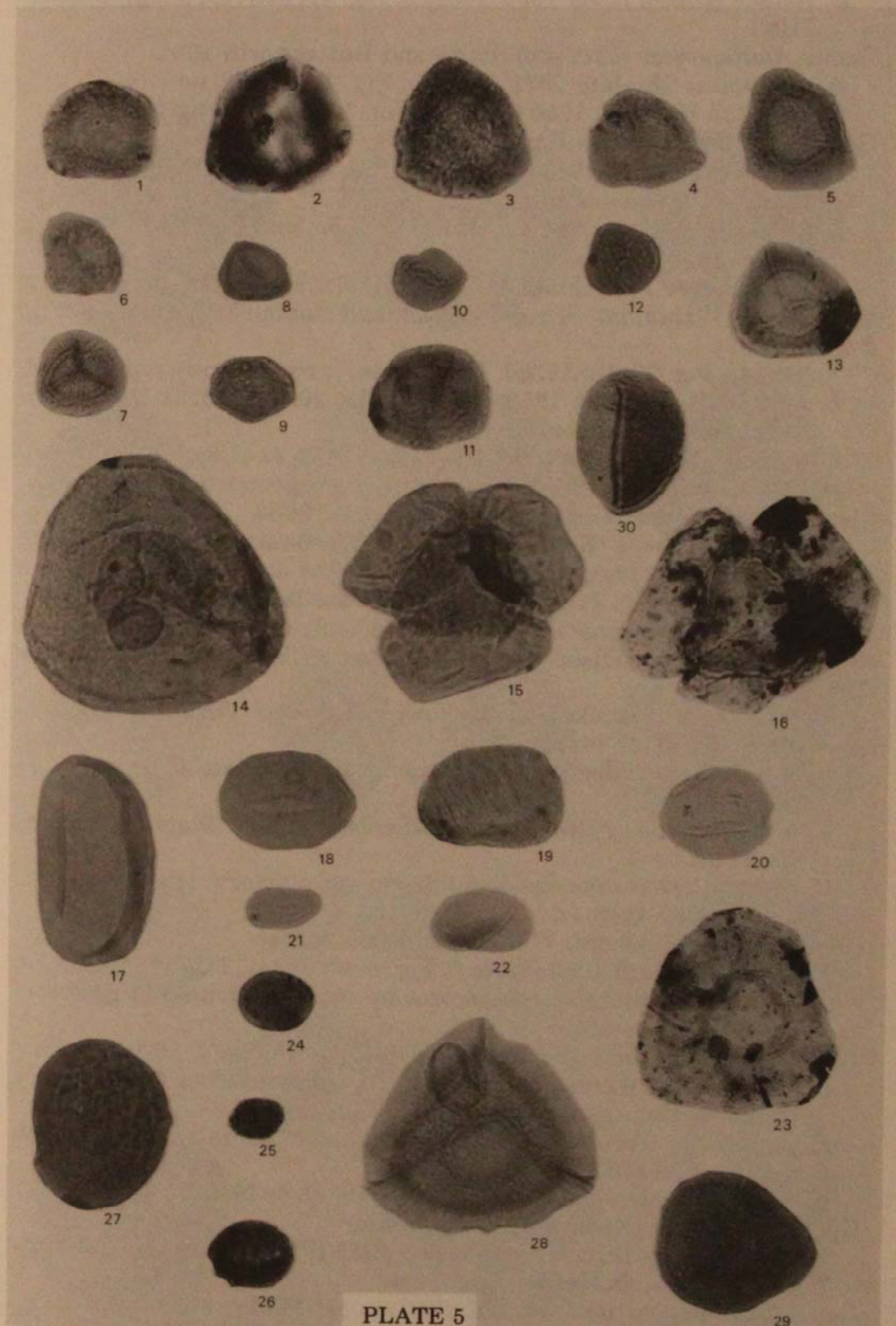

1
2
3
4
5
6
8
10
12
13
7
9
11
30
14
15
16
17
18
19
20
21
22
24
23
25
27
28
26
29

PLATE 5

E. zonalis (Loose) Knox 1950 (Plate 5, Fig. 29; 92x75μ) (magnification 210x)

Genus *Alatisporites* (Ibrahim) Smith and Butterworth 1967

A. pustulatus Ibrahim 1932 (Plate 5, Fig. 15; 78x76.4μ)

A. trialatus Kosanke 1950 (Plate 5, Fig. 16; 90x78.8μ)

Genus *Laevigatosporites* Ibrahim 1933

L. globosus Schemel 1951 (Plate 5, Fig. 24; 26x20.4μ). This is the most abundant species of this genus.

L. minimus (Wilson and Coe) Schopf, Wilson, and Bentall 1944 (Plate 5, Fig. 22; 34x22.4μ)

L. minor Loose 1934 (Plate 5, Fig. 18; 48.6x35μ). Occurs persistently.

L. minutus (Ibrahim) Schopf, Wilson, and Bentall 1944 (Plate 5, Fig. 21; 24x14μ, Fig. 25; 18x17.2μ). This species is consistently represented.

L. punctatus Kosanke 1950 (Plate 5, Fig. 20; 38.4x32μ). Only a few specimens were observed.

L. vulgaris Ibrahim 1933 (Plate 5, Fig. 17; 75.4x41.6μ).

L. sp. (Plate 5, Fig. 19; 51.6x36μ). Only one specimen was seen.

Genus *Thymospora* Wilson and Venkatachala 1963

T. pseudothiessenii (Kosanke) Wilson and Venkatachala 1963 (Plate 5, Fig. 26; 28.6x24μ). Only one specimen was observed.

T. sp. (Plate 5, Fig. 27; 61x50μ). This species is larger than *T. pseudothiessenii,* but otherwise similar to it. Only one specimen was seen.

Genus *Vestispora* (Wilson and Hoffmeister) Wilson and Venkatachala 1963

V. fenestrata (Kosanke and Brokaw) Wilson and Venkatachala 1963 (Plate 6, Fig. 1; 84x82μ)

V. cf. *laevigata* Wilson and Venkatachala 1963 (Plate 6, Fig. 2; 86.4x 76μ)

V. cf. *profunda* Wilson and Hoffmeister 1956 (Plate 6, Fig. 6; 66x64.6μ)

V. cf. *pseudoreticulata* Spode (in Smith and Butterworth 1967) (Plate 6, Fig. 3; 70.4x66.4μ)

Genus *Florinites* Schopf, Wilson, and Bentall 1944

F. florini Imgrund 1960 (Plate 6, Fig. 8; 63.6x44μ, Fig. 11; 59.2x44μ). This species, and *F. mediapudens* are the most common representatives of this genus.

F. cf. *junior* Potonie and Kremp 1956 (Plate 6, Fig. 4; 100.6x94.4μ)

F. mediapudens (Loose) Potonie and Kremp 1956 (Plate 6, Fig. 9; 59x 56μ). See discussion under *F. florini.*

F. pumicosus (Ibrahim) Schopf, Wilson, and Bentall 1944 (Plate 6, Fig. 5; 100.4x73.6μ)

F. similis Kosanke 1950 (Plate 6, Fig. 10; 88.6x76μ)

Genus *Wilsonites* (Kosanke) Kosanke 1959

W. cf. *delicatus* (Kosanke) Kosanke 1959 (Plate 6, Fig. 7; 66x64.6μ). Only one specimen was seen.

Genus *Grandispora* Hoffmeister, Staplin, and Malloy 1955

G. cf. *spinosa* Hoffmeister, Staplin, and Malloy 1955 (Plate 6, Fig. 18; 63x47.2μ). Only one specimen was seen.

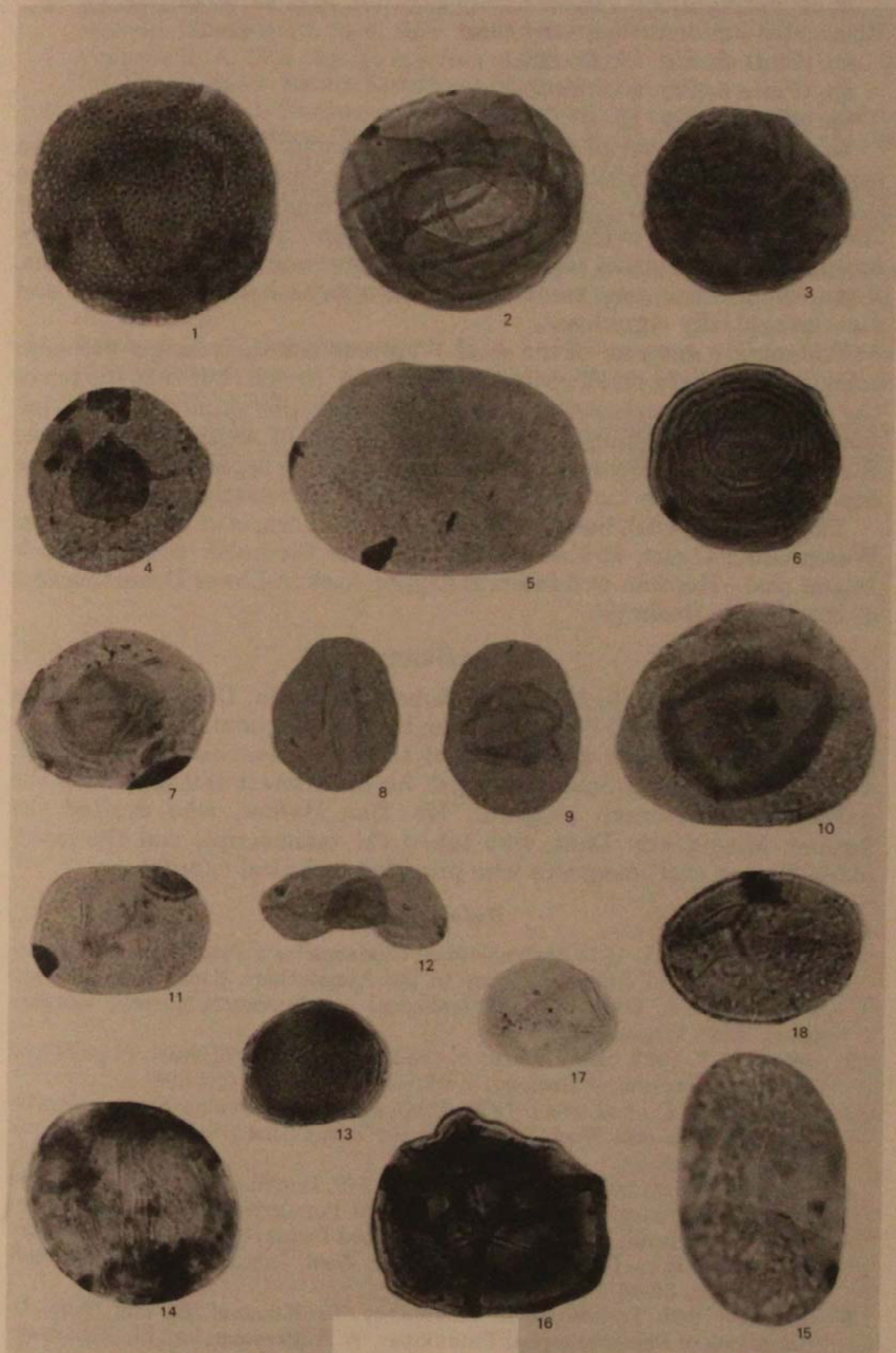


PLATE 6

Genus *Perotriletes* (Erdtman) ex Couper 1953
P. cf. *parvigracilis* Peppers 1970 (Plate 6, Fig. 13; 49x46μ)
Bisaccates (unidentified, very rare)
sp. (Plate 6, Fig. 12; 64x28μ)
sp. (Plate 6, Fig. 14; 76x68μ)
sp. (Plate 6, Fig. 15; 97.6x56.8μ)

In general, the overall assemblages have proven to be consistent from location to location, although the "bench" increments from location two indicate that there may be some variation through the vertical extent of the bed. The most evident difference is in the range of *Dictyotriletes bireticulatus* which was restricted to the lower one-half of the bed. This, if proven to be a consistent difference, will be both biologically and stratigraphically significant.

Preliminary analyses of the older Winifrede and the younger Stockton coals show that the small spore floras are very similar, but that the top of the range of *Ahrensisporites guerickei* var. *ornatus* occurs in the Winifrede and the beginning of the range of *Torispora securis* occurs in the Stockton. These differences may provide a basis for separating these three coal beds when they cannot be distinguished lithostratigraphically.

The Coalburg coal, based on its small spore flora, is of probable upper Westphalian C age. It also correlates rather favorably with the Rock Island coal—Herman coal interval (Upper Atokan-Lower Desmoinesian) of the Illinois Basin [9].

Acknowledgments

The authors wish to thank Dr. Robert B. Erwin, Director and State Geologist of the West Virginia Geological and Economic Survey, for his permission to publish the results of this investigation, Mr. Larry D. Woodfork, Assistant State Geologist, for his interest and support of the palynological research program, Mr. Dan Barker, who drafted the figures, Miss Cindy Dent, who typed the manuscript, and the many other Survey staff members who provided technical support.

References

1. Clendening, J. A. 1974. Palynological Evidence for a Pennsylvania Age Assignment of the Dunkard Group in the Appalachian Basin. Coal Geology Bulletin No. 3, West Virginia Geological and Economic Survey, Morgantown, West Virginia. 105 p.
2. Cross, A. T. 1952. Spore Floras of the Pennsylvanian of West Virginia and Kentucky. Journal of Geology, v. 55, no. 3, pt. 2, pp. 285-308.
3. Englund, K. J. et al (eds.). 1979. Proposed Pennsylvanian System Stratotype, Virginia and West Virginia. Amer. Geol. Inst., Selected Guidebook Series 1, pp. 29-35.
4. Gillespie, W. H., and Pfefferkorn, H.W. 1979. Distribution of commonly occurring plant megafossils in the proposed Pennsylvanian System Stratotype. *In:* Englund, K. J. et al (eds.). Proposed Pennsylvanian System Stratotype, Virginia and West Virginia. Amer. Geol. Inst., Selected Guidebook Series 1, pp. 86-96.
5. Gray, J. 1965. Techniques in Palynology. *In:* Kummel, B., and Raup, D. Handbook of Paleontological Techniques. W.H. Freeman and Co., San Francisco, pp. 471-699.

6. Kosanke, R. M. 1950. Pennsylvanian Spores of Illinois and Their Use in Correlation. Illinois State Geol. Surv. Bull. 74, 128 p.
7. Peppers, R. A. 1964. Spores in strata of Late Pennsylvanian Cyclothems in the Illinois Basin. Illinois State Geol. Surv. Bull. 90, 89 p.
8. ____________. 1970. Correlation and Palynology of coals in the Carbondale and Spoon Formations (Pennsylvanian) of the Northeastern Part of the Illinois Basin. Illinois State Geol. Surv. Bull. 93, 173 p.
9. Phillips, T. L. and Peppers, R. A. 1984. Changing Patterns of Pennsylvanian coal-swamp vegetation and implications of climatic control on coal occurrence. Int. Journ. of Coal Geol. v. 3, pp. 205-255.
10. Schemel, M. P. 1957. Small spore assemblages of mid-Pennsylvanian coals of West Virginia and adjacent areas. West Virginia Univ. unpubl. Ph.D. thesis, 222 p.
11. Smith, A. H. V., and Butterworth, M. A. 1967. Miospores in the coal seams of the Carboniferous of Great Britain. Special Papers in Paleontology, no. 1, The Paleontological Assoc., 324 p.
12. Tomlinson, R. C. 1957. Coal measures microspores analysis: a statistical investigation into sampling procedures and some other factors. Bull. Geol. Surv., Gt. Brit. v. 12, pp. 18-26.

