JOURNAL AND PROCEEDINGS
OF THE
ROYAL SOCIETY
OF NEW SOUTH WALES
FOR
1951
(INCORPORATED 1881)

VOLUME LXXXV
Parts I-IV

EDITED BY
IDA A. BROWNE, D.Sc.
Honorary Editorial Secretary

SYDNEY
PUBLISHED BY THE SOCIETY, SCIENCE HOUSE
GLOUCESTER AND ESSEX STREETS

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Part I*

Part II†

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Part III*

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OF THE

ROYAL SOCIETY

OF NEW SOUTH WALES

FOR

1951

(INCORPORATED 1881)

PART I

OF

VOL. LXXXV

Containing List of Members, Report of Council, Balance Sheet, Obituary Notices, Presidential Address and Papers read in April and May, 1951.

EDITED BY

Ida A. BROWNE, D.Sc.

Honorary Editorial Secretary

THE AUTHORS OF PAPERS ARE ALONE RESPONSIBLE FOR THE STATEMENTS MADE AND THE OPINIONS EXPRESSED THEREIN

SYDNEY
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A

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NOTICE.

The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity, it was resuscitated in 1850, under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales"; in 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, it assumed its present title, and was incorporated by Act of the Parliament of New South Wales in 1881.

TO AUTHORS.

Particulars regarding the preparation of manuscripts of papers for publication in the Society's Journal are to be found in the "Guide to Authors", which is obtainable on application to the Honorary Secretaries of the Society.

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I bequeath the sum of £   to the Royal Society of New South Wales, Incorporated by Act of the Parliament of New South Wales in 1881, and I declare that the receipt of the Treasurer for the time being of the said Corporation shall be an effectual discharge for the said Bequest, which I direct to be paid within   calendar months after my decease, without any reduction whatsoever, whether on account of Legacy Duty thereon or otherwise, out of such part of my estate as may be lawfully applied for that purpose.

[*Those persons who feel disposed to benefit the Royal Society of New South Wales by Legacies are recommended to instruct their Solicitors to adopt the above Form of Bequest.*]

The volumes of the *Journal and Proceedings* may be obtained at the Society's Rooms, Science House, Gloucester Street, Sydney.

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Reprints of papers are available.

LIST OF THE MEMBERS

OF THE

Royal Society of New South Wales

as at April 1, 1951

P Members who have contributed papers which have been published in the Society's Journal. The numerals indicate the number of such contributions.

‡ Life Members.

Elected.		
1944		Adamson, Colin Lachlan, Chemist, 36 McLaren-street, North Sydney.
1938	P 2	‡Albert, Adrien, D.Sc., Ph.D. *Lond.*, B.Sc. *Syd.*, A.R.I.C. *Gt. B.*, Professor of Medical Chemistry, The Australian National University, 183 Euston-road, London N.W.1.
1935		‡Albert, Michael Francois, " Boomerang," Billyard-avenue, Elizabeth Bay.
1950		Alexander, Albert Ernest, B.Sc., M.A., Ph.D., Professor of Chemistry, N.S.W. University of Technology ; p.r. 178 Raglan-street, Mosman.
1898		‡Alexander, Frank Lee, Surveyor, 5 Bennett-street, Neutral Bay.
1941		‡Alldis, Victor le Roy, L.S., Registered Surveyor, Box 57, Orange, N.S.W.
1948		Anderson, Geoffrey William, B.Sc., 17 Carlton-street, Harbord.
1948	P 2	Andrews, Paul Burke, c/o North Broken Hill Ltd., Broken Hill.
1950		Astbury, Norman Frederick, M.A. (*Cantab.*), M.I.E.E. (*Lond.*), F.Inst.P., F.R.S.A., Professor of Applied Physics, N.S.W. University of Technology, Broadway, Sydney.
1930	P 1	Aston, Ronald Leslie, B.Sc., B.E.. *Syd.*, M.Sc., Ph.D. *Camb.*, A.M.I.E. *Aust.*, Lecturer in Civil Engineering and Surveying in the University of Sydney ; p.r. 24 Redmyre-road, Strathfield. (President, 1948.)
1919	P 1	Aurousseau, Marcel, B.Sc., 16 Woodland-street, Balgowlah.
1935		Back, Catherine Dorothy Jean, M.Sc., The Women's College, Newtown.
1949	P 2	Backhouse, James Roy, M.Sc. *Syd.*, Lecturer, Sydney Technical College ; p.r. Fowler-avenue, Bexley North.
1924	P 2	Bailey, Victor Albert, M.A., D.Phil., F.Inst.P., Professor of Experimental Physics in the University of Sydney.
1934	P 2	Baker, Stanley Charles, M.Sc., A.Inst.P., Head Teacher of Physics, Newcastle Technical College, Tighe's Hill ; p.r. 8 Hewison-street, Tighe's Hill, N.S.W.
1937		Baldick, Kenric James, B.Sc., 19 Beaconsfield-parade, Lindfield.
1946	P 1	Barclay, Gordon Alfred, Chemistry Department, Sydney Technical College, Harris Street, Ultimo, N.S.W. ; p.r. 78 Alt Street, Ashfield.
1919		Bardsley, John Ralph, 76 Wright's-road, Drummoyne.
1950		Baxter, John Philip, B.Sc., Ph.D., A.M.I.Chem.E., Professor of Chemical Engineering, N.S.W. University of Technology, Broadway, Sydney.
1947		Beckmann, Peter, A.S.T.C., Lecturer in Chemistry, Technical College, Wollongong.
1933		Bedwell, Arthur Johnson, Eucalyptus Oil Merchant, " Kama," 10 Darling Point-road, Edgecliff.
1926		Bentivoglio, Sydney Ernest, B.Sc.Agr., 42 Telegraph-road, Pymble.
1937	P 7	Birch, Arthur John, M.Sc., D.Phil. *Oxon.*, The University Chemical Laboratory, Cambridge, England.
1916		‡Birrell, Septimus, 17 Appian Way, Burwood.
1920		‡Bishop, Eldred George, Manufacturing and General Engineer, 37-45 Myrtle-street, Chippendale ; p.r. 26A Wolseley-road, Mosman.
1939	P 3	Blake, George Gascoigne, M.I.E.E., F.Inst.P., " Holmleigh," Cecil-avenue, Pennant Hills.

