METHODS OF SOIL ANALYSIS

Part 1

Physical and Mineralogical Methods

Second Edition

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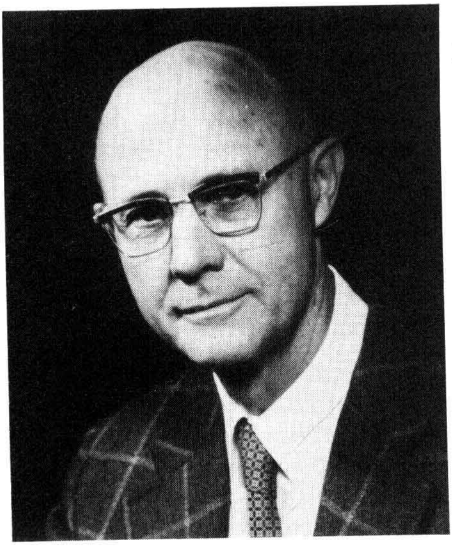

Charles A. Black

It is truly fitting that *Methods of Soil Analysis,* Part 1, Second Edition, be dedicated to Dr. Charles A. Black. Dr. Black was editor-in-chief of the 1965 *Methods of Soil Analysis,* Parts 1 and 2, one of the most successful and widely acclaimed of the Society's monograph series. His dedicated efforts were largely responsible for the overall high quality of the first edition of the monograph. It is also fitting to recognize Dr. Black for his contributions to research and teaching and for his current role as one of the chief spokespersons for agriculture.

Dr. Black was born 22 January 1916 in Lone Tree, Iowa. He received B.S. degrees in chemistry and soil science from Colorado State University in 1937, and the M.S. and Ph.D. degrees in soil fertility from Iowa State University in 1938 and 1942.

He began his professional career as a research fellow in the Department of Agronomy, Iowa State University in 1937, and in 1939 joined that faculty as instructor in soils. Except for service with the U.S. Navy during World War II, a visiting professorship at Cornell University in 1955–56, and a NSF Fellowship at UC-Davis in 1964–65, Dr. Black has remained at Iowa State. He retired as distinguished professor in 1979 to devote full time to his duties with the Council for Agricultural Science and Technology (CAST).

Dr. Black's research and teaching career has had a major influence on the discipline of soil science, particularly soil fertility and soil chemistry. He has contributed much to our knowledge of phosphate reactions in soils, uptake by plants, and interpretation of yield curves. He is author or co-author of approximately 100 research papers, has written two editions of a widely used textbook entitled *Soil-Plant Relationships,* and several editions of a laboratory manual on soil chemistry. He has also served as associate editor for the *SSSA Journal*; as consulting editor for *Soil Science,* and as editor of more than 100 publications issued by CAST. He has served the ASA and SSSA as a member of numerous committees, as SSSA president in 1961, and as ASA president in 1971. He has received numerous awards and honors, including the ASA Soil Science Award (1957), ASA Fellow (1962), Fellow of the American Institute of Chemists (1969), Honorary Member of SSSA (1975) and ASA (1981), AAAS Fellow (1976), the Henry A. Wallace Award from Iowa State University for Distinguished Service to Agriculture (1981), and the Bouyoucos Soil Science Distinguished Career Award, SSSA (1981).

Dr. Black's critical and forthright evaluation of research findings, coupled with a warm personality and a dry sense of humor, have made him a much sought-after counselor by students and colleagues. His graduate level soil-plant relationship courses at Iowa State were especially popular. Those privileged to learn under Dr. Black gained the type of knowledge and philosophy which has served them well in their varied careers.

Dr. Black's career took on a new dimension in 1970 when, largely under his direction, CAST was developed. He was the president of CAST in 1973 and then served as the executive vice-president of this innovative, independent association of agricultural science societies from 1973 through April 1985. Since May 1985 he has served as executive chairman of the board of directors of CAST.

He is providing invaluable service to the community of food and agricultural scientists through his dedicated efforts on the behalf of CAST. Through the Council, the scientific societies and the scientists they represent, can make an input into the development of national policies on food and agriculture by supplying scientific information to decision makers and opinion leaders.