Plant Fossils of the New River Gorge, West Virginia

William H. Gillespie
West Virginia University
and
U.S. Geological Survey
916 Churchill Circle
Charleston, West Virginia 25314

and

Herman W. Pfefferkorn
Department of Geology
University of Pennsylvania
Philadelphia, Pennsylvania 19104

Introduction

The New River Gorge, an often-described attraction in West Virginia (Gillespie, 1983) has long been recognized as an excellent locality for collecting fossil plants (Gillespie and Latimer, 1961). The gorge is of special interest to the professional paleobotanist and biostratigrapher because the fossil plants can be used to identify important geologic boundaries within the outcropping rocks. This information can then be used to correlate the rocks with those in other States and countries (Pfefferkorn and Gillespie, 1980b). The fossils are also useful to the botanist for tracing evolutionary trends in plants.

Previous Investigations

The first scientific description of the New River Gorge was published by Hildreth and Morton (1836, p. 87) who stated that "from the mouth of the Green [*sic*] River, to the mouth of Gauly [*sic*], a distance of about seventy miles, it has a descent of more than seven hundred feet. This portion of its course is called 'the cliffs of New River.' " Later paragraphs of this report correctly list the "Green" River as the "Greenbrier."

William B. Rogers, the first State Geologist for the Commonwealth of Virginia, mapped parts of the area during reconnaissance trips through West Virginia. These studies were published as State reports for the years 1836-1841 and later were compiled with other papers and published in book form by his wife (Rogers, 1884). In these reports, beds containing fossil plants were noted at several localities. Rogers (1859) also pointed out the similarities of the rocks in the New River Gorge to those in nearby States. In the 1870's, W. M. Fontaine (1874, 1876) collected numerous fossil plants near Quinnimont, Sewell Station, and Piney

Creek in the gorge area. I. C. White (1883, 1891) also studied these fossil plants, and later, David White (1895) published the first detailed lists of fossil plants from the gorge. On the basis of his collections, David White stated that the strata were equivalent to the Pottsville section [Group or Formation] of Pennsylvania and that "three-fourths of the forms are characteristic of the Sewanee [Conglomerate] of Tennessee, the coal-bearing shale of Washington County, Arkansas, probably the Sharon coal in Ohio and [rocks in] several places in Alabama." This paper is notable as one of the first to use fossil plants for regional correlation of rock strata in the United States and to discuss intercontinental similarities of the fossil plants. This was also the first significant paper in David White's famous controversy with I. C. White (1883, 1891) who had determined that certain strata in the Kanawha Valley and other parts of southern West Virginia were equivalent to the Allegheny Formation or Group of Pennslyvania. Later, David White (1900a) presented a detailed discussion of the relative ages of the strata as shown by the plant megafossils. After reviewing the problem, I. C. White (1908) finally accepted David White's conclusion that the strata in question were of Kanawha age. In an extensive monograph on the stratigraphic succession of the fossil floras in the anthracite basins of Pennsylvania, David White (1900b) noted that the floras were identical with those found in various places in West Virginia. He also referred to specific floral zones in the New River Gorge area (White, 1900b, pp. 814-823).

David White's catalog of the fossil flora of West Virginia is well known and contains the names of many fossil plants collected in the gorge and nearby areas (White, 1913). His monograph (White, 1943), published posthumously, on Early Pennsylvanian species of *Mariopteris*, *Eremopteris*, *Diplothemena*, and *Aneimites* from the Appalachian region has several descriptions and illustrations of fossils from mines near Sewell, Nuttallburg, Quinnimont, Anstead, Kanawha Falls, and Cotton Hill in the gorge area. Plant fossils from the area have also been collected and studied by Williams (1937), Bode (1958), and Read and Mamay (1964).

Geology

Rocks exposed along the New River Gorge area are of Carboniferous age, ranging from Late Mississippian at the southern end near Hinton to Middle Pennsylvanian at the northern end near Gauley Bridge (Figures 1,2). The geology of the area has been studied and mapped by Campbell and Mendenhall (1896), Krebs and Teets (1916), Hennen and Tucker (1919), Reger and Price (1926), Englund and others (1977, 1979), and Englund and Henry (1981). In 1972, the U. S. Geological Survey initiated a study for the establishment of a stratotype for the Pennsylvanian System. One of the criteria for the selection of the stratotype was that it contain a depositionally continuous sequence of all Pennsylvanian rocks, a sequence that was also depositionally continuous with underlying and overlying strata (Englund and others, 1979). These relationships are known to exist only in West Virginia. In the New River Gorge, a signifi-

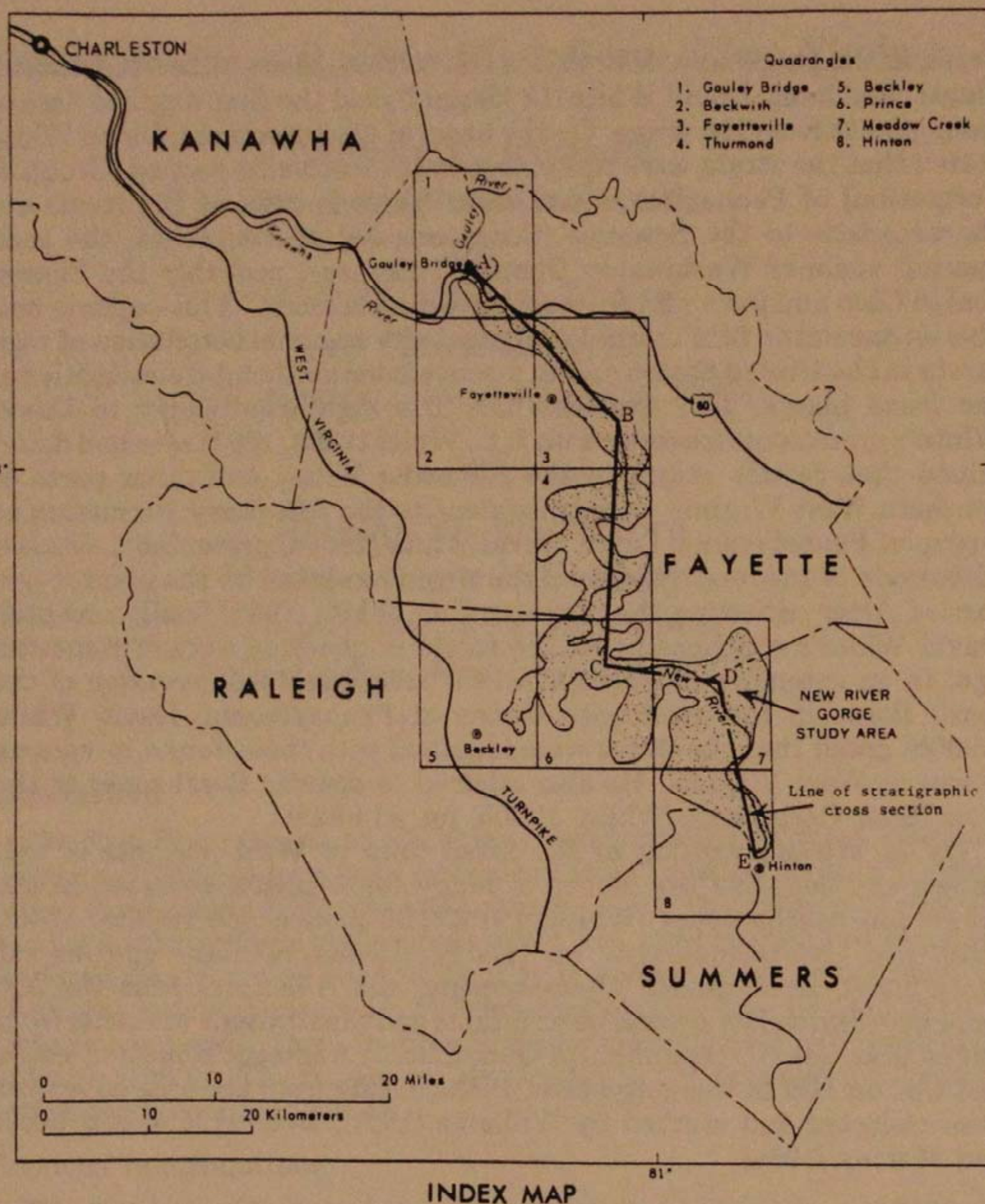


FIGURE 1. Map showing location of stratigraphic cross section (Fig. 2).

cant part of the Lower Pennsylvania Series containing two very important paleobotanical and geologic time boundaries—one between the Mississippian and Pennsylvanian Systems and the other between the Lower and Middle Pennsylvanian Series—is exposed. The fossil plants occurring immediately below and above these boundaries have been discussed in several papers (Gillespie and Pfefferkorn 1977, 1979a, b; Pfefferkorn and Gillespie 1979, 1980a, b, 1981, 1982).

Plant Fossils

Plant fossils have been found to be locally abundant in the New River Gorge and adjacent areas. The most persistent occurrences are in the

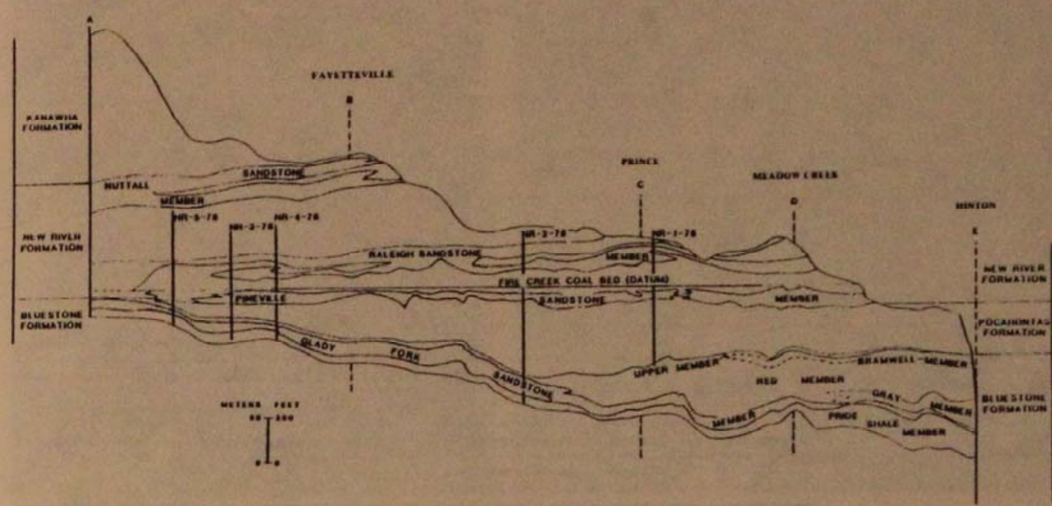


FIGURE 2. Generalized stratigraphic relationships in the New River Gorge area (After Englund, et al 1977).

dark shale immediately above the Fire Creek and Sewell coals, although they are often found in the shales above the Beckley, Hughes Ferry, Lower Douglass, Gilbert, Eagle, Powellton and No. 2 Gas coal beds, all of early or middle Pennsylvanian age. In addition, various horizons in the Upper Mississippian have also yielded nice specimens.

The common and/or important species found in the New River Gorge and adjacent area and their strateigraphic ranges are listed in Table 1.

The Upper Mississippian flora (Plates 1 and 2) is characterized by *Stigmaria stellata* Geoppert, *Sphenophyllum tenerrimum* Ettingshausen, *Sphenopteris elegans* (Brongniart) Sternberg, *S. launoitii* Stockmans & Williere, *Lyginopteris fragilis* Schlotheim, *L. bermudensiformis* Schlotheim, *Calamites radiatus* (Brongniart) Remy & Remy (*Archaeocalamites* Stur), *Lepidodendron* sp., probably *L. veltheimi* Sternberg, *Rhodeopteridium stachei* Stur, *Sphenopteridium bifidum* (Lindley & Hutton) Tschirk, and *Archaeopteridium tschermackei* (Stur) Kidston.

Upper Mississippian flora differs significantly from that of the overlying Lower Pennsylvanian Series (Plates 3 and 4) which contains *Neuropteris pocahontas* David White, *Spheropteris pottsvillea* (David White) Gastaldo & Boersma, *Karinopteris acuta* (Brnogniart) Boersma, *Alethopteris decurrens* (Artis) Zeiller, *Lepidodendron aculeatum* Sternberg, *L. obovatum* Sternberg, *L. dichotomum* Sternberg, *Stigmaria ficoides* (Sternberg) Brongniart, *Lyginopteris hoeninghausii* (Brongniart) Potonie, *Aulacotheca campbellii* (David White) Halle, *Holcospermum maizeretense* Stockmans and Williere, *Asterophyllites equisetiformis* (Sternberg) Brongniart, and *Sphenophyllum cuneifolium* (Sternberg) Zeiller.

The Nuttall Sandstone Member at the top of the New River Formation (upper Lower Pennsylvanian) forms the rim of the gorge. The flora of the New River Formation is succeeded by a flora containing *Sphenop-*

Table 1. Stratigraphic ranges of plant megafossils in the New River Gorge.

TABLE I— Stratigraphic ranges of plant megafossils in the New River Gorge.	UPPER MISSISSIPPIAN SERIES				LOWER PENNSYLVANIAN SERIES		MIDDLE PENNSYLVANIAN SERIES
	Bluefield Fm.	Hinton Fm.	Princeton SS.	Bluestone Fm.	Pocahontas Fm.	New River Fm.	Kanawha Fm.
"LYCOPODS"							
Lepidodendron aculeatum					—	—	—
Lepidodendron obovatum					—	—	—
Lepidodendron dichotomum					—	—	—
Stigmaria ficoides	—	—	—	—	—	—	—
Stigmaria stellata		—	—	—			
Cyperites bicarinatus	—	—	—	—	—	—	—
Lepidostrobophyllum spp.	—	—	—	—	—	—	—
"SPHENOPSIDS"							
Calamites radiatus	—	—	—	—			
Mesocalamites sp.	—	—	—	—	—	—	—
Mesocalamites cistii				—	—	—	—
Mesocalamites suckowii				—	—	—	—
Asterophyllites longifolius				—	—	—	—
Asterophyllites equisetiformis						—	—
Asterophyllites charaeformis						—	—
Annularia radiata							—
Calamostachys sp.				—	—	—	—
Sphenophyllum tenerrimum				—			
Sphenophyllum cuneifolium						—	—
"PTERIDOSPERMS"							
Sphenopteris elegans	—	—	—	—			
Sphenopteris launoitii				—			
Sphenopteridium bifidum				—			
Archaeopteridium tschermackei				—			
Lyginopteris fragilis				—			
Lyginopteris bermudensiformis				—			
Lyginopteris hoeninghausii					—	—	
Alethopteris parva				—			
Alethopteris decurrens						—	
"Neuropteris pocahontas"				—	—	—	
Neuropteris gigantea							—
Neuropteris heterophylla							—
Aulacotheca campbellii				—	—	—	
Holcospermum maizeretense				—	—	—	
"Mariopteris" pottsvillea					—	—	
Mariopteris muricata							—
Trigonocarpus sp.					—	—	—
"CORDAITES"							
Cordaites sp.	—	—	—	—	—	—	—