Elected.		
1948		Blanks, Fred Roy., B.Sc. (Hons.), Industrial Chemist, 12 Culworth-avenue, Killara.
1946		Blaschke, Ernst Herbert, 6 Illistron Flats, 63 Carrabella-street, Kirribilli.
1933	P 29	Bolliger, Adolph, Ph.D., F.R.A.C.I., Director of Research, Gordon Craig Urological Research Laboratory, Department of Surgery, University of Sydney. (President, 1945.)
1920	P 9	Booth, Edgar Harold, M.C., D.Sc., F.Inst.P., "Hills and Dales," Mittagong. (President, 1935.)
1939	P 25	Bosworth, Richard Charles Leslie, M.Sc., D.Sc. *Adel.*, Ph.D. *Camb.*, F.R.A.C.I., F.Inst.P., c.o. C.S.R. Co. Ltd., Pyrmont; p.r. 41 Spencer-road, Killara.
1948		Boyd, Eric Harold, B.A., B.Sc., Dip.Ed., F.P.S., The King's School, Parramatta.
1948		Boyd, Joan, B.Sc. Hons. *Lond.*, Dip.Ed. *Lond.*, The King's School, Parramatta.
1938		Breckenridge, Marion, B.Sc., Department of Geology, The University of Sydney; p.r. 19 Handley-avenue, Thornleigh.
1949	P 2	Brewer, Roy, B.Sc. *Syd.*, Research Officer, Division of Soils, C.S.I.R.O.; p.r. Block 1, Section 56, O'Connor, Canberra, A.C.T.
1946	P 1	Breyer, Bruno, M.D., Ph.D., M.A., F.R.A.C.I., Lecturer in Agricultural Chemistry, Faculty of Agriculture, University of Sydney, Sydney.
1919	P 1	Briggs, George Henry, D.Sc., Ph.D., F.Inst.P., Officer-in-Charge, Section of Physics, National Standards Laboratory of Australia, University Grounds Sydney; p.r. 13 Findlay-avenue, Roseville.
1942		Brown, Desmond J., M.Sc. (*Syd.*), Ph.D. (*Lond.*), D.I.C., Department of Medical Chemistry, Australian National University, 183 Euston-road, London, N.W.1.
1945		Brown, Norma Dorothy (Mrs.), B.Sc., Biochemist, 2 Macauley-street, Leichhardt.
1941		Brown, Samuel Raymond, A.C.A. *Aust.*, 87 Ashley-street, Chatswood.
1935	P 7	Browne, Ida Alison, D.Sc., Geology Department, The University of Sydney.
1913	P 23	‡Browne, William Rowan, D.Sc., Reader in Geology, University of Sydney. (President, 1932.)
1947		Buchanan, Gregory Stewart, B.Sc. (Hons.), Lecturer in Physical Chemistry, Sydney Technical College; p.r. 19 Ferguson-avenue, Thornleigh.
1940		Buckley, Lindsay Arthur, B.Sc., 29 Abingdon-road, Roseville.
1946		Bullen, Keith Edward, M.A., B.Sc. *N.Z.*, M.A. *Melb.*, Ph.D., Sc.D. *Camb.*, F.R.S., Professor of Applied Mathematics, University of Sydney, Sydney, N.S.W.
1898		‡Burfitt, W. Fitzmaurice, B.A., M.B., Ch.M., B.Sc. *Syd.*, F.R.A.C.S., "Radstoke," Elizabeth Bay.
1926		Burkitt, Arthur Neville St. George, M.B., B.Sc., Professor of Anatomy in the University of Sydney.
1950		Burton, Gerald, B.Sc. (*Syd.*), Geologist, c.o. Bureau of Mineral Resources, Canberra, A.C.T.

1950		Caldwell, John Henry, B.Sc. (*Syd.*), 63 Arthur-street, Homebush.
1938	P 2	‡Carey, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Tasmania.
1948		Carroll, Dorothy, B.A., B.Sc., Ph.D., D.I.C.
1903	P 5	‡Carslaw, Horatio Scott, Sc.D., LL.D., F.R.S.E., Emeritus Professor of Mathematics, University of Sydney, Fellow of Emmanuel College, Cambridge; Burradoo, N.S.W.
1945		Carter, Harold Burnell, B.V.Sc., Officer-in-Charge, Wool Biology Laboratory, 17 Randle-street, Sydney.
1950		Carver, Ashley George, 23A Shell Cove-road, Neutral Bay.
1944		Cavill, George William Kenneth, M.Sc., 40 Chandos-street, Ashfield.
1933		Chalmers, Robert Oliver, A.S.T.C., Australian Museum, College Street, Sydney.
1940		Chambers, Maxwell Clark, B.Sc., c/o Coty (England) Ltd., 35-41 Hutchinson-street, Moore Park; p.r. 58 Spencer-road, Killara.
1913	P 21	‡Cheel, Edwin, 40 Queen-street, Ashfield. (President, 1931.)
1935	P 2	Churchward, John Gordon, B.Sc.Agr., Ph.D., 1 Hunter-street, Woolwich.
1935		Clark, Sir Reginald Marcus, K.B.E., Central Square, Sydney.
1938		Clune, Francis Patrick, Author and Accountant, 15 Prince's-avenue, Vaucluse.
1941		Cohen, Max Charles, B.Sc., 9 Richmond-street, East, Toronto 1, Ontario, Canada.
1940		Cohen, Samuel Bernard, M.Sc., A.R.A.C.I., 74 Boundary-street, Roseville.
1940	P 2	Cole, Edward Ritchie, B.Sc., 7 Wolsten-avenue, Turramurra.
1940	P 1	Cole, Joyce Marie, B.Sc., 7 Wolsten-avenue, Turramurra.
1948		Cole, Leslie Arthur, Company Executive, 21 Carlisle-street, Rose Bay.
1940		Collett, Gordon, B.Sc., 27 Rogers-avenue, Haberfield.