FOREWORD

Characterization and, hence, our understanding of soils requires that they be precisely and reproducively analyzed or described. The parameters generated by such analyses are needed to generalize hypotheses for differences among soils as well as observations on the same soil under different circumstances of time and manipulation.

Mineralogical characteristics of soils simultaneously reflect the parent material as well as the processes which formed the soil from the geologic matrix. Knowing and understanding the mineralogical composition provides an insight into the behavior of soils under different temporal conditions and their usefulness or suitability for various purposes. To a great extent, the chemical properties of soils depend upon soil mineralogy.

The physical properties of soils, perhaps, more than the chemical properties, determine their adaptability to cultivation for food and fiber production—the most important use of soils on a densely populated planet. It is the physical properties which are most prominent in determining the adaptability of soils to other civilized activities including housing, communications, and recreation.

Great strides have been made in the conception of physical and mineralogical characteristics of soils and how they relate to each other and to chemical properties. These have been stimulated by and, in turn, have encouraged better methods of analysis. It is appropriate from time to time to record those analytical procedures that seem best to serve the scientific community in its understanding of soils.

The methods of analyses included in this volume provide a uniform set of procedures which can be used by the majority of scientists and engineers working with soil and, in that way, will improve their ability to communicate about their observations with each other. This volume also provides a launching point from which others might depart in an effort to refine methods and procedures or develop new ones. Given our rapidly changing understanding of soils and our ability to make new, different, and more precise measurements, it is certain that other volumes such as this will follow.

June 1986

JOHN PESEK, *president*
Soil Science Society of America

DALE M. MOSS, *president*
American Society of Agronomy

PREFACE

It has been more than 20 years since the first edition of *Methods of Soil Analysis, Part 1, Physical and Mineralogical Properties* was published under the able editorship of Dr. C. A. Black. The first edition was extremely well received. More than 13 000 copies have been sold, and sales have continued up to the present time at more than 500 copies per year.

Since the publication of the first edition there has been substantial progress in the development of improved physical and mineralogical measurements. The study of transport processes in soil in relation to environmental quality concerns has brought about an increased interest in the application of methods of physical measurement to field situations. More emphasis has been placed on the development of methods to cope with the inherent spatial variability of natural soils. In addition, techniques of measurement of physical and mineralogical properties of soils have generally been improved. Following a recommendation by the ASA Monographs Committee, publication of the second edition of the monograph was approved by the Executive Committee of ASA, and an editorial committee was appointed.

Major changes have been made in the subject coverage of Part 1, as compared to the first edition. The book consists of 50 chapters prepared by 71 authors and coauthors. Four chapters deal with statistical subject matter, including a new chapter on geostatistical methods applied to measurements in soils. Eight chapters focus on various mineralogical methods, and eight chapters describe methods for evaluation of the soil matrix and its structure. Methods for assessing the energy status of soil water, hydraulic conductivity and diffusivity of soils, intake rate, and water retention of soils are described in 16 chapters. There are five chapters on methods for measurement of thermal properties of soil, four chapters on methods for determining the concentration and flux of soil solutes, and five chapters on methods for study of the soil gas phase.

Members of the editorial committee who participated in the planning and development of the book are:

A. Klute, editor, Colorado State University, and USDA-ARS, Ft. Collins, CO
G. S. Campbell, Washington State University, Pullman, WA
R. D. Jackson, U. S. Water Conservation Laboratory, Tempe, AZ
M. M. Mortland, Michigan State University, East Lansing, MI
D. R. Nielsen, University of California, Davis, CA

To the many authors, who drew from their expertise to prepare descriptions of the many methods, I extend my thanks and appreciation. I also wish to express my appreciation to the members of the editorial committee, and to many other anonymous reviewers who provided their time and talents to help produce the monograph. Mr. R. C. Dinauer, and the ASA Headquarters staff are to be given special thanks for their diligence, and competence in handling the many mechanical details of production of the book.