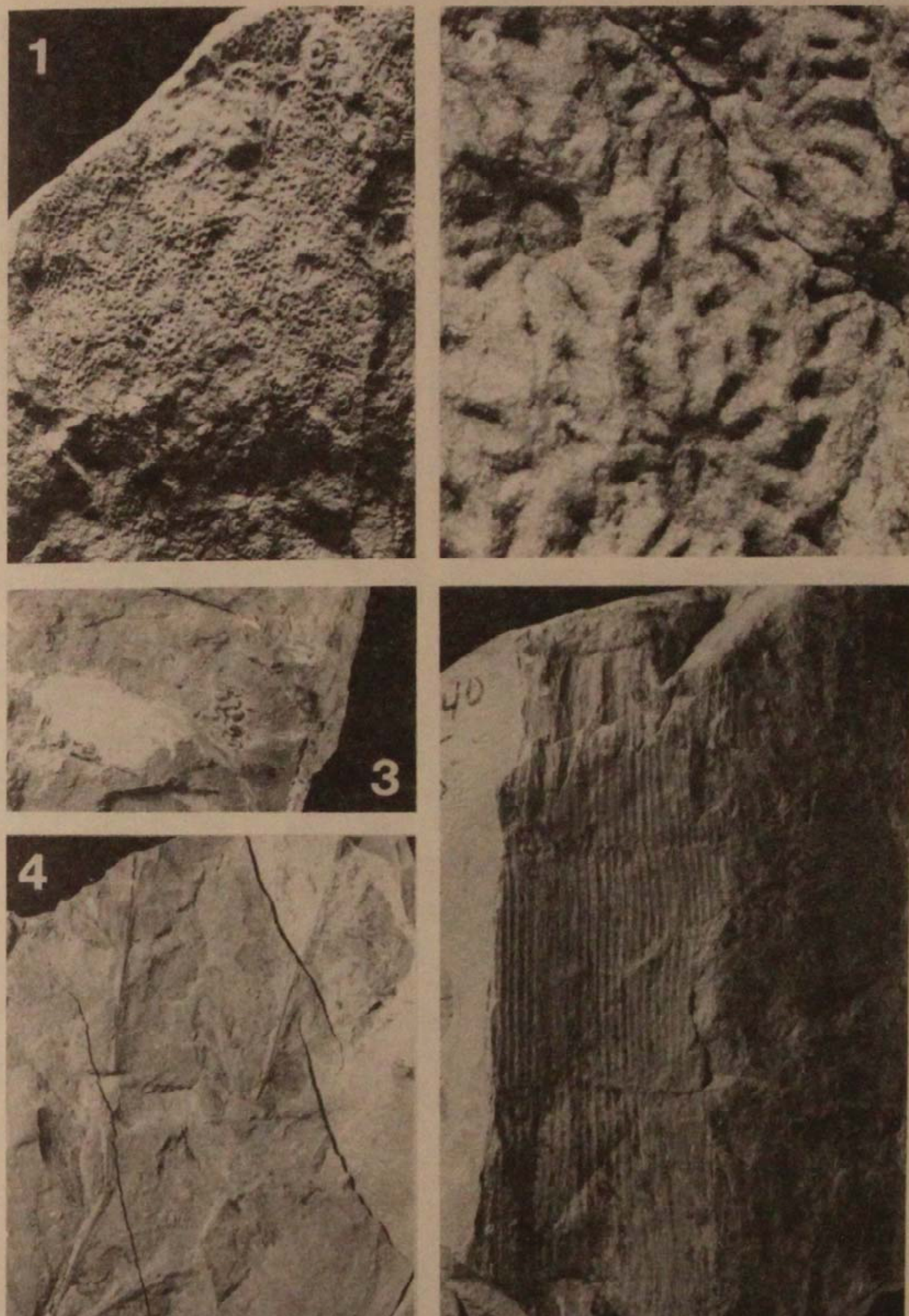


PLATE 1. Upper Mississippian plant fossils. Figure 1, *Stigmaria stellata* 1x; Figure 2, *Stigmaria stellata* 5x; Figure 3, *Alethopteris parva* 1x; Figure 4, *Archaeopteridium tschermackei* 1x; Figure 5, *Mesocalamites cistii* 1x.

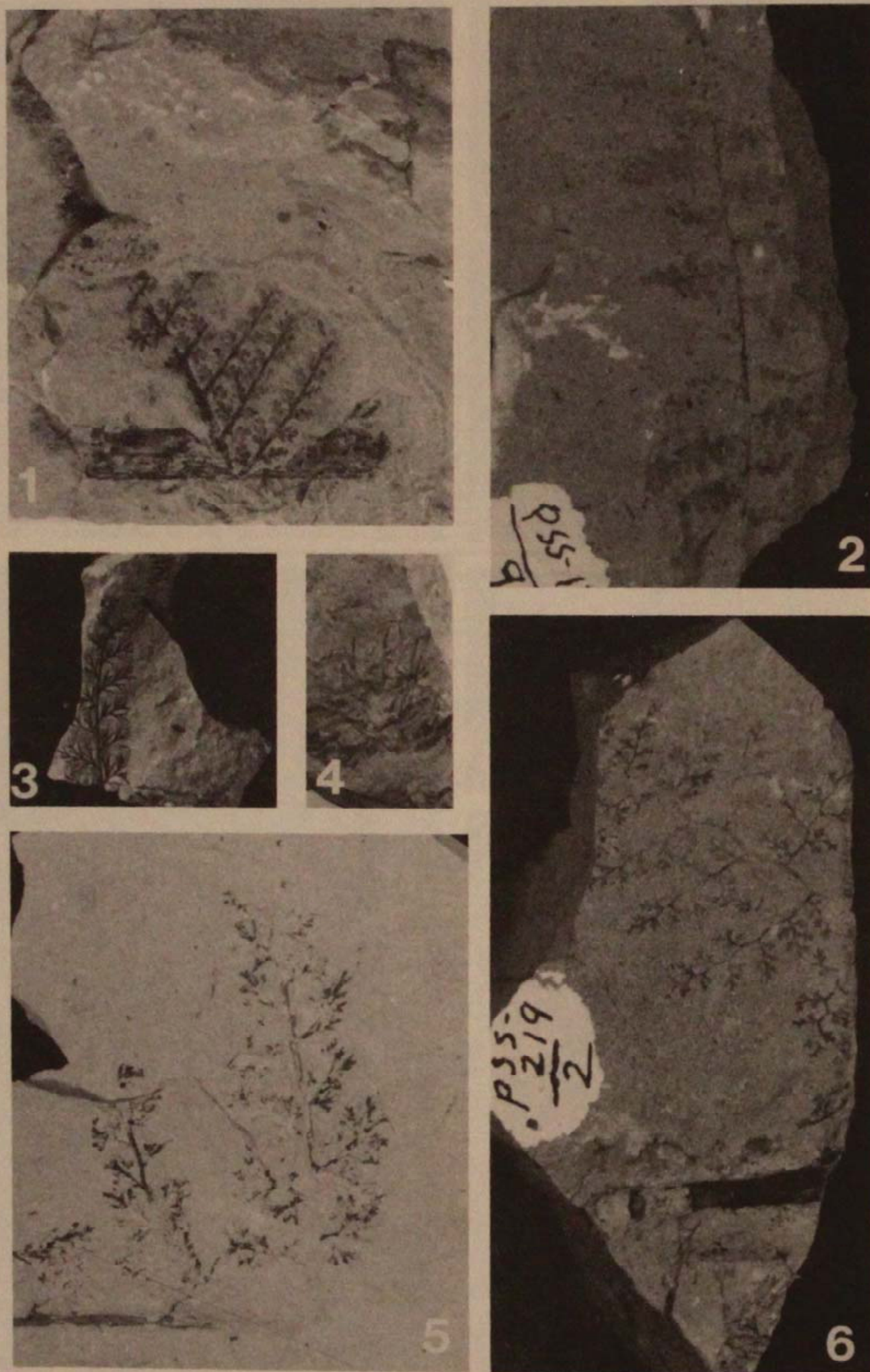


PLATE 2. Upper Mississippian plant fossils. Figure 1, *Lyginopteris fragilis* 1x; Figure 2, *Lyginopteris bermudensiformis* 1x; Figure 3, *Sphenopteridium bifidum* 1x; Figure 4, *Sphenophyllum tenerrimum* 1x; Figure 5, *Sphenopteris elegans* 1x; Figure 6, *Sphenopteris launoitii* 1x.

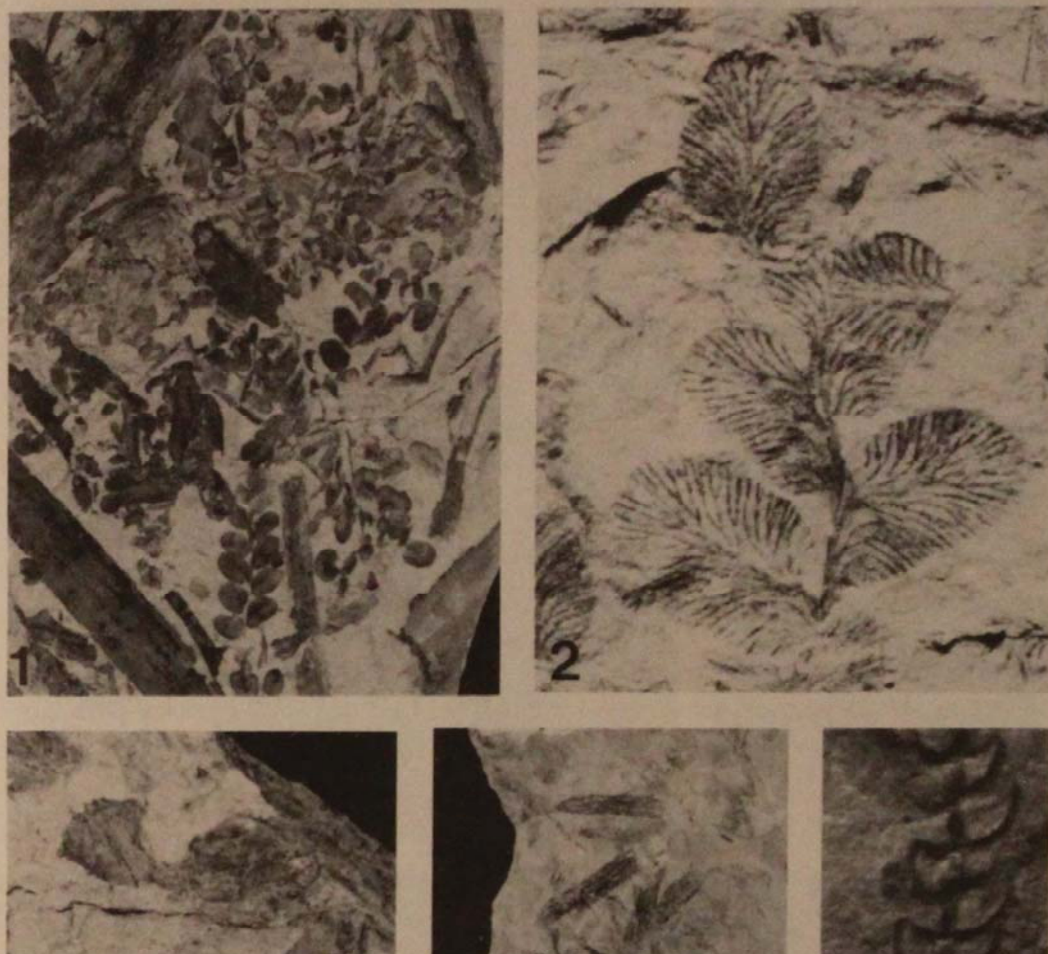


PLATE 3. Lower Pennsylvanian plant fossils. Figure 1, *Neuropteris pocahontas* 1x; Figure 2, *Neuropteris pocahontas* 5x; Figure 3, *Holcospermum maizeretense* 1x; Figure 4, *Aulacotheca campbellii* 1x; Figure 5, *Asterophyllites charaeformis* 5x; Figure 6, *Asterophyllites charaeformis* 1x.

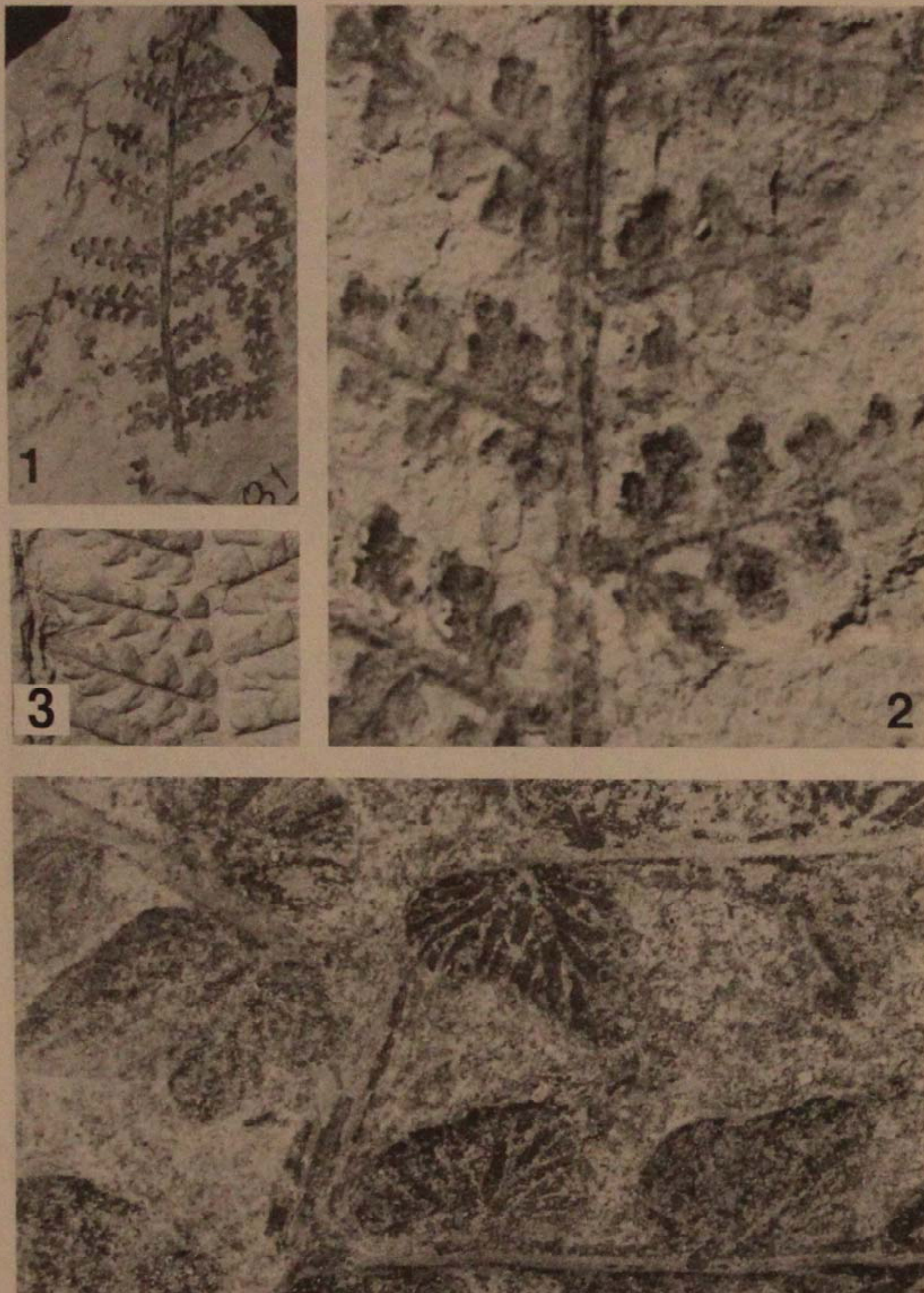


PLATE 4. Lower Pennsylvanian plant fossils. Figure 1. *Lyginopteris hoeninghausii* 1x; Figure 2. *Lyginopteris hoeninghausii* 5x; Figure 3, *Sphenopteris pottsvillea* 1x; Figure 4, *Sphenopteris pottsvillea* 5x.

teris schatzlarensis Stur, *Neuropteris gigantea* Sternberg, *Annularia radiata* Brongniart, *Mariopteris muricata* (Schlotheim) Zeiller and *Neuropteris heterophylla* (Brongniart) Sternberg in the overlying lower Kanawha Formation (lower Middle Pennsylvanian) that caps the hills in the area.

Several plant fossils, including *Asterophyllites longifolius* (Sternberg) Brongniart, *Mesocalamites suckowii* Brongniart, and several species of *Cordaites* spp., and *Calamites* spp. are long-ranging forms that may be found anywhere in the section.