Elected.		
1948		Cook, Cyril Lloyd, M.Sc., University of Manchester.
1946		Cook, Rodney Thomas, A.S.T.C., 10 Riverview-road, Fairfield.
1945		Coombes, Arthur Roylance, A.S.T.C. (Chem.), 14 Georges River-road, Croydon.
1913	P 5	‡Coombs, F. A., F.C.S., Instructor of Leather Dressing and Tanning, Sydney Technical College; p.r. Bannerman-crescent, Rosebery.
1933		Corbett, Robert Lorimer, Scot Chambers, Hosking-place, Sydney.
1940		Cortis-Jones, Beverly, M.Sc., 62 William-street, Roseville.
1919		Cotton, Frank Stanley, D.Sc., Research Professor in Physiology in the University of Sydney.
1909	P 7	‡Cotton, Leo Arthur, M.A., D.Sc., 113 Queen's Parade East, Newport Beach. (President, 1929.)
1941	P 1	Craig, David Parker, Ph.D., Chemistry Department, University College, Gower-street, London, W.C.1., England.
1921	P 1	‡Cresswick, John Arthur, A.R.A.C.I., F.C.S., Production Superintendent and Chief Chemist, c/o The Metropolitan Meat Industry Commissioner, State Abattoir and Meat Works, Homebush Bay; p.r. 101 Villiers-street, Rockdale.
1948		Cymerman, John, Ph.D., D.I.C., A.R.C.S., B.Sc., A.R.I.C., Lecturer in Organic Chemistry, University of Sydney.
1940		Dadour, Anthony, B.Sc., 25 Elizabeth-street, Waterloo.
1950		Dalziel, Edwin Robert, M.A. (*N.Z.*), Ph.D. (*Edin.*), M.I.M.S. (*U.S.A.*), c/o The Overseas Telecommunications Commission, 47 York-street Sydney.
1919	P 2	de Beuzeville, Wilfred Alex. Watt, J.P., " Melamere ", Welham-street, Beecroft.
1906		‡Dixson, Sir William, " Merridong ", Gordon-road, Killara.
1928		Donegan, Henry Arthur James, A.S.T.C., A.R.A.C.I., Analyst, Department of Mines, Sydney; p.r. 18 Hillview-street, Sans Souci.
1947		Downes, Alan Marchant, B.Sc. (Hons.), Grandview-avenue, Croydon, Victoria.
1950		Drummond, Heather Rutherford, B.Sc., 15 Watson-street, Neutral Bay.
1943		Dudgeon, William, Manager, Commonwealth Drug Co., 50-54 Kippax-street, Sydney.
1937	P 15	Dulhunty, John Allan, D.Sc., Geology Department, University of Sydney; p.r. 40 Manning-road, Double Bay. (President, 1947.)
1948		Dunlop, Bruce Thomas, B.Sc., Schoolteacher, 77 Stanhope-road, Killara.
1924		Dupain, George Zephirin, A.R.A.C.I., F.C.S., Director Dupain Institute of Physical Education and Medical Gymnastics, Manning Building, 449 Pitt-street, Sydney; p.r. " Rose Bank ", 158 Parramatta-road, Ashfield.
1934	P 55	Dwyer, Francis P. J., D.Sc., Lecturer in Chemistry, University of Sydney, Sydney.
1945		Eade, Ronald Arthur, B.Sc., 21 Steward-street, Leichhardt.
1950		Edgell, Henry Stewart, 8 Barkly-crescent, Forrest, Canberra, A.C.T.
1934	P 2	Elkin, Adolphus Peter, M.A., Ph.D., Professor of Anthropology in the University of Sydney. (President, 1940.)
1949		Ellison, Dorothy Jean, M.Sc. (Hons.) *N.Z.*, Science Teacher, Abbotsleigh, Wahroonga; p.r. 51 Tryon-road, Lindfield.
1940		Emmerton, Henry James, B.Sc., 1 Rosedale-road, Gordon.
1944		Erhart, John Charles, Chemical Engineer, c/o "Ciba" Coy., Basle, Switzerland.
1908		‡Esdaile, Edward William, 42 Hunter-street, Sydney.
1935		Evans, Silvanus Gladstone, A.I.A.A. *Lond.*, A.R.A.I.A., 6 Major-street, Coogee.
1949		Everingham, Richard, 3 The Bastion, Castlecrag.
1950		Fallon, Joseph James, B.Ec. (*Zurich*), Photographer, 11 Bennett-street, Bondi.
1909	P 7	‡Fawsitt, Charles Edward, D.Sc., Ph.D., F.R.A.C.I., Emeritus Professor of Chemistry, 14A Darling Point-road, Edgecliff. (President, 1919.)
1940		Finch, Franklin Charles, B.Sc., Kirby-street, Rydalmere, N.S.W.
1940		Fisher, Robert, B.Sc., 3 Sackville-street, Maroubra.
1933		Fletcher, Harold Oswald, Palæontologist, Australian Museum, College-street, Sydney.
1949		Flinter, Basil Harold, B.Sc. (Hons.), 75 Elizabeth Bay-road, Elizabeth Bay.
1932		Forman, Kenn. P., M.I.Refr.E., Box 1822, G.P.O., Sydney.
1940		Franki, Robert James Anning, B.Sc., 891 New South Head-road, Rose Bay.
1943		Frederick, Robert Desider Louis, B.E., 1540 High-street, Malvern, Victoria.
1950		Freeman, Hans Charles, B.Sc., Teaching Fellow in Chemistry, University of Sydney; p.r. 43 Newcastle-street, Rose Bay.