This second edition of Part 1 is dedicated to Dr. C. A. Black in recognition of his efforts as editor of the first edition, and its success as a publication of the American Society of Agronomy. I and the other members of the editorial committee hope that the revised edition will be as successful, and that it will be found useful by those who need information on physical and mineralogical methods.

April 1986

A. KLUTE, *editor*
Agricultural Research Service, USDA, and
Colorado State University, Ft. Collins, CO

CONTRIBUTORS

Lajpat R. Ahuja	Soil Physicist, Water Quality and Watershed Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Durant, Oklahoma
William R. Allardice	Staff Research Associate, Department of Land, Air, and Water Resources, University of California, Davis, California
R. R. Allmaras	Soil Scientist, Agricultural Research Service, U.S. Department of Agriculture, St. Paul, Minnesota
A. Amoozegar	Assistant Professor, Soil Science Department, North Carolina State University, Raleigh, North Carolina
Duwayne M. Anderson	Associate Provost for Research, Texas A&M University, College Station, Texas
Isaac Barshad	Soil Chemist, Soil and Plant Biology Department, University of California, Berkeley, California
J. W. Bauder	Professor of Soil Science, Cooperative Extension, Montana State University, Bozeman, Montana
George R. Blake	Professor Emeritus of Soil Physics, Soil Science Department, University of Minnesota, St. Paul, Minnesota
Charles W. Boast	Associate Professor of Soil Physics, Department of Agronomy, University of Illinois, Urbana, Illinois
Herman Bouwer	Director, U.S. Water Conservation Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Phoenix, Arizona
J. M. Bradford	Soil Scientist, National Soil Erosion Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Purdue University, West Lafayette, Indiana
R. R. Bruce	Soil Scientist, Southern Piedmont Conservation Research Center, Agricultural Research Service, U.S. Department of Agriculture, Watkinsville, Georgia
G. D. Bubenzer	Professor, Department of Agricultural Engineering, University of Wisconsin, Madison, Wisconsin
J. G. Cady	Lecturer in Pedology, Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, Maryland
Lyle D. Calvin	Professor of Statistics, Department of Statistics, Oregon State University, Corvallis, Oregon
Gaylon S. Campbell	Professor of Soils, Department of Agronomy and Soils, Washington State University, Pullman, Washington
D. L. Carter	Supervisory Soil Scientist, Snake River Conservation Research Center, Agricultural Research Service, U.S. Department of Agriculture, Kimberly, Idaho
D. K. Cassel	Professor of Soil Science, Department of Soil Science, North Carolina State University, Raleigh, North Carolina

She-Kong Chong Associate Professor of Soil Physics and Hydrology, Plant and Soil Science Department, Southern Illinois University, Carbondale, Illinois. Formerly Associate Professor of Forest Hydrology, Department of Forestry, Southern Illinois University, Carbondale, Illinois

Arthur T. Corey Professor Emeritus, Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, Colorado

Robert E. Danielson Professor, Department of Agronomy, Colorado State University, Fort Collins, Colorado

C. Dirksen Senior Scientist, Department of Soil Science and Plant Nutrition, Agricultural University, Wageningen, The Netherlands

Joe B. Dixon Professor of Soil Mineralogy, Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas

W. J. Dixon Professor of Biomathematics, Department of Biomathematics, School of Medicine, University of California, Los Angeles, California

L. R. Drees Research Associate, Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas

H. Flühler Professor of Soil Physics, Swiss Federal Institute of Technology, Zurich, Switzerland

Marcel Fuchs Scientist, Agricultural Research Organization, Institute of Soils and Water, Bet Dagan, Israel

Walter H. Gardner Professor of Soils Emeritus, Department of Agronomy and Soils, Washington State University, Pullman, Washington

G. W. Gee Staff Scientist, Battelle Pacific Northwest Laboratories, Richland, Washington

Richard E. Green Professor of Soil Science, Department of Agronomy and Soil Science, University of Hawaii, Honolulu, Hawaii