The fossil plants collected and studied from rocks in the New River Gorge and listed in Table 1 are those also found in similarly aged rocks in many other parts of the world, and therefore can be used for interbasinal and intercontinental stratigraphic correlation. However, some paleobotanists (Bode, 1958; Jongmans and Gothan, 1944) have stated that some of the changes reported in the North American section are not as abrupt as changes in the European section.

Further paleobotanical studies of the gorge area will undoubtedly reveal additional fossil plants, especially species found elsewhere in rocks of equivalent age.

Selected References

1. Bode, Hans. 1958. Die floristische Gliederung des Oberkarbons der Vereinigten Staaten von Nordamerika: Deutsche Geol. Gesell. Zeitschr., v. 110, pt. 2, p. 217-259.
2. Campbell, M. R., and Mendenhall, W. C. 1896. Geologic section along the New and Kanawha Rivers in West Virginia: U. S. Geol. Survey Ann. Rept. 17, pt. 2, p. 473-511.
3. Englund, K. J., Arndt, H. H., Gillespie, W. H., Henry, T. W., and Pfefferkorn, H. W. 1977. A field guide to the proposed Pennsylvanian System stratotype, West Virginia: Am. Assoc. Petroleum Geologists Field Guide, Guidebook for Field Trip, AAPG/SEPM Ann. Mtg., 80 p.
4. Englund, K. J., Arndt, H. H. and Henry, T. W., eds. 1979. Proposed Pennsylvanian System stratotype, Virginia-West Virginia: AGI Select Guidebook Ser., No. I, IX Internat. Congr. Carboniferous Stratigr. Geol. 138 p.
5. Englund, K. J., and Henry, T. W. 1981. Mississippian-Pennsylvanian boundary in the central part of the Appalachian region, Pt. I, Southwestern Virginia, southern West Virginia: Geol. Soc. America, Cincinnati, 1981, Field Trip Guidebook, No. I. p. 153-194.
6. Fontaine, W. M. 1874. The great conglomerate on New River, West Virginia: Am. Jour. Sci., 3rd Ser., v. 7, p. 459-465, 573-579.
7. ____________. 1876. Conglomerate series of West Virginia: Am. Jour. Sci., 3rd Ser., v. 11, p. 276-284, 374-384.
8. Gillespie, W. H. 1984. The Kanawha, *in* Bartlett, R. A., Rolling Rivers: An encyclopedia of America's Rivers: New York, McGraw-Hill Book Co. p. 126-129.
9. Gillespie, W. H., Clendening, J. A., and Pfefferkorn, H. W. 1978. Plant fossils of West Virginia: West Virginia Geol. Survey, Educational Ser., ED-3A, 172 p.
10. Gillespie, W. H., and Latimer, J. S., Jr. 1961. History and bibliography of West Virginia paleobotany: Castanea, v. 26, p. 157-171.
11. Gillespie, W. H., and Pfefferkorn, H. W. 1977. Plant fossil and biostrati-

graphy at the Mississippian/Pennsylvanian boundary in the Pennsylvanian System stratotype area, West Virginia/Virginia [Abst.]: Bot. Soc. America Ann. Mtg., Abstr. of Papers, p. 37.
12. ___________. 1979a. Distribution of commonly occurring plant megafossils in the proposed Pennsylvanian System stratotype, *in* Englund, K. J., and others, eds., Proposed Pennsylvanian System stratotype, Virginia and West Virginia: AGI Selected Guidebook Ser. No. I, p. 86-96.
13. ___________. 1979b. Paleobotany, *in* The Mississippian and Pennsylvanian (Carboniferous) System in the United States—West Virginia and Maryland: U. S. Geol. Survey Prof. Paper 1110-D, p. D30-D31.
14. Hennen, R. V., and Tucker, R. C. 1919. Fayette County: Morgantown, West Virginia Geol. Survey [County Report], 1002 p.
15. Hildreth, S. P., and Morton, S. G. 1836. Observations on the bituminous coal deposits of the valley of the Ohio, and the accompanying rock strata, with notices of the fossil organic remains and the relics of vegetable and animal bodies, illustrated by a geologic map, numerous drawings of plants and shells and by views of interesting scenery: Am. Jour. Sci., v. 29, p. 1-154.
16. Jongmans, W. J., and Gothan, W. 1934. Florenfolge und verleichende Stratigrafie des Karbons der ostlichen Staaten Nord Amerika's. Vergleich mit West-Europa; Heerlen, Geol. Bur. Heerlen, Jaarverslag over 1933, p. 17-44.
17. Krebs, C. E., and Teets, D. D., Jr. 1916. Raleigh County and western part of Mercer and Summers Counties: Morgantown, West Virginia Geol. Survey [County Report] 648 p.
18. Pfefferkorn, H. W. and Gillespie, W. H. 1979. Plant megafossils in the proposed Pennsylvanian System stratotype [Abstr.]: IX Int. Cong. Carboniferous Stratig. Geol. Abstract of papers, p. 163 (Univ. Illinois, Urbana.)
19. ___________. 1980a. A bibliography of compression-impression floras of Pennsylvanian age in North America 1821 to 1977: Philadelphia, Pa., Schlotheimiana, Spec. Paper, 44 p.
20. ___________. 1980b. Biostratigraphy and biogeography of plant compression fossils in the Pennsylvanian of North America; Chap. 3 of Biostratigraphy of fossil plants, successional and paleoecological analyses: Stroudsburg, Pa., Dowden, Hutchinson and Ross, p. 93-118.
21. ___________. 1981. Biostratigraphic significance of plant megafossils near the Mississippian-Pennsylvanian boundary in southern West Virginia and southwestern Virginia, *in* Geol. Soc. America Cincinnati 1981 Field Trip Guidebook, v. 1, p. 159-164.
22. ___________. 1982. Plant megafossils near the Mississippian-Pennsylvanian boundary in the Pennsylvanian System stratotype, West Virginia/Virginia, *in* Biostratigraphic data for a mid-Carboniferous boundary: Leeds, England, Subcommission on Carboniferous Stratigraphy, p. 128-133.
23. Read, C. B., and Mamay, S. H. 1964. Upper Paleozoic floral zones and floral provinces of the United States: U. S. Geol. Survey Prof. Paper 454-K, 34 p.
24. Reger, D. B., and Price, P. H. 1926. Mercer, Monroe and Summers Counties: Morgantown, West Virginia Geol. Survey [County Report], 963 p.
25. Rogers, W. B. 1884. A reprint of annual reports and other papers on the geology of the Virginias: New York, D. Appleton Co., 832 p.
26. ___________. 1859. On the parallelism of the Lower Carboniferous of Pennsylvania and Virginia and of Nova Scotia and New Brunswick: Boston Soc. Nat. History Procl, v. 7, p. 170-173.
27. White, David. 1895. The Pottsville series along New River, West Virginia: Geol. Soc. America Bull., v. 6, p. 305-320.

28. ____________. 1900a. Relative ages of the Kanawha and Allegheny series as indicated by fossil plants: Geol. Soc. America Bull., v. 11, p. 145-178.
29. ____________. 1900b. The stratigraphic succession of the fossil floras of the Pottsville Formation in the southern anthracite coal fields, Pennsylvania: U. S. Geol. Survey Ann. Rept., v. 20, Pt. II, p. 749-930.
30. ____________. 1913. The fossil flora of West Virginia: West Virginia Geol. Survey, v. 5(a), p. 390-453, 488-491.
31. ____________. 1926. General features of the Mississippian floras of the Appalachian trough, *in* Mercer, Monroe, and Summers Counties: Morgantown, West Virginia: West Virginia Geol. Survey [County Report], p. 837-843.
32. ____________. 1943. Lower Pennsylvanian species of *Mariopteris, Eremopteris, Diplothmena,* and *Aneimites* from the Appalachian region (a posthumous work); assembled and edited by C. B. Read: U. S. Geol. Survey, Prof. Paper 197-C, p. 85-140.
33. White, I. C. 1883. Section of the New River coal series XII at Sewell Station on the Chesapeake and Ohio Railway: The Virginias, v. 4, p. 126-127.
34. ____________. 1891. Stratigraphy of the bituminous coal field of Pennsylvania, Ohio, and West Virginia: U. S. Geol. Survey Bull. 65, 212 p.
35. ____________. 1903. Levels above tide; true meridians; report on coal: Morgantown, West Virginia Geol. Survey, v. 2, 725 p.
36. ____________. 1908. Supplementary coal report: Morgantown, West Virginia Geol. Survey, v. 2-A, 720 p.
37. Williams, Lou. 1937. A study of *Neuropteris schlehani* Stur: Jour. Paleontology, v. ii, p. 462-465.

Lithologic Characteristics of Immediate Mine Roof That Have Contributed to Roof Falls in Selected Coal Mines of Eastern Kentucky

Alan D. Smith
Department of Quantitative and Natural Sciences
Robert Morris College
Coraopolis, PA 15108

Abstract

The first 4 immediate mine-bed characteristics of 250 roof falls in 5 different coal mines located in Pike, Martin, and Floyd Counties of the Eastern Kentucky Coalfield were investigated to profile the basic lithologies and their associated thickness. The mine roof falls occurred in the Peach Orchard, Pond Creek, Broas, and Fireclay coal seams.

Most of the mine roof falls were associated with the Pond Creek coal seam, had evidence of cracks or joints in the roof before the actual fall, and relatively thin layers (0.1 to 3.9 inches) in the immediate roof. The first immediate roof bed

was characterized by shales, laminated shales, and black shales (50%) and coal top, including bone coal (28.4%). Thicknesses of the first layer were commonly in the 2 to 4 and 10 to 70 inches range, with 2 to 4 inches most frequent. The second immediate roof bed was also characterized by a predominance of shales (33%), coal (19%) however, these figures may be higher due to relatively large numbers of missing or unknown cases (38%). The vast majority of falls (67%) had second immediate layers of thickness less than 20 inches. Similar roof beds were found in the third and fourth immediate roof but, due to the difficulty in access to measure these parameters in actual roof falls, a relatively large percentage of missing cases was found.

Although the first step in preventing roof falls is to characterize the basic lithologic and geologic characteristics of the immediate roof beds, further study is recommended to core in adjacent stables areas with no recent record of ground control problems, under similar conditions, to determine if the lithologic profiles found in this study are unique to potential roof fall areas.

Introduction

Roof fall occurrence is a common ground control problem. In fact, roof falls are so common many mining operations consider it a part of the regularly computed downtime (Peng, 1978). In some instances, it may cost as much to clean up a fall as it does to mine actual coal. Loss of revenues and death of workers are common results of roof falls. Roof falls have been shown to be the major cause of death in underground coal mines in the United States. Nearly all roof failures can be traced to 2 major causes: 1. The interaction of stresses in the roof, pillars, and floor exceeded the rupture point of the roof rock strata (Moebs, 1974); and 2. Geologic disturbances in the immediate roof, such as slickensides, channel sands, transition zones, rider coal seams, kettlebottoms, cracks and joints and the presence of water, are often associated with roof falls (Pothini and Schonfeldt, 1979); Hylbert, 1981; Horne, et al., 1978).

Geographic Location

The study area under investigation is located in portions of Floyd, Martin, and Pike Counties of Kentucky. This area is in the heart of the eastern Kentucky coal mining district.

General Stratigraphy

All of the coal seams used in the present study are part of the Breathitt Formation in the Lower and Middle Pennsylvanian Series. It is generally accepted that the deposition of these coals and their associated sandstones, shales, and underclays took place on deltas and delta lobes with the source area to the northwest and sediment transportation to the east and southeast (Englund, 1964; Ferm, 1974; and Hylbert, 1981). Deposition of these deltas and delta lobes took place within the Pocahontas Basin, which is a smaller basin within the larger Appalachian Basin (Hylbert, 1981).

The 4 different coal seams that were examined included: the Broas, the Peach Orchard (Coalbury), and the Pond Creek (Lower Elkhorn), all in Martin County, the Pond Creek again in Pike County, and the Fire Clay coal seam in Floyd County. The intervals between coal seams are cyclic, either a coarsening upward or fining upward sequence (Hylbert, 1981). This cyclic sequence is a key stratigraphic relationship that permits the stimulateous study of several coal seams.

The Broas coal seam is stratigraphically the highest coal seam in the study. It can range in thickness from 0 to 5 feet and has no real distinctive features. Below the Broas coal seam are the Upper Peach Orchard and Lower Peach Orchard coal seams. In this section of Martin County the Upper Peach Orchard and the Lower Peach Orchard coal seam come together to form a single coal seam that can range in thickness from 4 to 15 feet. Because the Broas and Peach Orchard coal seams were examined over the same geographic area, their associated rocks are relatively similar. The sandstones range from very coarse to fine grained and may be cross bedded. Lenticular sandstone bodies are common and can cover an area 5 miles wide and be 150 feet thick. These bodies usually have a sharp basal contact and a gradational contact at the upper boundary of the body. The siltstones and shales of the study area are generally laminated and interstratified with thin beds of very-fine to medium grained sandstones. The shales locally are highly carbonaceous. These shales also contain plant fragments, siderite nodules, and calcite concretions (Outerbridge, 1963).

The Fire Clay coal seam in Floyd County is stratigraphically below the Peach Orchard coal seam. It ranges in thickness from 0 to 6 feet, with the thickest portion located in the north-central section of the McDowell Quadrangle (Rice, 1968). A distinctive characteristic for identifying the Fire Clay coal seam is the flint-clay parting, which may be of volcanic origin. The major rock units associated with the Fire Clay coal seam are medium-to-fine grained sandstones, which are often cross-bedded or massive. These sandstones in many instances grade laterally into laminated sandstones and interbedded shales (Rice, 1968).

The Pond Creek is stratigraphically the lowest coal seam in this study. The Pond Creek coal seam is an extensive and uniform coal bed which generally is not exposed in eastern Kentucky. It has a thickness of 1 to 7 feet and locally may contain splint and canneloid coal at the top of the seam. The roof strata over the Pond Creek coal seam is commonly a shale, but locally it may have a thin to thickly bedded sandstone in close proximity to the coal seam (Wolcott and Jenkins, 1966). A rider coal seam approximately 10 to 20 feet above the Pond Creek is usually present in the shale.

Methods

Cooperation by 4 mining companies allowed the investigation and data collection of mine roof falls in 5 different mines (Figure 1) to determine the distribution and basic lithologic nature of the immediate roof bed. The parameters studied included thickness and lithologic characteristics of the first to fourth immediate roof beds, the thinnest thickness of immediate roof beds, and presence of cracks in the bed, before the actual

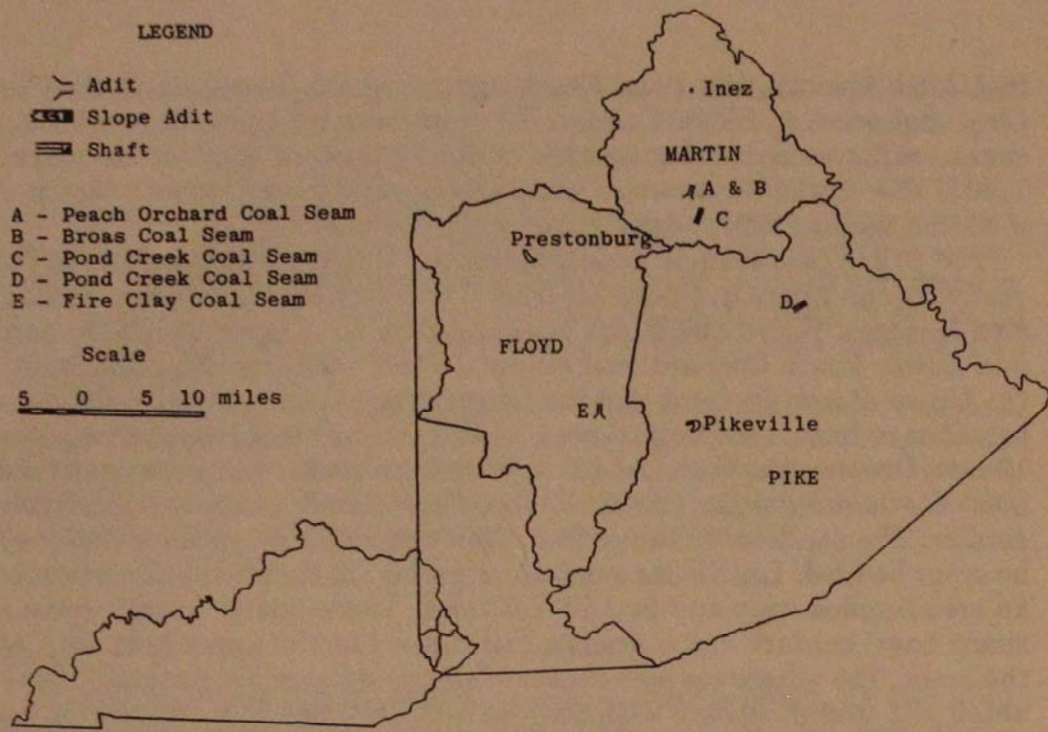


FIGURE 1. Location of entrances to the coal seams for the mines studied.

mine roof fall. All lithologic observations and seam dimensions were completed on the exposed roof rock of failed areas. No effort was made to infer any lithologic characteristic on the basis of the failed material itself. A total of 250 roof falls were measured and used as the basis for this study.