Elected.		
1940		Freney, Martin Raphael, B.Sc. entral Wool Testing House, 17 Randle-street, Sydney.
1944	P 2	Friend, James Alan, M.Sc. (*Syd.*), Ph.D. (*Camb.*), Biochemistry Unit, C.S.I.R.O., Wool Textile Research Laboratories, 572 Flinders-lane, Melbourne, C.1.
1945		Furst, Hellmut Friedrich, B.D.S. (*Syd.*), D.M.D. (*Hamburg*), Dental Surgeon, 158 Bellevue-road, Bellevue Hill.
1948		Gardiner, Edward Carson, A.M.I.E. (*Aust.*), Electrical Engineer in Charge of Construction at the Captain Cook Graving Dock, for the Department of Works and Housing ; p.r. 39 Spencer-street, Rose Bay.
1935	P 2	Garretty, Michael Duhan, D.Sc., " Surry Lodge ", Mitcham Road, Mitcham, Victoria.
1939	P 4	Gascoigne, Robert Mortimer, Chemistry Department, University of Liverpool, England.
1926		Gibson, Alexander James, M.E., M.Inst.C.E., M.I.E.Aust., Consulting Engineer, 906 Culwulla Chambers, 67 Castlereagh-street, Sydney ; p.r. " Wirruna," Belmore-avenue, Wollstonecraft.
1942	P 6	Gibson, Neville Allan, M.Sc., A.R.I.C., Industrial Chemist, 217 Parramatta-road, Haberfield.
1947		Gill, Naida Sugden (Miss), B.Sc., 45 Neville-street, Marrickville.
1947		‡Gill, Stuart Frederic, School Teacher, 45 Neville-street, Marrickville.
1940		Gillis, Richard Galvin, Senior Lecturer, Organic Chemistry, Melbourne Technical College ; p.r. 4 Tennyson-avenue, Caulfield, S.E.7, Victoria.
1948		Glasson, Kenneth Roderick, B.Sc., Geologist, Lake George Mines Ltd., Captain's Flat, N.S.W.
1945		Goddard, Roy Hamilton, F.C.A. *Aust.*, Royal Exchange, Bridge-street, Sydney.
1947		Goldsworthy, Neil Ernest, M.B., Ch.M. *Syd.*, Ph.D., D.T.M. & H. *Camb.*, D.T.M. & H. *Eng.*, D.P.H. *Camb.*, 65 Roseville-avenue, Roseville.
1949		Gordon, William Fraser, B.Sc. *Syd.*, Industrial Chemist ; p.r. 176 Avoca-street, Randwick.
1936		Goulston, Edna Maude, B.Sc., 83 Birriga-road, Bellevue Hill.
1949		Gover, Alfred Terence, M.Com., 32 Benelong-road, Cremorne.
1948		Gray, Charles Alexander Menzies, B.Sc., B.E., 75 Woniora-road, Hurstville.
1938		Griffiths, Edward L., B.Sc., A.R.A.C.I., A.R.I.C., Chief Chemist, Department of Agriculture ; p.r. 151 Wollongong-road, Arncliffe.
1946	P 1	Gutmann, Felix, Ph.D., F.Inst.P., M.I.R.E., N.S.W. University of Technology, Broadway, Sydney.
1948	P 7	Gyarfas, Eleonora Clara, M.Sc. *Budapest*, Ph.D. (*Syd.*), Research Assistant, University of Sydney ; p.r. 53 Simpson-street, Bondi.
1947		Hall, Lennard Robert, B.Sc., Geological Survey, Department of Mines, Bridge-street, Sydney.
1934		Hall, Norman Frederick Blake, M.Sc., Chemist, 15A Wharf-road, Longueville.
1892		‡Halloran, Henry Ferdinand, L.S., A.M.I.E.Aust., F.S.I.Eng., M.T.P.I.Eng., 153 Elizabeth-street, Sydney ; p.r. 23 March-street, Bellevue Hill.
1949		Hampton, Edward John William, A.S.T.C. ; p.r. 1 Hunter Street, Waratah, N.S.W.
1940	P 14	Hanlon, Frederick Noel, B.Sc., Geologist, Department of Mines, Sydney.
1905	P 6	‡Harker, George, D.Sc., F.R.A.C.I. ; p.r. 89 Homebush-road, Strathfield.
1936		Harper, Arthur Frederick Alan, M.Sc., A.Inst.P., National Standards Laboratory, University Grounds, City-road, Chippendale.
1934		Harrington, Herbert Richard, Teacher of Physics and Electrical Engineering, Technical College, Harris-street, Ultimo.
1948	P 2	Harris, Clive Melville, A.S.T.C., A.R.A.C.I., Demonstrator, Chemistry Department, Sydney Technical College ; p.r. 12 Livingstone-road, Lidcombe.
1949		Harris, Henry Maxwell, B.Sc., B.E., Assistant Engineer, W.C. & I.C., 25 Prospect-road, Summer Hill.
1946		Harrison, Ernest John Jasper, B.Sc., Geologist, N.S.W. Geological Survey, Department of Mines, Sydney.
1934		Hayes, William Lyall, A.S.T.C., A.R.A.C.I., Works Chemist, c/o Wm. Cooper & Nephews (Aust.) Ltd., Phillip-street, Concord ; p.r. 34 Nicholson-street, Chatswood.
1919		Henriques, Frederick Lester, 208 Clarence-street, Sydney.
1945		Higgs, Alan Charles, Manager, Asbestos Products Pty. Ltd. ; p.r. corner Bungaloe-avenue and New-street, Balgowlah.