S. C. Gupta Associate Professor of Soil Physics, Department of Soil Science, University of Minnesota, St. Paul, Minnesota

B. F. Hajek Professor, Agronomy and Soil Department, Auburn University, Auburn, Alabama

K. H. Hartge Professor of Soil Science, University of Hannover, Federal Republic of Germany

Marion L. Jackson The F. H. King Professor of Soil Science, Department of Soil Science, University of Wisconsin, Madison, Wisconsin

Ray D. Jackson Research Physicist, U.S. Water Conservation Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Phoenix, Arizona

W. Doral Kemper Director, Snake River Conservation Research Center, Agricultural Research Service, U.S. Department of Agriculture, Kimberly, Idaho

Oscar Kempthorne Professor of Statistics, Department of Statistics, Iowa State University, Ames, Iowa

Dennis C. Kincaid Agricultural Engineer, Snake River Conservation Research Center, Agricultural Research Service, U.S. Department of Agriculture, Kimberly, Idaho

A. Klute Soil Scientist and Professor, Agricultural Research Service, U.S. Department of Agriculture, and Agronomy Department, Colorado State University, Fort Collins, Colorado

George W. Kunze Professor Emeritus of Soil Mineralogy, Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas

Chin H. Lim Formerly Post-doctoral Fellow, Department of Soil Science, University of Wisconsin, Madison, Wisconsin. Now at Guthrie Research Chemara, Negri Sembilan, Malaysia

R. J. Luxmoore Soil and Plant Scientist, Oak Ridge National Laboratory, Oak Ridge, Tennessee

Murray B. McBride Associate Professor of Soil Chemistry, Department of Agronomy, Cornell University, Ithaca, New York

Max M. Mortland Professor, Department of Crop and Soil Sciences, Michigan State University, East Lansing, Michigan

Yechezkel Mualem Soil Scientist, Seagram Centre for Soil and Water Sciences, The Hebrew University of Jerusalem, Rehovot, Israel

Donald E. Myers Professor of Mathematics, Department of Mathematics, University of Arizona, Tucson, Arizona

D. R. Nielsen Professor, Department of Land, Air and Water Resources, University of California, Davis, California

J. D. Oster Extension Soil and Water Specialist, Department of Soil and Environmental Sciences, University of California, Riverside, California

A. J. Peck Chief Research Scientist, Division of Groundwater Research, CSIRO, Wembley, Western Australia. Formerly Senior Principal Research Scientist

Roger G. Petersen Professor of Statistics, Department of Statistics, Oregon State University, Corvallis, Oregon

Arthur E. Peterson Professor, Department of Soil Science, University of Wisconsin, Madison, Wisconsin

Claude J. Phene Supervisory Soil Scientist, Water Management Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Fresno, California

Stephen L. Rawlins Soil Physicist, National Program Staff, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland

Ronald C. Reeve Civil Engineer, Irrigation and Drainage, Agricultural Research Service, U.S. Department of Agriculture, Columbus, Ohio

J. D. Rhoades Supervisory Soil Scientist, U.S. Salinity Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Riverside, California

D. E. Rolston Professor of Soil Science, Department of Land, Air and Water Resources, University of California, Davis, California

Russell C. Rosenau Technician, Snake River Conservation Research Center, Agricultural Research Service, U.S. Department of Agriculture, Kimberly, Idaho

Charles B. Roth Professor of Soil Mineralogy/Chemistry, Department of Agronomy, Purdue University, West Lafayette, Indiana

Brij L. Sawhney Soil Chemist, The Connecticut Agricultural Experiment Station, New Haven, Connecticut

Lewis H. Stolzy Professor of Soil Physics, Department of Soil and Environmental Sciences, University of California, Riverside, California

P. Lorenz Sutherland Assistant Professor, Department of Agronomy, Southeast Colorado Research Center, Colorado State University, Lamar, Colorado

Kim H. Tan Professor of Agronomy, Department of Agronomy, University of Georgia, Athens, Georgia

Sterling A. Taylor Professor of Soil Physics, Department of Soils and Biometeorology, Utah State University, Logan, Utah. Deceased 8 June 1967