Results

Table 1 lists the frequency counts, relative frequencies, and cumulative frequencies for name of coal seam examined, presence of cracks in the mine roof before the fall, thickness and basic lithology of the first through the fourth immediate roof beds.

Most of the mine-roof falls were associated with Pond Creek coal seam (64%) since 2 mines were surveyed in the Pond Creek and only 1 mine in each of the other coal seams. In addition, most mine roof falls had evidence of cracks or joints in the roof before the actual fall (75%), and relatively thin immediate layers of approximately 0.1 to 3.9 inches (82%). The first immediate roof bed was characterized by predominantly shales, laminated shales, and black shales (50%) and coal top, including bone coal (28.4%). Thicknesses of the first layer were commonly in the 2 to 4 and 10 to 70 inches range, with 2 to 4 inches most frequent. The second immediate roof bed was also characterized by a predominance of shales (33%), coal (19%) however, these figures may be higher due to relatively large numbers of missing or unknown cases (38%). The vast majority of falls (67%, once adjusted for missing cases) had second immediate layers of thickness less than 20 inches. Similar roof beds were found in the third and fourth immediate roof but, due to the difficulty in

Table 1. Frequency Counts, Relative Frequencies, and Cumulative Frequencies for Selected Lithologic Parameters of the Immediate Mine Roof and Associated Information of failed areas

Parameters	*Value Labels*	*Absolute Frequency*	*Relative Frequency (%)*	*Adjusted[a] Frequency (%)*
Name of Coal Seam	Peach Orchard	62	24.8	24.8
	Pond Creek	159	63.6	88.4
	Broas	14	5.6	94.0
	Fireclay	15	6.0	100.0
	TOTAL	250	100.0	
Presence of cracks in Roof Before Fall	YES	188	75.2	85.1
	NO	33	13.2	100.0
	UNKNOWN	29	11.6	100.0
	TOTAL	250	100.0	
Thickness of Thinnest Immediate Layer (in.)	0.1-1.9	103	41.2	41.2
	2.0-3.9	101	40.4	81.6
	4.0-5.9	30	12.0	93.6
	6.0-7.9	6	2.4	96.0
	8.0-9.9	4	1.6	97.6
	10.0-99.9	4	1.6	92.2
	100.0-1000.0	2	0.8	100.0
	TOTAL	250	100.0	
Thickness of First Immediate Roof Bed (in.)	0.1-1.9	9	3.6	3.6
	2.0-3.9	53	21.2	24.8
	4.0-5.9	12	4.8	29.6
	6.0-7.9	4	1.6	31.2
	8.0-9.9	6	4.2	33.6
	10.0-29.9	44	17.6	51.2
	30.0-49.9	34	14.8	66.0
	50.0-69.9	40	16.0	82.0
	70.0-89.9	21	8.4	90.4
	90.0-109.9	13	5.2	95.6
	110.0-149.9	7	2.8	98.4
	150.0-199.9	1	0.4	98.8
	200.0-249.9	3	1.2	100.0
	TOTAL	250	100.0	
Lithology of First Immediate Roof Bed	Shales	71	28.4	28.4
	Bone Coal	32	12.8	41.2
	Sandstone	20	8.0	49.2
	Lam Coal	39	15.6	64.8
	Lam Shales	31	12.4	77.2
	Black Shales	22	8.8	86.0
	Lam Sandstone	35	14.0	100.0
	TOTAL	250	100.0	
Thickness of Second Immediate Roof Bed (in.)	0.1-9.9	68	27.2	45.3
	10.0-19.9	33	13.2	67.3
	20.0-29.9	7	2.8	72.0
	30.0-39.9	9	3.6	78.0
	40.0-49.9	5	2.0	81.3
	50.0-59.9	5	2.0	84.7
	60.0-69.9	8	3.2	90.0
	70.0-79.9	5	2.0	93.3
	80.0-89.9	1	0.4	94.0
	90.0-99.9	2	0.8	95.3
	110.0-149.9	7	2.8	100.0
	MISSING	100	40.0	100.0
	TOTAL	250	100.0	

Table 1.—*Continued*

Parameters	*Value Labels*	*Absolute Frequency*	*Relative Frequency (%)*	*Adjusteda Frequency (%)*
Lithology of Second Immediate Roof Bed	Shales	35	14.0	9.8
	Bone Coal	7	2.8	27.1
	Sandstone	19	7.6	39.9
	Coal	40	16.0	65.2
	Lam Shales	26	10.4	81.9
	Black Shales	21	8.4	95.5
	Lam Sandstone	7	2.8	100.0
	MISSING	95	38.0	100.0
	TOTAL	250	100.0	
Thickness of Third Immediate Roof Bed (in.)	0.1-1.9	10	4.0	9.8
	2.0-3.9	8	3.2	17.6
	4.0-5.9	6	2.4	23.5
	6.0-7.9	7	2.8	30.4
	8.0-9.9	4	1.6	34.3
	10.0-29.9	29	11.6	62.7
	30.0-49.9	14	5.6	76.5
	50.0-69.9	14	5.6	90.2
	70.0-89.9	7	2.8	97.1
	90.0-99.9	3	1.2	100.0
	MISSING	145	58.0	100.0
	TOTAL	250	100.0	
Lithology of Third Immediate Roof Bed	Shales	50	20.0	47.6
	Bone Coal	5	2.0	52.4
	Sandstone	19	7.6	70.5
	Siderite Shale	3	1.2	73.3
	Coal	14	5.6	86.7
	Lam Shales	6	2.4	92.4
	Lam Sandstone	8	3.2	100.0
	MISSING	145	58.0	100.0
	TOTAL	250	100.0	
Thickness of Fourth Immediate Roof Bed (in.)	0.1-1.9	5	5.6	6.9
	2.0-3.9	7	2.8	16.7
	4.0-5.9	4	1.6	22.2
	6.0-7.9	11	4.4	37.5
	8.0-9.9	5	2.0	44.4
	10.0-29.9	29	11.6	86.1
	30.0-49.9	7	2.8	95.4
	50.0-99.9	3	1.2	100.0
	MISSING	178	71.2	100.0
	TOTAL	250	100.0	
Lithology of Fourth Immediate Roof Bed	Shales	19	7.6	25.7
	Bone Coal	17	6.8	48.6
	Sandstone	6	2.4	56.8
	Siderite Shale	8	3.2	67.6
	Coal	4	1.6	73.0
	Lam Shales	18	7.2	97.3
	Lam Sandstone	2	0.8	100.0
	MISSING	176	70.4	100.0
	TOTAL	250	100.0	

NOTE: Lam denotes laminated or thinly bedded rock.

access to measure these parameters in actual roof falls, a relatively large percentage of missing cases were found.

Conclusions

The nature of the overlying and underlying rocks in a coal mine may be a significant factor in the minability of the coal seam. The material in the first few feet above the coal must be strong enough to remain stable for the required time period when it is supported by bolts, timbers, cables, or combinations of roof support systems. As shown in this study, shale and fine-grained rocks are the most common in the immediate roof and are probably the most varied in composition and character. Some shales are relatively hard and moisture resistant or with little shrink-swell potential, while others are relatively soft, fractured, or characterized by secondary features that make them difficult to support. Obviously, as indicated by the results of the study, shale dominated layers with increasing carbon or coal content in the first four major strata are strong indicators of roof failure. Since the behavior of a rock mass subjected to changes in stress induced by mining activities is governed by both the mechanical properties of the intact rock material and the number and nature of the geological discontinuities present in the rock mass, the first step in prevening mine roof falls is to characterize the associated basic lithology and thickness of the immediate mine roof. As discussed in the results section, a basic profile of the immediate roof of unstable and eventually fallen areas was established for the coal seams and geographical areas studied. The next step for further research would be to core into adjacent stable areas with no record of ground control problems, under similar conditions associated with their unstable counterparts, to determine if the profiles determined in this research are unique to areas having ground control problems. This would be important to estimate how the lithologic characters derived from mine roof falls could be used as a predictive tool in locating potential fall areas.

References

1. Englund, K. J. 1964. Geology of the Middlesboro South Quadrangle, Kentucky: U. S. Geological Survey Geologic Quadrangle Map GZ 301, scale 1:24,000.
2. Ferm, J. C. 1974. Carboniferous models in Eastern United States and their significance, *in* Briggs, Garrett, editor, Carboniferous of the Southeastern United States: Geological Society of America Special Paper 148, p. 79-95.
3. Horne, J. C., Ferm, J. C., Carrucio, F. T., and Baganz, B. P. 1978. Depositional models in coal exploration and mine planning, *in* Ferm, J. C., and Horne, J. C., editors, Carboniferous depositional environment in the Appalachian region: Carolina Coal Group, Department of Geology, University of South Carolina, p. 544-575.
4. Hylbert, D. K. 1981. Delineation of geologic roof hazards in selected coalbeds in Eastern Kentucky—with landsat imagery studies in Eastern Kentucky and the Dunkard Basin: U. S. Bureau of Mines Open File Report, Contract No. J0188002, 97 p.
5. Moebs, Noel N. 1973. Geologic guidelines in coal mine design, *in* Proceedings, Bureau of Mines Technology Transfer Seminar, March 6, 1973, Lexington, Kentucky: U. S. Bureau of Mines Information Circular 8630, p. 63-69.

6. Outerbridge, W. F. 1963. Geology of the Inez Quadrangle, Kentucky: U. S. Geological Survey Geologic Quadrangle Map GZ-226, scale 1: 24,000.
7. Peng, S. S. 1978. Coal mine ground control: New York, John Wiley and Sons, Inc., 450 p.
8. Pothini, B. R. and Schonfeldt, H., von. 1979. Roof fall prediction at Island Creek Coal Company, *in* Brawer, C. O., editor, Stability in Coal Mining: San Francisco, Miller Freeman Publisher, p. 214-227.
9. Rice, C. L. 1968. Geologic map of the McDowell Quadrangle Floyd and Pike Counties, Kentucky: U. S. Geologic Survey Geologic Quadrangle Map GQ-732, scale 1: 24,000.
10. Wolcott, D. E., and Jenkins, E. C. 1966. Geologic map of the Meta Quadrangle Pike County, Kentucky: U. S. Geologic Survey Quadrangle Map GA 497, scale 1: 24,000.

Hypothesis Testing and Model Comparisons of Trend Surfaces and Three-Dimensional Modeling Techniques Applied to Mapping Selected Roof Fall Characteristics in a West Virginia Coal Mine

Alan D. Smith
Department of Quantitative and Natural Science
Robert Morris College
Coraopolis, Pennsylvania 15108

Abstract

Cost-sensitive mine planning systems assume that the physical and economic conditions that will have the greatest impact on cost and coal quality can be predicted accurately enough to assist mine planners in making decisions. Several such factors, namely vertical height of mine opening, mine roof span in or adjacent to fall area, structure contour of maximum mine roof height, and height, from mine roof edge, to second and third rock break horizon of roof strata, extremely important parameters in forecasting potential ground control problems, were measured and mapped for 21 recent mine roof falls in a West Virginia coal mine. The coal mine is mining in a nine-foot, Upper Freeport seam. The major research and analysis tools used in the present study were polynominal-trend surface analyses, hypothesis testing and model comparisons of trend surfaces, and three-dimensional models generated from commercially available computer software, via the incremental drum plotter.

The mean thickness of the vertical height of mine opening was 2.70 m, average mine roof span in or adjacent to fall area was 5.59 m, maximum roof height averaged 2.862 above the roof edge, and the means for the second and third heights, above the roof top to the rock break horizons of the roof falls studied

were 1.83 and 0.65 meters, respectively. Traditional ANOVA techniques and hypothesis testing and model comparisons of trend surfaces delineated the third-order trend surface ($R^2 = 0.7100$) for vertical height of mine opening, the second-degree surface ($R^2 = 0.5864$) for mine roof span in or adjacent to fall area, and the fourth-order polynominal trend surface for the height to second rock break horizon of roof strata in the mine roof fall as the best predictive models. However, no trend surface accounted for enough explained variance in predicting maximum mine roof fall height and third horizon, measure from roof top, as a function of location in the mine site.

Introduction

The stability of coal mining tunnels, entries, rooms, and associated openings plays a major role in the success of any major underground project. Hence, if the main access openings to a new coal mine become deformed and damaged by strata movement to the extent of requiring serious repairs, special problems may arise which will have an influence on ventilation, impairment to speed and reliability of transport systems as well as the direct and indirect costs involved with the repair program (Wells and Whittaker 1981).

The mechanical design of a roof support system is basically a matter of a working knowledge of statics and dynamics, assuming that the imposed loads and mining conditions are known. However, in the Appalachian Coal Fields, the general conditions are known well enough to allow for the majority of mining operations, including traditional room-and-pillar as well as longwall mining techniques, to be furnished with-standard and commercially available supports. Of course, these support systems and roof control procedures are equipped with suitable variants and options (Hutchinson 1981). The overall design of a mining system, which design incorporates not only size and capacity of the equipment to be used; but includes: equipment adaptability to the mining scheme; equipment versus human constraint, operation at the designed levels; and coordination of operation, maintenance and support design (Hutchinson 1981).

Hence, a multitude of factors must be considered in the successful underground operation. Cost-sensitive mine planning systems have been developed to help coal companies design underground mines that will recover coal reserves in the most profitable method. Information obtained from borehole logs, local mines, mining equipment manufacturers, and previous mining experience should be used in the mine planning process. According to Ellison and Scovazzo (1981), cost-sensitive mine planning assumes that the physical and economic conditions that will have the greatest impact on cost and coal quality can be predicted accurately enough to assist mine planners in making decisions. In the planning process, many maps, such as coal seam thickness, expected roof caving conditions, geologic lineaments, roof shale thickness, distant to the first sandstone, overburden thickness, underclay thickness, as well as a host of other factors, can be generated as overlays on each other to assist planners in selecting appropriate locations and orientations for the portal, mains, submains, and longwall panels.

The thrust of the present study is to examine the spatial distributions of vertical height of mine opening, mine roof span in or adjacent to fall area, structure contour of maximum mine roof height, and height to second and third rock break horizon of roof strata, as measured from the roofline, from a study of recent mine roof falls in a particular site in West Virginia. In addition, if spatially predictive relationships exist within the mine layout, a model of their characteristics will be plotted. If these relationships exist, they should prove useful in a cost-sensitive mine plan to avoid selected interactions of these parameters in planning room or main entry development.

Methods

The major research tools used in the present study are polynomial-trend surface analyses, hypothesis testing and model comparisons of trend surfaces, and three-dimensional models generated from commercially available computer software via the incremental plotter.