Elected.		
1938	P 4	Hill, Dorothy, M.Sc. *Q'ld.*, Ph.D. *Cantab.*, Geological Research Fellow, University of Queensland, Brisbane.
1936		Hirst, Edward Eugene, A.M.I.E., Vice-Chairman and Joint Managing Director, British General Electric Co. Ltd.; p.r. " Springmead," Ingleburn.
1928		Hirst, George Walter Cansdell, B.Sc., A.M.I.E. (*Aust.*), " St. Cloud," Beaconsfield-road, Chatswood.
1948	P 5	Hogarth, Julius William, 8 Jeanneret-avenue, Hunter's Hill.
1916		‡Hoggan, Henry James, A.M.I.M.E. *Lond.*, A.M.I.E. *Aust.*, Consulting and Designing Engineer, 81 Frederick-street, Rockdale.
1941		Howard, Harold Theodore Clyde, B.Sc., Principal, Technical College, Granville.
1938	P 13	Hughes, Gordon Kingsley, B.Sc., Department of Chemistry, University of Sydney, Sydney.
1923	P 3	‡Hynes, Harold John, D.Sc., B.Sc.Agr., Biologist, Department of Agriculture, Box 36A, G.P.O., Sydney; p.r. " Belbooree," 10 Wandella-avenue, Roseville.
1943		Iredale, Thomas, D.Sc., F.R.I.C., Chemistry Department, University of Sydney p.r. 96 Roseville-avenue, Roseville.
1942	P 1	Jaeger, John Conrad, M.A., D.Sc., University of Tasmania, Hobart, Tasmania.
1909	P 15	Johnston, Thomas Harvey, M.A., D.Sc., C.M.Z.S., Professor of Zoology in the University of Adelaide. (Cor. Mem., 1912.)
1949	P 1	Joklik, Gunther F., B.Sc., c/o Bureau of Mineral Resources, Canberra, A.C.T.
1935	P 6	Joplin, Germaine Anne, B.Sc., Ph.D., D.Sc., c/o Bureau of Mineral Resources, Canberra, A.C.T.
1948	P 1	Jopling, Alan Victor, B.Sc., B.E., Geology Department, N.S.W. University of Technology, Broadway, Sydney.
1930		Judd, William Percy, 123 Wollongong-road, Arncliffe.
1935		Kelly, Caroline Tennant (Mrs.), Dip.Anth., " Withington ", Castle Hill-road, Castle Hill.
1940		Kennard, William Walter, 9 Bona Vista-avenue, Maroubra.
1924	P 1	Kenny, Edward Joseph, Geological Surveyor, Department of Mines, Sydney; p.r. 17 Alma-street, Ashfield.
1948		Kimble, Frank Oswald, Engineer, 16 Evelyn-avenue, Concord.
1943		Kimble, Jean Annie, B.Sc., Research Chemist, 383 Marrickville-road, Marrickville.
1920		Kirchner, William John, B.Sc., A.R.A.C.I., Manufacturing Chemist, c/o Messrs. Burroughs Wellcome & Co. (Australia) Ltd., Victoria-street, Waterloo; p.r. 18 Lyne-road, Cheltenham.
1948		Knight, Oscar Le Maistre, B.E. *Syd.*, A.M.I.C.E., A.M.I.E.Aust., Engineer, 10 Mildura-street, Killara.
1950		Knowles, George Henry Anderson, B.Sc. (*Syd.*), Soil Conservationist, Box 49, P.O., Hay, N.S.W.
1948		Koch, Leo E., Dr.Phil.Hrabil (*Cologne*), Research Lecturer, N.S.W. University of Technology; p.r. 39 Bond-street, Mosman.
1939	P 2	Lambeth, Arthur James, B.Sc., " Naranje," Sweethaven-road, Wetherill Park, N.S.W.
1949		Lancaster, Kelvin John, B.Sc., 43 Balfour-road, Rose Bay.
1950		Langley, Julia Mary, " Linwood," Womerah-street, Turramurra.
1936		Leach, Stephen Laurence, B.A., B.Sc., A.R.A.C.I., British Australian Lead Manufacturers Pty. Ltd., Box 21, P.O., Concord.
1946		Lederer, Michael, Newcastle Technical College, Tighe's Hill.
1947		Le Fevre, Raymond James Wood, D.Sc., Ph.D., F.R.I.C., Professor of Chemistry, Chemistry Department, University of Sydney, Sydney.
1936	P 2	Lemberg, Max Rudolph, D.Phil., Institute of Medical Research, Royal North Shore Hospital, St. Leonards.
1929	P 56	‡Lions, Francis, B.Sc., Ph.D., A.R.I.C., Reader, Department of Chemistry, University of Sydney. (President, 1946-47.)
1947		Lloyd, James Charles, B.Sc. *Syd.*, N.S.W. Geological Survey, 41 Goulburn-street, Liverpool.

Elected.		
1940	P 1	Lockwood, William Hutton, B.Sc., c.o. Institute of Medical Research, The Royal North Shore Hospital, St. Leonards.
1906		‡Loney, Charles Augustus Luxton, M.Am.Soc.Refr.E., National Mutual Building, 350 George-street, Sydney.
1949		Loughnan, Frederick Charles, "Bodleian", 26 Kenneth-street, Longueville.
1950		Low, Angus Henry, B.Sc., 74 Turnbull-street, Merewether.
1947		Lowenbein, Gladys Olive (Mrs.), B.Sc. *Melb.*, F.R.I.C. *Gt. B.*, A.R.A.C.I., 5 Berrima Flats, 12 Mulwarrie-avenue, Randwick.
1943		‡Luber, Daphne (Mrs.), B.Sc., 98 Lang-road, Centennial Park.
1945		Luber, Leonard, Pharmacist, 80 Queen-street, Woollahra.
1948	P 2	Lyons, Lawrence Ernest, B.A., M.Sc., Chemistry Department, University College, Gower-street, London, W.1.
1942		Lyons, Raymond Norman Matthew, M.Sc., Biochemical Research Worker, 84 Marine-parade, Maroubra.
1939	P 4	Maccoll, Allan, M.Sc., Department of Chemistry, University College, Gower-street, London, W.C.1.
1949		McCarthy, Frederick David, Dip.Anthr., Curator of Anthropology, Australian Museum, Sydney; p.r. 10 Tycannah-road, Northbridge.
1943		McCoy, William Kevin, Analytical Chemist, c/o Mr. A. J. McCoy, 39 Malvern-avenue, Merrylands.
1950		McCullagh, Morris Behan, Inspecting Engineer, 23 Wallaroy-road, Edgecliff.
1949		McElroy, Clifford Turner, 147 Arden-street, Coogee.
1940		McGregor, Gordon Howard, 4 Maple-avenue, Pennant Hills.
1948		McInnes, Gordon Elliott, Department of Geology, The University of Sydney; p.r. 46 Laycock-street, Bexley.
1906	P 2	‡McIntosh, Arthur Marshall, "Moy Lodge," Hill-street, Roseville.
1944	P 7	McKenzie, Hugh Albert, B.Sc., 52 Bolton-street, Guildford.
1943	P 1	McKern, Howard Hamlet Gordon, A.S.T.C., A.R.A.C.I., Assistant Chemist, Museum of Applied Arts and Sciences; p.r. Flat 2, 42A Waimea-street, Burwood.
1947		McMahon, Patrick Reginald, M.Agr.Sc. *N.Z.*, Ph.D. *Leeds*, A.R.I.C., A.N.Z.I.C., Lecturer-in-charge, Sheep and Wool Department, Sydney Technical College, East Sydney.
1927		McMaster, Sir Frederick Duncan, Kt., "Dalkeith," Cassilis, N.S.W.
1943		McNamara, Barbara Joyce (Mrs.), M.B., B.S., Yeoval, 7.W.
1946		McPherson, John Charters, 14 Sarnar-road, Greenwich.
1946	P 1	McRoberts, Helen May, B.Sc., New England University College, Armidale.
1947		Magee, Charles Joseph, D.Sc.Agr. *Syd.*, M.Sc. *Wis.*, Chief Biologist, Department of Agriculture; p.r. 4 Alexander-parade, Roseville.
1950		Mahoney, Albert John, B.Sc., Industrial Chemist, 112 Archer-street, Chatswood.
1947	P 1	Maley, Leo Edmund, M.Sc., B.Sc. (Hons.), A.R.A.C.I., A.M.A.I.M.M., 116 Maitland-road, Mayfield.
1940		Malone, Edward E., 33 Windsor-road, St. Mary's.
1947	P 14	Mapstone, George E., M.Sc., A.R.A.C.I., M.Inst.Pet., Chief Chemist of National Oil Pty. Ltd., Glen Davis; p.r. 2 Anderson Square, Glen Davis, N.S.W.
1949		Marshall, Charles Edward, Ph.D., D.Sc., Professor of Geology, The University of Sydney, Sydney.
1944		Martin, Cyril Maxwell, Chemist, 22 Wattle-street, Haberfield.
1946		May, Albert, Ph.D., M.A., 94 Birriga-road, Bellevue Hill.
1935	P 1	Maze, William Harold, M.Sc., Registrar, The University of Sydney, Sydney.
1949		Meares, Harry John Devenish, Technical Librarian, Colonial Sugar Refining Co. Ltd., Box 483, G.P.O., Sydney.
1912		‡Meldrum, Henry John, B.A., B.Sc., Lecturer, The Teachers' College, University Grounds, Newtown; p.r. 98 Sydney-road, Fairlight.
1929	P 25	Mellor, David Paver, D.Sc., F.R.A.C.I., Reader, Department of Chemistry, University of Sydney; p.r. 137 Middle Harbour-road, Lindfield. (President, 1941-42.)
1950		Millar, Lily Maud (Mrs.), 4 Waratah House, 43 Bayswater-road, King's Cross.
1940		Millership, William, M.Sc., Chief Chemist, Davis Gelatine (Aust.) Pty. Ltd., 15 Shaw-avenue, Earlwood.
1922	P 30	Morrison, Frank Richard, F.R.A.C.I., F.C.S., Deputy Director, Museum of Applied Arts and Sciences, Harris-street, Board, Sydney. (President, 1950-1951.)
1941		Morrissey, Mathew John, B.A., F.S.T.C., A.R.A.C.I., M.B., B.S., c/o Residents' Quarters, Sydney Hospital, Macquarie Street, Sydney.
1934		Mort, Francis George Arnot, A.R.A.C.I., Chemist, 110 Green's Road, Fivedock.