M. Th. van Genuchten Research Soil Scientist, U.S. Salinity Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Riverside, California

R. J. Wagenet Associate Professor, Department of Agronomy, Cornell University, Ithaca, New York

A. W. Warrick Professor, Department of Soil and Water Science, University of Arizona, Tucson, Arizona

Joe L. White Professor of Soil Mineralogy, Department of Agronomy, Purdue University, West Lafayette, Indiana

Lynn D. Whittig Professor of Soil Science, Department of Land, Air and Water Resources, University of California, Davis, California

P. J. Wierenga Professor of Soil Physics, Department of Crop and Soil Sciences, New Mexico State University, Las Cruces, New Mexico

L. P. Wilding Professor of Pedology, Soil and Crop Sciences Department, Texas A&M University, College Station, Texas

Lucian W. Zelazny Professor of Soil Mineralogy, Agronomy Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

Conversion Factors for SI and non-SI Units

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Unit	To convert Column 2 into Column 1 multiply by
	Length		
0.621	kilometer, km (10^3 m)	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
3.28	meter, m	foot, ft	0.304
1.0	micrometer, μm (10^{-6} m)	micron, μ	1.0
3.94×10^{-2}	millimeter, mm (10^{-3} m)	inch, in	25.4
10	nanometer, nm (10^{-9} m)	Angstrom, Å	0.1
	Area		
2.47	hectare, ha	acre	0.405
247	square kilometer, km^2 (10^3 m)^2	acre	4.05×10^{-3}
0.386	square kilometer, km^2 (10^3 m)^2	square mile, mi^2	2.590
2.47×10^{-4}	square meter, m^2	acre	4.05×10^3
10.76	square meter, m^2	square foot, ft^2	9.29×10^{-2}
1.55×10^{-3}	square millimeter, mm^2 (10^{-6} m)^2	square inch, in^2	645
	Volume		
6.10×10^4	cubic meter, m^3	cubic inch, in^3	1.64×10^{-5}
2.84×10^{-2}	liter, L (10^{-3} m^3)	bushel, bu	35.24
1.057	liter, L (10^{-3} m^3)	quart (liquid), qt	0.946
3.53×10^{-2}	liter, L (10^{-3} m^3)	cubic foot, ft^3	28.3
0.265	liter, L (10^{-3} m^3)	gallon	3.78
33.78	liter, L (10^{-3} m^3)	ounce (fluid), oz	2.96×10^{-2}
2.11	liter, L (10^{-3} m^3)	pint (fluid), pt	0.473
9.73×10^{-3}	meter^3, m^3	acre-inch	102.8
35.3	meter^3, m^3	cubic foot, ft^3	2.83×10^{-2}

continued on next page

Conversion Factors for SI and non-SI Units

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Unit	To convert Column 2 into Column 1 multiply by
	Mass		
2.20×10^{-3}	gram, g (10^{-3} kg)	pound, lb	454
3.52×10^{-2}	gram, g	ounce (avdp), oz	28.4
2.205	kilogram, kg	pound, lb	0.454
10^{-2}	kilogram, kg	quintal (metric), q	10^{2}
1.10×10^{-3}	kilogram, kg	ton (2000 lb), ton	907
1.102	megagram, Mg (tonne)	ton (U.S.), ton	0.907
	Yield and Rate		
0.893	kilogram per hectare, kg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12
7.77×10^{-2}	kilogram per cubic meter, kg m^{-3}	pound per bushel, lb bu^{-1}	12.87
1.49×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 60 lb	67.19
1.59×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 56 lb	62.71
1.86×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 48 lb	53.75
0.107	liter per hectare, L ha^{-1}	gallon per acre	9.35
893	megagram per hectare, Mg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
0.446	megagram per hectare, Mg ha^{-1}	ton (2000 lb) per acre, ton $acre^{-1}$	2.24
2.24	meter per second, m s^{-1}	mile per hour	0.447
	Specific Surface		
10	square meter per kilogram, m^2 kg^{-1}	square centimeter per gram, cm^2 g^{-1}	0.1
10^{3}	square meter per kilogram, m^2 kg^{-1}	square millimeter per gram, mm^2 g^{-1}	10^{-3}