Results

One mine was selected for the study from West Virginia, Upper Freeport Coal Seam, to apply cost-sensitive mapping procedures with the combined use of trend surface analyses and three-dimensional modeling techniques. However, due to proprietary purposes, the mine site will remain unidentified. A total of 21 actual mine roof falls were measured and data concerning vertical height of mine opening, mine roof span in or adjacent to fall area, structure contour or maximum mine roof height, and height to second and third rock break horizon of roof strate, were collected. As shown in Figure 1, the majority of falls occurred in the entry or crosscut (52.4 percent) or in an intersection (47.6 percent). The means for each measured parameter were as follows: vertical height of mine opening (2.71 m), mine roof span (5.59 m), roof fall height above roof edge (2.86 m), height above roof edge to second rock break horizon (1.83 m), and third rock break horizon (0.653 m).

Each roof fall location was recorded and trend surface analyses, via SYMAP (Dougenik and Sheehan 1979) and a computer program suggested by Smith (1982), were performed (See Table 1). In addition, selected three-dimensional models were created. Tables 2 and 3 illustrate the result of the model comparisons and hypothesis testing of polynomial trend surfaces in predicting spatial distributions of selected mine roof fall characteristics. Table 2 is the hypothesis testing results, in standard analysis of variance (ANOVA) format, to determine if the third degree, polynomial trend surface for vertical height of mine opening is significant. The variance accounte for by the third-degree surface was 71.00 percent and this was found to be statistically significant ($p=0.0452$). Finally, Table 3 is a summary of the F-ratios, probability levels, R^2 for both the full and restricted models, degrees of freedom-numerator, degrees of freedom-denominator, and significance for each

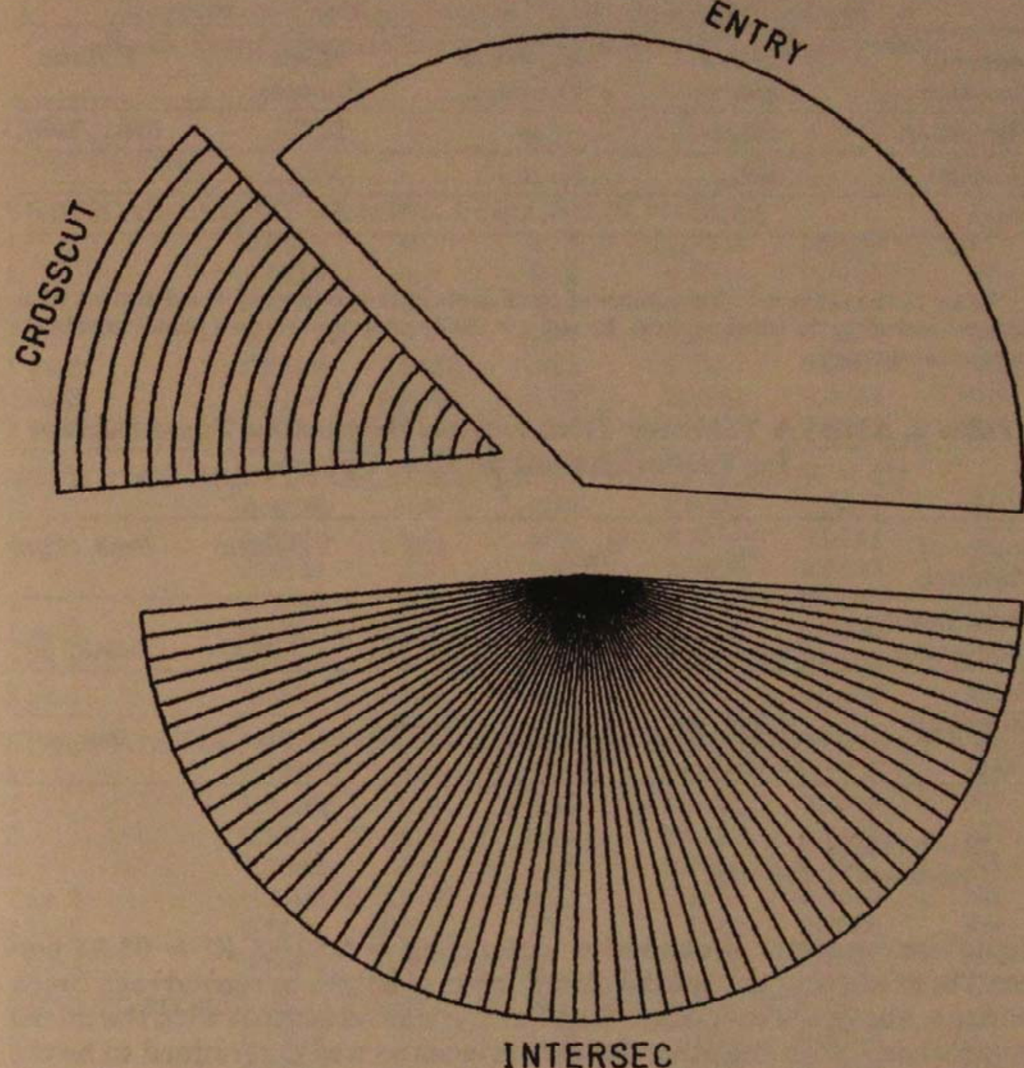


FIGURE 1. Graphically depicted distribution of location of mine roof falls used in the present study.

trend surface for the associated roof fall parameters. As evident from table 3, the highest degree surface in predicting vertical height of mine opening over random variation was the third-order, however, it was shown not to be statistically a better predictor than the lower surfaces (3 vs. 4 term was not significant, $p = 0.8552$). The second degree surface was shown to be significant ($R^2 = 58.64$ percent, $p = 0.0131$) over random variation, but was not significantly a better predictor than the other surfaces. No significant polynomial trends were found for structure contour maximum mine roof height and height to third horizon of roof strata in mine roof. However, the fourth degree surface accounted for a

Table 1. Typical Analysis of Variance Table for Polynomial Trend Surfaces

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Squares*	*F Ratio*
Regression	SS_{Reg}	m	MS_{Reg}	MS_{Reg}/MS_{Res}
Residual	SS_{Res}	n - m - 1	MS_{Res}	
Total	SS_T	n - 1		

Note: In the table, m is the number of coefficients in the polynomial-trend surface equation, not including the constant term, b_o; and n is the number of valid data points used in the regression equation.

Table 2. ANOVA Table for Third Degree, Polynomial Trend Surface for Vertical Height of Mine Opening

Source of Variation	*SS*	df_n/df_d	*MS*	*F-Ratio*	*Prob. Sign.*
Third Degree Regression	16.404465	9	1.822718	2.9931	0.0452 S*
Error (Residual)	6.698796	11	0.608982		
Total	23.103271	20			

$R_f^2 = 0.7100$, $R_r^2 = 0.0$
*Significant at 0.05 level.

significant amount of explained variance ($p = 0.0100$, $R^2 = 98.04$ percent) in predicting the spatial distribution of height to second rock break horizon, above the roof edge. This finding was consistent with the model comparisons with the other degree surfaces as was determined to be the best predictor.

The graphic displays of the three-dimensional plots for selected mine roof parameters can be found in Figures 2 through 5. Figure 2 illustrates the spatial distribution of vertical height of mine opening to roof edge. Figure 3 displays mine roof span in or adjacent to fall area, Figure 4 portrays height to second horizon of roof strata, and Figure 5 presents height to third rock break horizon, from roof edge, at roof strata.

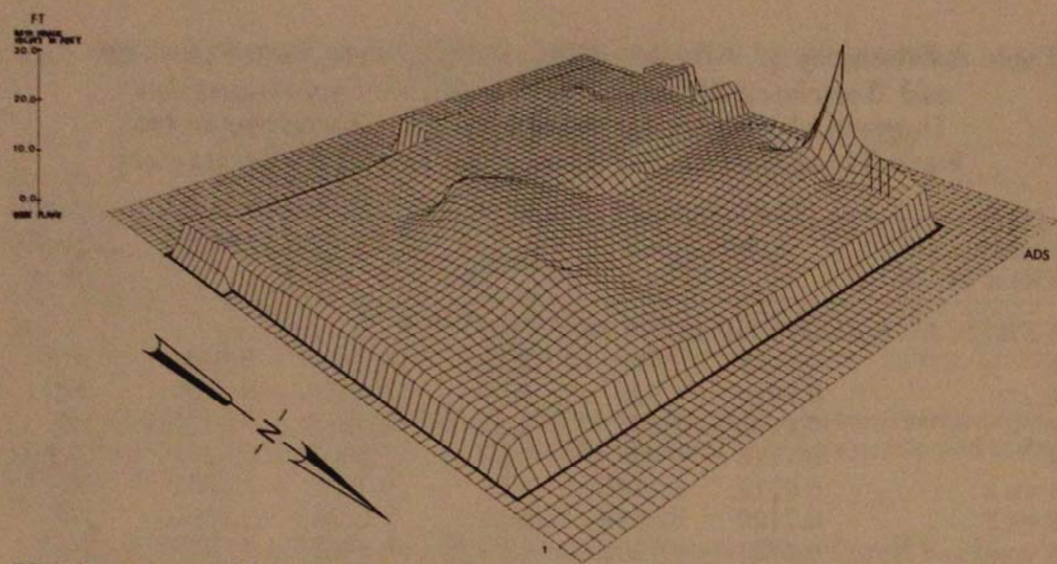
Discussion

As evident from Figures 2 through 5, and the statistical information displayed in Tables 2 through 4, significant and predictive trends exist for vertical height of mine opening, mine roof span in or adjacent to fall area, and height to second break horizon of roof strata. However, no trends were found to be statistically significant for maximum mine roof height, above the roof edge, and third horizon of roof strata.

Table 3. Summary of F-Ratios, Probability Levels, R^2 for Both the Full and Restricted Models, Degrees of Freedom-Numerator, Degrees of Freedom-Denominator, and Significance for Each Trend Surface for Associated Roof Fall Parameters

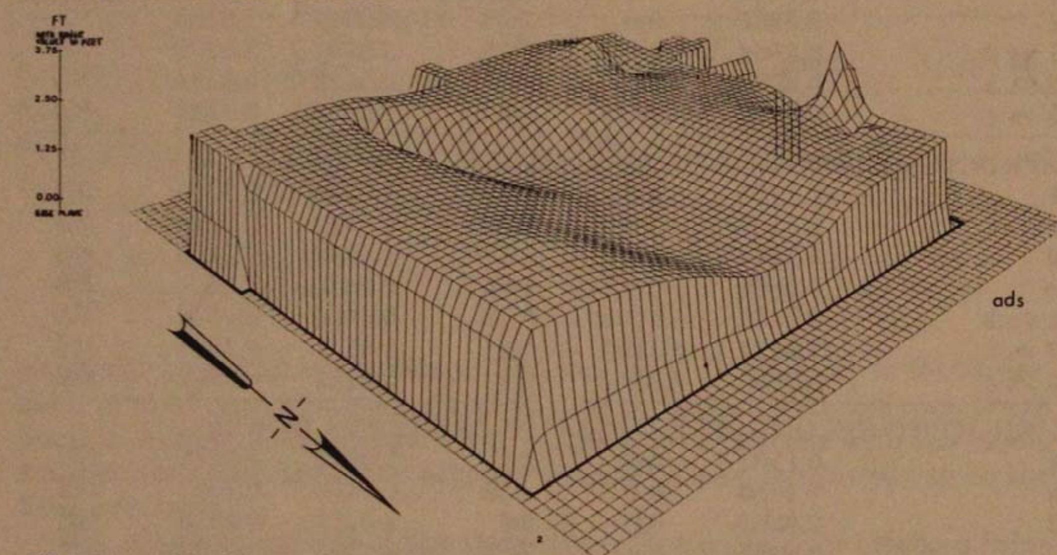
Order of Trend Surface	R_f^2	R_r^2	d_{f_n}/d_{f_d}	*F-Ratio*	*Prob.*	*Significance*
VERTICAL HEIGHT OF MINE OPENING (N = 21)						
1	0.5438	0.0	2/18	10.7266	0.0009	S**
2	0.6019	0.0	5/15	4.5351	0.0102	S*
3	0.7100	0.0	9/11	2.9931	0.0452	S*
4	0.7778	0.0	14/6	1.5003	0.3218	NS
1 vs 2	0.6019	0.5438	3/15	0.7297	0.5501	NS
2 vs 3	0.7100	0.6019	4/11	1.0261	0.4361	NS
3 vs 4	0.7778	0.7100	5/6	0.3660	0.8552	NS
MINE ROOF SPAN IN OR ADJACENT TO FALL AREA (N = 21)						
1	0.3499	0.0	2/18	4.8439	0.0207	S*
2	0.5864	0.0	5/15	4.2539	0.0131	S*
3	0.6849	0.0	9/11	2.6570	0.0647	NS
4	0.8850	0.0	14/6	3.2995	0.0750	NS
1 vs 2	0.5864	0.3499	3/15	2.8597	0.0720	NS
2 vs 3	0.6849	0.5864	4/11	0.8598	0.5174	NS
3 vs 4	0.8850	0.6849	5/6	2.0889	0.1980	NS
STRUCTURE CONTOUR OF MAXIMUM MINE ROOF HEIGHT (N = 21)						
1	0.1769	0.0	2/18	1.9338	0.1735	NS
2	0.3102	0.0	5/15	1.3492	0.2975	NS
3	0.5574	0.0	9/11	1.5393	0.2465	NS
4	0.6898	0.0	14/6	0.9530	0.5641	NS
1 vs 2	0.3102	0.1769	3/15	0.9666	0.4342	NS
2 vs 3	0.5574	0.3102	4/11	1.5359	0.2588	NS
3 vs 4	0.6898	0.5574	5/6	0.5121	0.7602	NS
HEIGHT TO SECOND HORIZON OF ROOF STRATA (N = 19)						
1	0.1204	0.0	2/16	1.0955	0.3582	NS
2	0.1640	0.0	5/13	0.5102	0.7639	NS
3	0.6399	0.0	9/9	1.7774	0.2023	NS
4	0.9804	0.0	14/4	14.2723	0.0100	S**
1 vs 2	0.1640	0.1204	3/15	0.2260	0.8767	NS
2 vs 3	0.6399	0.1640	4/9	2.9740	0.0804	NS
3 vs 4	0.9804	0.6399	5/4	13.8767	0.0123	S**
HEIGHT TO THIRD HORIZON OF ROOF STRATA (N = 10)						
1	0.0455	0.0	2/7	0.1669	0.8496	NS
2	0.3769	0.0	5/4	0.4840	0.7769	NS
1 vs 2	0.3769	0.0455	3/4	0.7093	0.5950	NS

NOTE: The symbols * denote statistical significance at 0.05 level, ** denote statistical significance at 0.01 level, both for a two-tailed, nondirectional test.



Height to second horizon of roof strata

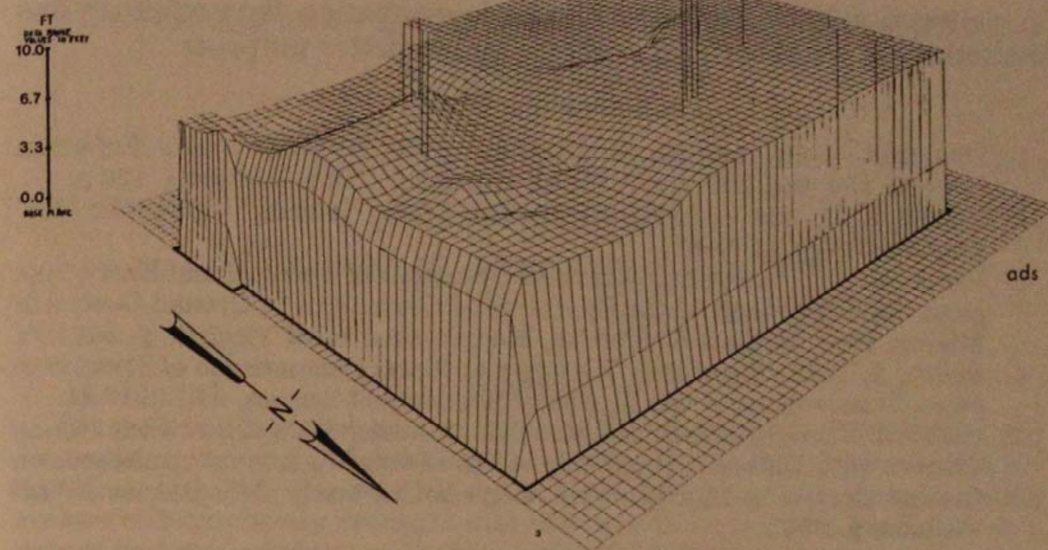
FIGURE 2. Three-dimensional model displaying spatial distribution of vertical height of mine opening from roof edge for the present mine layout, as viewed from the northeast direction.