Elected.		
1950		Mortlock, Allan John, B.Sc. (Hons.), Research Officer, Division of Physics, C.S.I.R.O. ; p.r. 28 Stanley-street, Chatswood.
1948		Mosher, Kenneth George, B.Sc., Geologist, c.o. Joint Coal Board, 66 King-street, Sydney.
1944		Moye, Daniel George, Geologist, 6 First-avenue, Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.
1946		Mulholland, Charles St. John, B.Sc., Geologist, Department of Mines, Sydney.
1948		Mulley, Joan W., Technical Officer, C.S.I.R.O. ; p.r. 4 Billyard-avenue, Elizabeth Bay.
1915		‡Murphy, Robert Kenneth, Dr.Ing., Chem., A.S.T.C., M.I.Chem.E., F.R.A.C.I., Principal, Sydney Technical College, Sydney.
1923	P 2	Murray, Colonel Jack Keith, B.A., B.Sc.Agr., Administrator, Territory of Papua, New Guinea, Government House, Port Moresby.
1950		Murray, Patrick Desmond Fitzgerald, M.A., D.Sc., Professor of Zoology, University of Sydney.
1948		Naylor, Betty Yvonne, B.Sc., 6 Niblick-avenue, Roseville.
1930	P 7	Naylor, George Francis King, M.A., M.Sc., Dip.Ed., A.A.I.I.P., Lecturer in Philosophy and Psychology, University of Queensland, Brisbane, Qld.
1943		‡Neuhaus, John William George, 190 Old Prospect-road, Wentworthville.
1932		Newman, Ivor Vickery, M.Sc., Ph.D., F.R.M.S., F.L.S., Professor of Botany, The University of Ceylon, Colombo, Ceylon.
1950		Ney, Michel, B.Sc., Research Assistant, Geology Department, The University of Sydney ; p.r. 6 Fairlight-avenue, Killara.
1943		Nicol, Alexander Campbell, A.S.T.C., A.R.A.C.I., Chief Chemist, Crown Crystal Glass Co. ; p.r. 200 Paine-street, Maroubra.
1935		Nicol, Phyllis Mary, M.Sc., Sub-Principal, The Women's College, Newtown.
1945	P 1	Noakes, Lyndon Charles, Geologist, c/o Mineral Resources Survey, Canberra, A.C.T.
1938	P 1	Noble, Norman Scott, D.Sc.Agr., M.Sc., D.I.C., c/o C.S.I.R.O., 314 Albert-street, East Melbourne, Vic.
1920	P 4	‡Noble, Robert Jackson, M.Sc., B.Sc.Agr., Ph.D., Under Secretary, Department of Agriculture, Box 36A, G.P.O., Sydney ; p.r. 32A Middle Harbour-road, Lindfield. (President, 1934.)
1947		Nordon, Peter, A.S.T.C., A.R.A.C.I., Chemical Engineer, 39 Tahlee-street, Burwood.
1948		Northcott, Jean, B.Sc. (Hons.), Chemistry Department, The University of Sydney ; p.r. 38 Canberra-street, Lane Cove.
1940	P 25	Nyholm, Ronald Sydney, M.Sc., Chemistry Department, University College, Gower-street, London, W.C.1, England.
1935	P 4	O'Connell, Rev. Daniel J. K., S.J., D.Sc., D.Ph., F.R.A.S., Riverview College Observatory, Sydney.
1947		Old, Adrian Noel, B.Sc.Agr., Chemist, Department of Agriculture ; p.r. 4 Springfield-avenue, Pott's Point.
1921	P 11	Osborne, George Davenport, D.Sc. *Syd.*, Ph.D. *Camb.*, Lecturer and Demonstrator in Geology in the University of Sydney. (President, 1944.)
1950		Oxenford, Reginald Augustus, B.Sc., 9 Cambridge-street, Singleton, N.S.W.
1920	P 77	Penfold, Arthur Ramon, F.R.A.C.I., F.C.S., Director, Museum of Applied Arts and Sciences, Harris-street, Broadway, Sydney. (President, 1931.)
1949	P 1	Penrose, Ruth Elizabeth, B.Sc., 92 Baringa-road, Northbridge.
1948		Perry, Hubert Roy, B.Sc., 74 Woodbine-street, Bowral.
1938		Phillips, Marie Elizabeth, B.Sc., Botany Department, University, Manchester, 13, England.
1935		Phillips, Orwell, 55 Darling Point-road, Edgecliff.
1946		Pinwill, Norman, B.A. (*Q'land*), The Scots College, Bellevue Hill.
1943	P 7	Plowman, Ronald Arthur, B.Sc. *Lond.*, A.S.T.C., A.R.A.C.I., Analytical Chemist, 21 Harris-street, Normanhurst.
1919		Poate, Hugh Raymond Guy, M.B., Ch.M. *Syd.*, F.R.C.S. *Eng.*, L.R.C.P. *Lond.*, F.R.A.C.S., Surgeon, 225 Macquarie-street, Sydney ; p.r. 38 Victoria-road, Bellevue Hill.
1949		Poggendorff, Walter Hans George, B.Sc.Agr., Chief of the Division of Plant Industry, N.S.W. Department of Agriculture, Box 36A, G.P.O., Sydney.