Pressure			
9.90	megapascal, MPa (10^6 Pa)	atmosphere	0.101
10	megapascal, MPa (10^6 Pa)	bar	0.1
1.00	megagram per cubic meter, Mg m^{-3}	gram per cubic centimeter, g cm^{-3}	1.00
2.09×10^{-2}	pascal, Pa	pound per square foot, lb ft^{-2}	47.9
1.45×10^{-4}	pascal, Pa	pound per square inch, lb in^{-2}	6.90×10^3
Temperature			
1.00 (K − 273)	Kelvin, K	Celsius, °C	1.00 (°C + 273)
(9/5 °C) + 32	Celsius, °C	Fahrenheit, °F	5/9 (°F −32)
Energy, Work, Quantity of Heat			
9.52×10^{-4}	joule, J	British thermal unit, Btu	1.05×10^3
0.239	joule, J	calorie, cal	4.19
10^7	joule, J	erg	10^{-7}
0.735	joule, J	foot-pound	1.36
2.387×10^{-5}	joule per square meter, J m^{-2}	calorie per square centimeter (langley)	4.19×10^4
10^5	newton, N	dyne	10^{-5}
1.43×10^{-3}	watt per square meter, W m^{-2}	calorie per square centimeter minute (irradiance), cal cm^{-2} min^{-1}	698
Transpiration and Photosynthesis			
3.60×10^{-2}	milligram per square meter second, mg m^{-2} s^{-1}	gram per square decimeter hour, g dm^{-2} h^{-1}	27.8
5.56×10^{-3}	milligram (H_2O) per square meter second, mg m^{-2} s^{-1}	micromole (H_2O) per square centimeter second, μmol cm^{-2} s^{-1}	180
10^{-4}	milligram per square meter second, mg m^{-2} s^{-1}	milligram per square centimeter second, mg cm^{-2} s^{-1}	10^4
35.97	milligram per square meter second, mg m^{-2} s^{-1}	milligram per square decimeter hour, mg dm^{-2} h^{-1}	2.78×10^{-2}
Angle			
57.3	radian, rad	degrees (angle), °	1.75×10^{-2}

continued on next page

Conversion Factors for SI and non-SI Units

To convert Column 1 into Column 2, multiply by	Column 1 SI Unit	Column 2 non-SI Unit	To convert Column 2 into Column 1 multiply by
	Electrical Conductivity		
10	siemen per meter, S m^{-1}	millimho per centimeter, mmho cm^{-1}	0.1
	Water Measurement		
9.73×10^{-3}	cubic meter, m^3	acre-inches, acre-in	102.8
9.81×10^{-3}	cubic meter per hour, m^3 h^{-1}	cubic feet per second, ft^3 s^{-1}	101.9
4.40	cubic meter per hour, m^3 h^{-1}	U.S. gallons per minute, gal min^{-1}	0.227
8.11	hectare-meters, ha-m	acre-feet, acre-ft	0.123
97.28	hectare-meters, ha-m	acre-inches, acre-in	1.03×10^{-2}
8.1×10^{-2}	hectare-centimeters, ha-cm	acre-feet, acre-ft	12.33
	Concentrations		
1	centimole per kilogram, cmol kg^{-1} (ion exchange capacity)	milliequivalents per 100 grams, meq 100 g^{-1}	1
0.1	gram per kilogram, g kg^{-1}	percent, %	10
1	megagram per cubic meter, Mg m^{-3}	gram per cubic centimeter, g cm^{-3}	1
1	milligram per kilogram, mg kg^{-1}	parts per million, ppm	1
	Plant Nutrient Conversion		
	Elemental	***Oxide***	
2.29	P	P_2O_5	0.437
1.20	K	K_2O	0.830
1.39	Ca	CaO	0.715
1.66	Mg	MgO	0.602

23 April 1986

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