Height to third horizon of roof strata

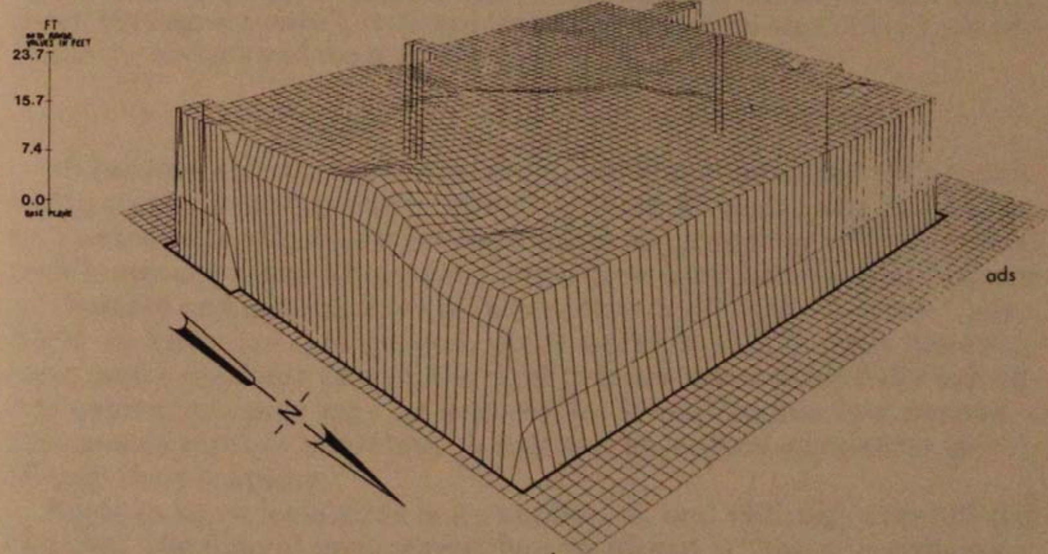
FIGURE 3. Three-dimensional model displaying spatial distribution of mine roof span in or adjacent to fall area for the present mine layout, as viewed from the northeast direction.

The major benefit of modeling research is to be able to visualize the actual distributions of important parameters associated with roof falls. Examples illustrated in this research allow the user to portray selected distributions of parameters in order to take preventative measures in the future to avoid potentially problematic areas. The use of plotting statistical as well as actual contour surfaces, allows the investigator a chance to actually visualize what the surface looks like and the residuals



Vertical height of mine opening (roof edge)

FIGURE 4. Three-dimensional model displaying spatial distribution of height to second rock break horizon, from the roof edge, for the present mine layout, as viewed from the northeast direction.



Mine roof span in or adjacent to fall area

FIGURE 5. Three-dimensional model displaying spatial distribution of height to third rock break horizon, from the roof edge, for the present mine layout, as viewed from the northeast direction.

or errors in prediction and their magnitudes. This process can bring in the investigator's "common sense" and geological and engineering judgment into play to determine the best fit. With the increasing use and availability of appropriate software and hardware, computer modeling should be used in conjunction with statistical models in estimating the usefulness and limitations of trend-surfaces analyses for predictive purposes.

Literature Cited

1. Dougenik, J. A., and D. E. Sheehan. 1979. SYMAP User's Reference Manual. Harvard University Press, Cambridge, Massachusetts, 170 p.
2. Ellison, R. D., and V. A. Scovazzo. 1981. Profit Planning Begins with Mapping. Coal Age, 81:68-81.
3. Hutchinson, T. L. 1981. Design and Operation of Powered and Entry Supports. In Proceedings of the First Annual Conference on Ground Control in Mining. West Virginia University, Morgantown, West Virginia, p. 201-208.
4. Smith, A. 1982. Hypothesis Testing and Model Comparisons of Trend Surfaces. Transactions of the Kentucky Academy of Science, 44(1-2):17-21.
5. Wells, B. T., and B. N. Whittaker. 1981. Stability Behavior of Coal Mining Tunnels with Different Supports. In Proceedings of Annual Conference on Ground Control in Mining. West Virginia University, Morgantown, West Virginia, p. 67-75.

The Right to Know About Chemical Hazards in West Virginia

Leo Uzych, J.D., M.P.H.
103 Canterbury Drive
Wallingford, Pennsylvania 19086

Abstract

The presence of hazardous substances in the workplace and community is a severe, and growing, public health problem affecting West Virginia, and the nation in general. It is therefore important for legislators to enact laws granting workers and community residents with the right to know about hazardous substances in their workplaces and communities. West Virginia currently has a community right to know law as well as a hazardous substance posting law affecting the workplace. Right to know legislation is a complicated and evolving area. The federal government has also promulgated a "hazard communication," which grants limited right to know protection to workers in manufacturing industries. The scientific community in West Virginia should become knowledgeable about right to know legal developments, and actively consider measures which may increase the degree to which state and federal legislation grants right to know protection to workers and the general public.

Hazardous substances in the workplace and community are an escalating public health problem affecting West Virginia, and the nation. One potentially effective legal mechanism for grappling with the public health menace posed by possibly hazardous substances in the nation's workplaces and communities is the enactment of "right to know" laws. Right to know laws, in general, grant workers, and in some instances community residents as well, the right to know about potentially hazardous substances they may be exposed to. West Virginia has enacted a community right to know law, as well as a hazardous substances law affecting the workplace.[1-2]

Right to know legislation is a complicated, and evolving, area of legal concern. The federal government has developed a "hazard communication."[3] This communication, published in the *Federal Register* in November, 1983, requires chemical manufacturers and importers to assess chemical hazards. The federal communication has been challenged, on various grounds, in federal court. The ultimate effect of the federal communication on right to know laws in West Virginia, and other states, is presently uncertain.

The United States is an increasingly chemically-polluted society. The number of chemical compounds and products found in the nation is over 10 million.[4] This number grows by 2 to 3 thousand names each year. Hazardous substances are found frequently in the industrial workplace in a variety of enterprises, including public safety, manufacturing, agriculture, construction, transportation, health care, and numerous other industries and services. Industry uses an estimated 63,000 commercial chemicals to create products ranging from pesticides and paints to plastics and pharmaceuticals.[5] The National Institute for Occupational Safety and Health ("NIOSH"), in 1972, conducted a National Occupational Hazards Survey ("NOHS"). According to the NOHS data, about 25 million American workers are potentially exposed to 1 or more of the nearly 8,000 hazards identified by NIOSH.[6]

Exposure to potentially harmful substances also greatly affects the general public. An estimated more than 80% of the United States population have measurable pesticide residues in their bodies.[7] About 90% of Michigan residents, or over 8 million people, consumed food contaminated with polybrominated biphenyl, when a flame retardant was mixed accidentally with livestock feed. Overall, it is estimated that as many as 40 to 50 million Americans may have been exposed at some point to 1 or more of the hazardous chemicals regulated by the federal Occupational Safety and Health Administration ("OSHA").[6]

It is difficult to precisely determine the extent of the public health danger presented by the presence of potentially hazardous substances in the nation's workplaces and communities. One major problem is a paucity of toxicity data. An estimated 6,000 facilities make possibly hazardous chemicals in the country.[8] There are more than 5 million chemical derivatives, and 53,500 are inventoried or regulated by the United States Environmental Protection Agency as potentially hazardous.[9] However, toxicity data are not available on more than 80% of the agents. Of the literally tens of thousands of commercially important chemicals, only a few have been subjected to extensive toxicity testing. According to a study by a committee of the National Research Council of available toxicity data, complete health hazard assessments are possible for only about 10% of pesticides and 18% of drugs.[10] Sufficient data are not available to conduct even a partial health hazard assessment for about 89% of chemicals in commerce, 84% of cosmetics, and 81% of food additives.

In some instances, there may be a latency period of months, or even years, between the time of initial exposure to a toxic agent and the onset of distinct clinical symptoms. Incomplete industrial records may be a problem. Based on a survey conducted by a United States Senate Committee, many of the 53 largest chemical companies claim that they do not have records of where they dumped their wastes prior to 1968.[7]

Although it may be difficult to precisely determine the scope of the problem, selected, available data suggests that the exposure of workers as well as the general public to hazardous substances may be associated with substantial health problems. Data on occupational illnesses resulting from occupational exposure have been compiled by the Bureau of Labor Statistics ("BLS").[6] BLS reported approximately 162,000 new cases of occupational illness in 1977, and 143,500 in 1978. The figures do not include the number of workers totally disabled from occupational illness associated with chemical exposure who have left the workforce. An analysis of the data, published in the *Federal Register*, reportedly shows that 57.9% of occupational illnesses in 1977, and 60.5% in 1978, fall into categories of illnesses (not including malignant and benign tumors) most likely to be related to chemical exposure.

The United States Public Health Service estimates that up to 390,000 workers contract work-related diseases each year.[11] An estimated between 4 and 20% of cancer cases may be associated with exposure to occupational carcinogens. Job-related diseases may also cause an estimated 100,000 non-accidental deaths yearly. According to a draft report prepared for the Environmental Protection Agency, over the past five years nearly 7000 accidents involving toxic chemicals have killed 139 people and injured 1478.[12] In addition, 217,457 people had to be evacuated. The data reported to the Environmental Protection Agency further shows that, in the past five years, 420 million pounds of toxic chemicals were released in accidents, mostly in chemical plants but also in other businesses and in transportation.

Hazardous material spills during transport may be a major source of public health problems. Each day, an estimated 180,000 chemical shipments make their way across the nation, carrying everything from nail polish to nuclear weapons.[8] During the decade 1971 to 1980, 111,293 incidents of hazardous material spills during transport were reported to the United States Department of Transportation.[13] The spills resulted in 248 deaths and 6873 injuries. The chemical transportation emergency response center ("CHEMTREC"), of the Chemical Manufacturers Association, receives about 150 calls every weekday concerning chemical spills; some 15 to 20 are generally considered as genuine emergency calls by the response center.[14]

Hazardous wastes may also be a major source of public health problems. The amount of hazardous wastes generated each year in the country is estimated at between 150 and 275 million metric tons.[15] A study has reportedly found that in areas of New Jersey where toxic waste dumps were located cancer death rates were as much as 50% above average.[15] Of the 30,000 waste disposal sites in the nation, it is estimated that there are between 1,000 and 2,000 sites which may pose serious health hazards to communities.[11]

Health problems associated with exposure to hazardous substances are an international problem. An estimated 100,000 persons were exposed to gas leaking from a Union Carbide plant in Bhopal, India.[16] It is believed that at least 2,500 persons died as the result of the leaking of methyl isocyanate gas from the Union Carbide plant. In view of the extensive use of potentially hazardous substances in the United States, it is possible that a similar-type disaster may occur in our country.

The leaking of possibly harmful substances has specifically affected West Virginia. In August, 1985, toxic gas leaked from a Union Carbide chemical facility in Institute, West Virginia.[17-20] About 135 people, both inside and outside the plant, were subsequently treated for eye, throat and lung irritation. Questions were raised about the toxicity of the released chemicals, methylene chloride and aldicarb oxime. A few days later, 1,000 gallons of a mixture of chemicals being processed into hydraulic brake fluid leaked at Union Carbide's nearby South Charleston works.

Workers and community residents may often be in the best position to discover or suspect exposure to potentially harmful chemical and physical agents and possible associated health problems, provided that they are aware of the identity of the pertinent substances as well as potential associated health hazards. Prompt, complete awareness of the nature of possibly toxic exposures may help affected persons obtain timely, adequate medical care, and further assist, in appropriate instances, with the instituting of legal remedies provided by pertinent federal and state laws.[21] Knowledge of possible toxic exposures may also assist affected persons in making informed decisions about their choice of residence or employment in a particular place. It is therefore the author's opinion that industry, government, and other potential sources of hazardous substances, should be legally obligated to provide information about potentially dangerous exposures in terms that are plainly understandable to lay persons.[7]

Many state legislatures have, in fact, recently enacted laws granting right to know protection to workers. Florida, California, Illinois, Rhode Island, Delaware, Minnesota, and Maryland are selected states which have promulgated laws extending right to know protection to workers.[21] In some instances, laws have been passed which further extend right to know protection to community residents. The Iowa Hazardous Chemicals Risks Right to Know Act states in part that the public has a right to be informed about the presence of hazarous chemicals in the community and the possible health and environmental hazards that the chemicals pose.[22] The Pennsylvania Worker and Community Right to Know Act recognizes that employees, their families, and the general public have a right to know the identity of chemicals they may be exposed to, potential health hazards that exist, and the symptoms that may be experienced because of exposure.[23] West Virginia is one of the states which have enacted right to know laws granting protection to workers as well as community residents.

In April, 1985, the West Virginia Legislature passed Enrolled Committee Substitute for Senate Bill No. 338, creating the "Community Right to Know Act."[1]

The legislative findings of the Community Right to Know Act state in part that the health and safety of persons living in the state may be improved by providing access to information concerning hazardous substances they may be exposed to in their daily lives. The findings further recognize that individuals have a basic right to the information provided by the Community Right to Know Act, including the risks presented by hazardous substances, thereby allowing them to make reasoned decisions and to take informed action concerning their living conditions. The Legislature thus declared that it is the intent and purpose of the Community Right to Know Act to establish a program for the disclosure of information about hazardous substances in and near the community, and to provide a procedure by which state residents may obtain access to such information.

Several communication mechanisms are used by the Community Right to Know Act. One of them is the creation of a list of hazardous substances. The law provides that the director of the state department of health shall develop a list of hazardous substances. The director shall provide the list, and the definition of a physical hazard, to any employer who may request it. "Physical hazard" is defined in the law as meaning a chemical for which there is scientifically valid evidence that it is a combustible liquid, a compressed gas, explosive, flammable, an organic peroxide, an oxidizer, pyrophoric, unstable (reactive), or water reactive.

A legislative rule establishes a list of hazardous substances, as required by the Community Right to Know Act.[24] Legislative Rule 16-31, Series I, 1985 provides in part that the director of health has developed a comprehensive list of the names of hazardous substances posing a health hazard that contains all the substances listed in the 3 publications defined in section 3.1 of the rule. Section 3.1 defines "hazardous substance" as meaning an element, chemical compound or mixture of elements and/or compounds which is a physical hazard as defined in the rule or is listed by: (1) the federal Occupational Safety and Health Administration in the Code of Federal Regulations; or by (2) the American Conference of Governmental Industrial Hygienists in "Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment;" or by (3) the National Toxicology Program in "Annual Report on Carcinogens."[24] The list of hazardous substances is published in section 5 of the legislative rule.

The Community Right to Know Act further provides that any state resident may request from the director a copy of any hazardous substance fact sheet and other information submitted by an employer for any facility. "Hazardous substance fact sheet" is defined in the law as meaning any document containing the information described in section 5, subsection (a)(1) through subsection (a)(8) of the Community Right to Know Act. Subsection a of Section 5 of the Act states that any employer who normally stores any hazardous substances in quantities greater than 55 gallons or 500 pounds shall provide to the director, the county sheriff of the county, and to the fire chief of the local fire department most proximate to the facility at which such substances are stored certain information specified in the law. The information includes the chemical name or common name used on the material safety data sheet and/or container label; physical and major chemical characteristics of the pertinent hazardous substances; the physical hazards of the hazardous substances; primary routes of entry; any generally applicable precautions for safe handling and use; emergency and first-aid procedures; and the health hazards of the pertinent substances.