Elected.		
1896		‡Pope, Roland James, B.A. *Syd.*, M.D., Ch.M., F.R.C.S. *Edin.*, c/o Perpetual Trustee Co., 33 Hunter-street, Sydney.
1946		Potter, Bryce Harrison, B.Sc. (Hons.) *Syd.*, 68 Wharf-road, Gladesville.
1921	P 2	Powell, Charles Wilfrid Roberts, F.R.I.C., A.R.A.C.I., Company Executive, c/o Colonial Sugar Refining Co., O'Connell-street, Sydney ; p.r. " Wansfell," Kirkoswald-avenue, Mosman.
1938		Powell, John Wallis, A.S.T.C., A.R.A.C.I., Managing Director, Foster Clark (Aust.) Ltd., 17 Thurlow-street, Redfern.
1945		Prescott, Alwyn Walker, B.Eng., Lecturer in Mechanical and Electrical Engineering in the University of Sydney ; p.r. Harris-road, Normanhurst.
1927		Price, William Lindsay, B.E., B.Sc., Teacher of Physics, Sydney Technical College ; p.r. 8 Wattle-street, Killara.
1918	P 1	Priestley, Henry, M.D., Ch.M., B.Sc., 54 Fuller's-road, Chatswood. (President, 1942-43.)
1945		Proud, John Seymour, Mining Engineer, 4 View-street, Chatswood.
1893		‡Purser, Cecil, B.A., M.B., Ch.M. *Syd.*, " Ascot," Grosvenor-road, Wahroonga.
1935	P 3	‡Quodling, Florrie Mabel, B.Sc., Lecturer in Geology, University of Sydney
1922	P 6	Raggatt, Harold George, D.Sc., Director, Bureau of Mineral Resources, Geology and Geophysics, 485 Bourke-street, Melbourne, C.1, Victoria.
1940	P 2	Ralph, Colin Sydney, B.Sc., 24 Canberra-street, Epping.
1919	P 3	Ranclaud, Archibald Boscawen Boyd, B.Sc., B.E., 57 William-street, Sydney.
1936		Randall, Harry, Buena Vista-avenue, Denistone.
1947		Ray, Nancy Evelyn (Mrs.), Plastics Manufacturer.
1947		Ray, Reginald John, Plastics Manufacturer and Research Chemist.
1931	P 1	Rayner, Jack Maxwell, B.Sc., F.Inst.P., Chief Geophysicist, Bureau of Mineral Resources, Geology and Geophysics, 485 Bourke-street, Melbourne, Vic.
1947		Reuter, Fritz Henry, Ph.D. (*Berlin*, 1930), F.R.A.C.I., 94 Onslow-street, Rose Bay.
1946		Rhodes-Smith, Cecil, 261 George-street, Sydney.
1950		Rickwood, Frank Kenneth, Lecturer in Geology, The University of Sydney.
1947		Ritchie, Arthur Sinclair, A.S.T.C., Lecturer in Mineralogy and Geology, Newcastle Technical College ; p.r. 188 St. James-road, New Lambton, N.S.W.
1947		Ritchie, Bruce, B.Sc. (Hons.), c/o Pyco Products Pty. Ltd., 576 Parramatta-road, Petersham.
1939	P 19	Ritchie, Ernest, M.Sc., Senior Lecturer, Chemistry Department, University of Sydney, Sydney.
1939	P 3	Robbins, Elizabeth Marie (Mrs.), M.Sc., 344 Railway-parade, Guildford.
1933		Roberts, Richard George Crafter, Electrical Engineer, c/o C. W. Stirling & Co., Asbestos House, York and Barrack-streets, Sydney.
1940		Robertson, Rutherford Ness, B.Sc. *Syd.*, Ph.D. *Cantab.*, Senior Plant Physiologist, C.S.I.R.O., Division of Food Preservation, Private Bag, P.O., Homebush ; p.r. Flat 4, 43 Johnston-street, Annandale.
1949	P 4	Robertson, William Humphrey, B.Sc., Astronomer, Sydney Observatory, Sydney.
1935	P 2	Room, Thomas G., M.A., F.R.S., Professor of Mathematics in the University of Sydney.
1940		Rosenbaum, Sidney, 23 Strickland-avenue, Lindfield.
1948		Rosenthal-Schneider, Ilse, Ph.D., 48 Cambridge-avenue, Vaucluse.
1940		Ross, Jean Elizabeth, B.Sc., Dip.Ed., 5 Stanton-road, Haberfield.
1948		Ross, Leonard Paul, B.Sc., 137 Burwood-road, Enfield.
1945		Rountree, Phyllis Margaret, D.Sc. *Melb.*, Dip.Bact. *Lond.*, Royal Prince Alfred Hospital, Sydney.
1945		Sampson, Aileen (Mrs.), Sc.Dip. (A.S.T.C., 1944), 9 Knox-avenue, Epping.
1920		Scammell, Rupert Boswood, B.Sc. *Syd.*, A.R.A.C.I., F.C.S., c/o F. H. Faulding & Co. Ltd., 98 Castlereagh-street, Redfern ; p.r. 10 Buena Vista-avenue, Clifton Gardens.
1948	P 1	Schafer, Harry Neil Scott, B.Sc., 18 Bartlett-street, Summer Hill.
1946	P 1	Scott, Beryl (Miss), B.Sc., Geology Department, University of Tasmania.
1940		Scott, Reginald Henry, B.Sc., 3 Walbundry-avenue, East Kew, Victoria.
1950		Searl, Robert Alexander, B.Sc., Geologist, c/o Bureau of Mineral Resources, Canberra, A.C.T.
1949		See, Graeme Thomas, Analytical Chemist, 2 Skipton Flats, corner Mount and Dudley-streets, Coogee.