"Employer," as used in the law, means a person engaged in a business in the state having a standard industrial classification, as designated by the standard industrial classiciation manual prepared by the federal office of management and budget, within major group members 20 through 39, inclusive. A guide prepared for the Community Right to Know Act explains that manufacturing industries are defined using the federal Office of Management and Budget's Standard Industrial Classification (SIC) Codes. All industries falling within SIC codes 20 through 39 are manufacturing industries.[25]

The Community Right to Know Act further contains special provisions pertaining to proprietary information. "Proprietary information" is defined in the law as meaning any formula, pattern, device, or compilation of information which is used in an employer's business, and which gives the employer an opportunity to obtain an advantage over competitors who do not know or use it. In submitting the information required by the law pertaining to the hazardous substance fact sheet, an employer may withhold the specific chemical identity, including the quantity, the chemical name, and other specific identification of a hazardous substance, on the grounds that such information is proprietary information. However, the law indicates that certain conditions must be met. The conditions are: other information is submitted which describes the properties and effects of the pertinent hazardous substance; and the employer specifically indicates the type of information that is being withheld as proprietary information.

West Virginia has also enacted a right to know law pertaining to the posting of warning notices in work areas. Chapter 21, Article 3, Section 18 of the West Virginia Code states that it is the policy of the state to require employers to disclose to employees the hazards of exposure in the workplace to hazardous substances.[2] For this purpose, the commissioner of labor shall establish a list of chemical substances and materials which have been determined or are suspected to be hazardous to the health of employees who may be exposed to them in the course of employment. The commissioner shall limit the list to no more than 600 substances, selected from lists included in 29 Code of Federal Regulations 1910.1000, Subpart Z, which the commissioner elects to include because of either frequency of use in the state, frequency of exposure or over exposure of workers in the state, the seriousness of the effects of such exposure, or other reasons which the commissioner determines to be sufficient.

In the author's opinion, limiting the list to no more than 600 substances may adversely affect the potential efficacy of the law. The range of chemicals covered by a right to know law is a major factor associated with its potential effectiveness. The number of regulated substances covered by right to know laws in various states ranges from 300 to nearly 30,000.[26]

The commissioner of labor is required by law to publish and update, at least annually, the list of substances, and to include for each listed substance any standard levels of safe exposure published by the federal secretary of labor in the *Federal Register*.

Chapter 21, Article 3, Section 18 of the West Virginia Code further contains requirements pertaining to the posting of warning notices. Any employer of 10 or more employees using or producing any substance on the list of chemical substances shall conspicuously post a warning notice in the work area where the pertinent substance is used. The notice shall include the name of the hazardous substance and common symptoms of overexposure.

In the author's opinion, limiting the posting requirement to employers of 10 or more employees may also adversely affect the law's efficacy, because the range of employers and employees covered is another important factor affecting the potential effectiveness of a right to know law. The law further states that the provisions of Section 18 shall not apply to any coal mine, coal mining or coal processing plant, and any agricultural or horticultural activity.

Again in the author's opinion, possible future debates involving right to know issues should closely consider labeling requirements. It is the author's view that all containers of hazardous chemicals should be labelled with information including, at the minimum, the chemical name or common name. The Pennsylvania Worker and Community Right to Know Act, for instance, provides that the employer shall ensure that each container of a hazardous substance is labeled with the common name or chemical name, a hazard warning, and the name, address, and telephone number of the substance's manufacturer.[23]

The availability of information concerning hazardous substances may have limited practical value if affected persons lack the requisite training and education to take full advantage of the available information. It is therefore the author's view that a comprehensive state right to know law must include a training and education program for persons potentially exposed to hazardous substances. The Rhode Island Hazardous Substances Right to Know Act, for example, provides that each employer must offer employee training and education programs before the employee's initial assignment.[27] The training must include information about the nature of the hazards, appropriate work practices, protective measures, and emergency procedures. Additional instruction must be provided whenever the employee may be routinely exposed to additional hazardous substances or if the potential for exposure is increased.

In November, 1983, a "hazard communication" was published in the *Federal Register.*[3] The federal communication requires chemical manufacturers and importers to assess the hazards of chemicals which they produce or import. All employers having workplaces in the manufacturing division must provide information to their employees about hazardous chemicals by means of hazard communication programs, including labels, material safety data sheets, training, and access to written records.

The federal hazard communication, in the author's judgment, does an inadequate job of protecting the public health. The communication is limited specifically to providing protection to workers in manufacturing. In 1978, employees in manufacturing accounted for less than 30% of total employment.[6] OSHA's estimate is that, in 1981, only 54% of chemically-related occupational illnesses occurred in the manufacturing sector.[11] The federal communication covers an estimated 14 million workers in 300,000 manufacturing establishments.[28] However, an estimated 60 million workers are left unprotected.[29]

In addition to the narrow range of workers covered, the federal communication explicitly covers only about 600 substances.[11] In the author's view, a federal right to know law should cover all compounds regulated by OSHA; all compounds which may be carcinogenic, mutagenic, or teratogenic, as defined by the United States Department of Health and Human Services' Annual List of Carcinogens, the United States Environmental Protection Agency, or the International Agency for Research on Cancer; pesticides regulated by the Environmental Protection Agency; and radioactive materials regulated by the Nuclear Regulatory Commission.[11]

The federal hazard communication has been challenged in federal court. A coalition of groups, including the Public Citizen Health Research Group, filed a petition for review of the hazard communication in November, 1983, in the United States Court of Appeals for the Third Circuit ("Third Circuit"). The petition alleges in part that the federal communication is arbitrary and capricious because it fails to provide workers with adequate information relating to the hazards they may be exposed to in the workplace. Petitions for review of the federal communication were also filed by several states, including Massachusetts, Illinois, and New York. The later state petitions were subsequently transferred to the Third Circuit and consolidated with the Public Citizen petition.

In a decision dated May 24, 1985, the Third Circuit ruled in part that the federal hazard communication preempt state hazard disclosure laws with respect to disclosure to employees in the manufacturing sector.[30] The Court did not rule specifically with respect to the question of whether the federal communication may further preempt state hazard disclosure provisions affecting workers outside the manufacturing sector. However, the Court did note that there is evidence that workers in sectors other than manufacturing are exposed to the hazards associated with the use of toxic materials. The federal Secretary of Labor ("Secretary") has given no statement of reasons why it would not be feasible to require that those workers be given the same training and material safety data sheets as must be given to workers in the manufacturing sector. The Coûrt's opinion states that the Secretary will therefore be directed by the court to reconsider the application of the federal hazard communication to employees in other, or non-manufacturing, sectors, and to order its application to other sectors unless the Secretary can state reasons why such application would not be feasible.

In some states, including West Virginia, right to know laws have been enacted which specifically extend right to know protection to community residents. It is the author's view that state right to know provisions which are intended specifically to grant right to know protection to community residents are outside the preemptive power of OSHA. OSHA's mandate under the Occupational Safety and Health Act of 1970 extends only to assuring so far as possible every working man and woman in the nation safe and healthful working conditions.[31] Right to know provisions which are explicitly community oriented should therefore be outside the jurisdiction and preemptive power of OSHA.

The West Virginia Community Right to Know Act contains a provision relating to federal legislation and the right to know. The provision states in part that it is the intention of the Legislature that upon passage of federal legislation which would assure access by citizens of the state to information "substantially similar" to that which they could obtain under the Community Right to Know Act, the Act shall be subject to expiration and therefore have no further effect.[1] The law further contains a "severability" clause.

The Third Circuit opinion also addresses issues relating to "trade secrets," or information possibly conferring a competitive advantage. The Court ruled that the federal government's definition of trade secrets is invalid. The opinion states that the Secretary will be directed to reconsider a trade secret definition, which will not include chemical identity information that is readily discoverable through reverse engineering. The Court also ruled that the trade secret access rule is invalid insofar as it limits access to trade secret information to health professionals. The Secretary will be directed to adopt a rule permitting access by employees to trade secret information.

Right to know legislation raises issues of major social importance which are also closely associated with science-related policy development. It is therefore virtually important for members of the scientific community in West Virginia, and elsewhere, to become knowledgeable about, and involved with, continuing legal developments in the right to know area. Close attention should be directed towards measures which may possibly increase the degree to which workers and community residents in West Virginia are protected from hazardous substances, and potential associated health harms. Further attention should be directed towards measures which may increase the effectiveness of the federal hazard communication, particularly including an extension of right to know protection to workers not covered by the present communication.

References

1. Enrolled Committee Substitute for Senate Bill No. 338 ("Community Right to Know Act").
2. Chapter 21, Article 3, Section 18, of the West Virginia Code.
3. 48 Fed. Reg. 53280 et seq. (November 25, 1983).
4. Stroud R. Firefighters face unknowns in right-to-know protection. Occupational Health & Safety 1985; 54(6):18.
5. Nelkin, D., and M. Brown. Knowing about workplace risks: workers speak out about the safety of their jobs. Science for the People 1984; 16(1):17.
6. 47 Fed. Reg. 12092 et seq. (March 19, 1982).
7. Compensation for and prevention of community environmental disease (Policy Statement, adopted by the Governing Council, of the American Public Health Association, November 14, 1984). AJPH 1985; 75(3):302.
8. Aydelotte C. Bhopal tragedy focuses on changes in chemical industry. Occupational Health & Safety 1985; 54(3):33.
9. Yoder E. Hazardous materials response system. Topics in Emergency Medicine 1985; 7(1):1.
10. Anonymous. Chemicals largely untested (spectrum). Environment 1984; 26(3):21.
11. Increasing worker and community awareness of toxic hazards in the workplace (Policy Statement, adopted by the Governing Council, of the American Public Health Association, November 14, 1984). AJPH 1985; 75(3):305.

12. Anonymous. Statistics on toxic chemical accidents compiled. Chemical and Engineering News 1985; 63(41):7.
13. Wanke, L. A. Toxic chemical spills. Topics in Emergency Medicine 1985; 7(1):9.
14. Anonymous. Rash of chemical spills occurs on single day. Chemical and Engineering News 1985; 63(33):6.
15. Regenstein L. The toxics boomerang. Environment 1983; 25(10):36.
16. Marwick C. Bhopal tragedy's repercussions may reach American physicians. JAMA 1985;253(14):2001.
17. Anonymous. Union Carbide: new accidents revive safety issues. Chemical and Engineering News 1985; 63(33):4.
18. Anonymous. Carbide sued over Institute chemical leak. Chemical and Engineering News 1985; 63(34):5.
19. Anonymous. Carbide explains one of the Institute leaks. Chemical Week 1985; 137(9):5.
20. Brooks, K. Slow action on a Carbide leak. Chemical Week 1985; 137(8):7.
21. Uzych, L. The need for chemical disclosure legislation. Nebraska Medical Journal 1985; 70(6):193.
22. Chapter 455D, Senate File 2248, Iowa "Hazardous Chemicals Risks Right to Know Act."
23. Act 159 of 1984, Pennsylvania Worker and Community Right to Know Act.
24. West Virginia Director of Health Legislative Rules, Chapter 16-31, Series I, 1985 (July 10, 1985).
25. Guide to the West Virginia Community Right to Know Act (West Virginia Department of Health).
26. Himmelstein, J. S., and H. Frumkin. The right to know about toxic exposures. N. Engl. J. Med. 1985; 312(11):687.
27. Uzych L. Disclosure of information concerning chemical hazards in Rhode Island. Rhode Island Medical Journal 1985; 68(8):367.
28. McElveen, J. C. Despite pre-emption threat local right-to-know laws increase. Occupational Health and Safety 1985; 54(1):20.
29. Anonymous. OSHA rules for wrong reason. Philadelphia Inquirer, November 26, 1983:8A (col. 1).
30. United Steelworkers of America v. Auchter, No. 83-3554 (3d Cir. May 24, 1985).
31. Public Law 91-596 (Occupational Safety and Health Act of 1970).

Minutes of the Annual Business Meeting
West Virginia Academy of Science
59th Annual Meeting
Hyma Auditorium
West Virginia Wesleyan College
Buckhannon, West Virginia

April 7, 1984

Dr. K. B. Welliver, Vice President, West Virginia Wesleyan College, welcomed the West Virginia Academy of Science as well as the Junior Academy to the campus.

Dr. B. Das Sarma, President of WVAS, called the business meeting to order, and kept minutes since Dr. John Chisler, recording secretary, could not attend.

The minutes of the April 16, 1983, business meeting were distributed and approved. Copies of the Treasurer's report were distributed, and approved.

The nominating committee, consisting of Drs. Das Sarma, Pauley, and Hanrahan, nominated Dr. William C. Kuryla, Corporate Manager, Applied Toxicology Services, Union Carbide Corporation, as President-Elect. There were no other nominations from the floor and Dr. Kuryla was elected unanimously.

An invitation to hold the 1985 Annual Meeting extended by Fairmont State College was accepted.

Dr. Ed Keller gave the status of the Proceedings of the Academy. The cost of printing is going up considerably and it was considered that some actions be taken to maintain the financial health of the Academy.

Dr. Blaydes made a motion to increase library charges for the Proceedings from $15.00 to $20.00/year, starting with Volume 57. It was seconded by Dr. Pauley, the motion carried. Dr. Krabacher proposed that $2.00 be charged the authors for each abstract published. This is to start with Volume 58. Dr. Violet Phillips seconded the motion, and the motion passed.

Dr. Pauley made a motion to include the past President, Editor, and the Annual Meeting Chairperson in the Executive Committee. The motion was seconded by Dr. Blaydes. Dr. Keller inquired whether all voting members of the Executive Committee needed to be elected officers. It was assumed that the motion is in keeping with the constitution of WVAS. The motion passed.

The meeting appreciated the past services of D. Russell Wheeler and Dr. Leland Taylor who passed away. Necrology for them will be included in the Proceedings.

The Business Meeting adjourned at 10:05 a.m.

B. Das Sarma
For John A. Chisler
Secretary

WEST VIRGINIA ACADEMY OF SCIENCE
ANNUAL TREASURER'S REPORT
FISCAL YEAR 1983-1984

April 1984
WVAS Annual Meeting
West Virginia Wesleyan College
Buckhannon, West Virginia

January 1, 1983 to December 31, 1983

CASH RECEIPTS

Balance on hand January 1, 1983		$ 8,813.58
Dues	$1,695.00	
Institutional Memberships	1,000.00	
Proceedings	1,010.00	
Contributions (Talent Search)	81.50	
Annual Meeting	443.00	
Page Charges	314.00	
Interest on Savings	444.48	
Advertisements	390.00	
TOTAL RECEIPTS FOR YEAR	$5,377.98	
TOTAL RECEIPTS & BALANCE ON HAND		$14,191.56

CASH DISBURSEMENTS

Printing (McClain)	$4,530.73	
Printing (Printech)	171.25	
Contributions (Jr. Acad. Sci. $900.00 Hurlbutt Mem. Fund $100.00)	1,000.00	
Annual Meeting	529.30	
Postage	103.74	
National Assoc. of Academy of Science (dues)	30.00	
Secretarial Help	26.80	
Miscellaneous	76.70	
Talent Search	75.00	
TOTAL DISBURSEMENTS	$6,543.52	
CASH ON HAND December 31, 1983		$ 7,648.04
(Savings—$922.01)		
(Checking—$2,726.03)		
(Certificates of Deposit—$4,000.00)		

Respectfully submitted,

Roy B. Clarkson

Roy B. Clarkson, Treasurer, WVAS

We the undersigned members of the audit committee, have examined the records of the treasurer of the WVAS from January 1, 1983 to December 31, 1983, and find them to be correct.

E. C. Keller, Jr.
David Blaydes
Roland L. Guthrie