Elected.		
1933		Selby, Esmond Jacob, Dip.Com., Sales Manager, Box 175 D, G.P.O., Sydney.
1936		Sellenger, Brother Albertus, St. Ildephonsus College, New Norcia, W.A.
1950		Sergeyeff, William Peter, Mining Geologist and Engineer, 92 Herbert-street, Rockdale.
1948		‡Sharp, Kenneth Raeburn, c/o S.M.H.E.A., Cooma, N.S.W.
1938		Sheahan, Thomas Henry Kennedy, B.Sc., Chemist, c/o Shell Co. of Aust., North Terrace, Adelaide.
1936	P 2	Sherrard, Kathleen Margaret Maria (Mrs.), M.Sc. *Melb.*, 43 Robertson-road, Centennial Park.
1948		Sherwood, Ian Russell, D.Sc., F.R.A.C.I., Research Bacteriologist, Research Laboratory, Colonial Sugar Refining Co. Ltd., John-street, Pyrmont.
1945		Shulman, Albert, B.Sc., Industrial Chemist, Flat 2, Linden Court, Linden-avenue, Woollahra.
1945	P 3	Simmons, Lewis Michael, B.Sc. (Hons.) *Lond.*, Ph.D. *Lond.*, F.R.A.C.I., Head of Science Department, Scots College ; p.r. The Scots College, Victoria-road, Bellevue Hill.
1948	P 1	Simonett, David Stanley, B.Sc., Geography Department, The University of Sydney ; p.r. 14 Selwyn-street, Artarmon.
1943		Simpson, John Kenneth Moore, Industrial Chemist, "Browie," Old Castle Hill-road, Castle Hill.
1950		Sims, Kenneth Patrick, B.Sc., 13 Onyx-road, Artarmon.
1933		Slade, George Hermon, B.Sc., Director, W. Hermon Slade & Co. Pty. Ltd., Manufacturing Chemists, Mandemar-avenue, Homebush ; p.r. "Raiatea," Oyama-avenue, Manly.
1940		Smith, Eric Brian Jeffcoat, 1 Rocklands-road, Wollstonecraft.
1947		Smith-White, William Broderick, M.A. *Cantab.*, B.Sc. *Syd.*, Department of Mathematics, University of Sydney ; p.r. 28 Cranbrook-avenue, Cremorne.
1919		Southee, Ethelbert Ambrook, O.B.E., M.A., B.Sc., B.Sc.Agr., Principal, Hawkesbury Agricultural College, Richmond, N.S.W.
1949		Stanton, Richard Limon, B.Sc., Teaching Fellow in Geology, The University of Sydney, Sydney ; p.r. 42 Hopetoun-avenue, Mosman.
1916		‡Stephen, Alfred Ernest, F.C.S., c/o Box 1158 HH, G.P.O., Sydney.
1914		‡Stephens, Frederick G. N., F.R.C.S., M.B., Ch.M., 135 Macquarie-street, Sydney ; p.r. Captain Piper's-road and New South Head-road, Vaucluse.
1948	P 2	Stevens, Neville Cecil, B.Sc., Geology Department, The University of Sydney ; p.r. 12 Salisbury-street, Hurstville.
1900	P 1	‡Stewart, J. Douglas, B.V.Sc., F.R.C.V.S., Emeritus Professor of Veterinary Science in the University of Sydney ; p.r. "Berelle," Homebush-road, Strathfield. (President, 1927.)
1942		Still, Jack Leslie, B.Sc., Ph.D., Professor of Biochemistry, The University of Sydney, Sydney.
1916	P 1	‡Stone, Walter George, F.S.T.C., F.R.A.C.I., Chief Analyst, Department of Mines, Sydney ; p.r. 26 Rosslyn-street, Bellevue Hill.
1918		‡Sullivan, Herbert Jay, Director in Charge of Research and Technical Department, c/o Lewis Berger & Sons (Australia) Ltd., Rhodes ; Box 23, P.O., Burwood ; p.r. "Stonycroft," 10 Redmyre-road, Strathfield.
1919		‡Sutherland, George Fife, A.R.C.Sc. *Lond.*, 47 Clanwilliam-street, Chatswood.
1920		Sutton, Harvey, O.B.E., M.D., D.P.H. *Melb.*, B.Sc. *Oxon.*, Professor of Preventive Medicine and Director, School of Public Health and Tropical Medicine, University of Sydney ; p.r. "Lynton," 27 Kent-road, Rose Bay.
1941	P 2	Swanson, Thomas Baikie, M.Sc. *Adel.*, c/o Technical Service Department, Icianz, Box 1911, G.P.O., Melbourne, Victoria.
1948		Swinbourne, Ellice Simmons, Organic Chemist, A.S.T.C., A.R.A.C.I., 1 Raglan-street, Manly.
1915	P 3	‡Taylor, Brigadier Harold B., M.C., D.Sc., F.R.I.C., F.R.A.C.I., Government Analyst, Department of Public Health, 93 Macquarie-street, Sydney ; p.r. 12 Wood-street, Manly.
1944		Thomas, Andrew David, Squadron Leader, R.A.A.F., M.Sc., A.Inst.P., 26 Darebin-street, Heidelberg, N.22, Victoria.
1946		Thomas, Ifor Morris, M.Sc., Department of Zoology, University of Adelaide, Adelaide, S.A.
1946	P 2	Thompson, Nora (Mrs.), B.Sc. *Syd.*, c/o Australasian Petroleum Coy., Port Moresby, Papua.
1919		Thorne, Harold Henry, M.A. *Cantab.*, B.Sc. *Syd.*, F.R.A.S., Lecturer in Mathematics in the University of Sydney ; p.r. 55 Railway-crescent, Beecroft.

Elected.		
1935		Tommerup, Eric Christian, M.Sc., A.R.A.C.I., Queensland Agricultural College, Lawes, via Brisbane, Queensland.
1923		Toppin, Richmond Douglas, A.R.I.C., 51 Crystal-street, Petersham.
1940		Tow, Aubrey James, M.Sc., No. 5, " Werrington," Manion-avenue, Rose Bay.
1949		Trebeck, Prosper Charles Brian, A.C.I.S., F.Com.A. *Eng.*, F.F.I.A., A.A.A., J.P., Central Australian Hotel, Bourke.
1943		Turner, Ivan Stewart, M.A., M.Sc., Ph.D., p.r. 120 Awaba-street, Mosman.
1949	P 1	Vallance, Thomas George, 57 Auburn-street, Sutherland.
1921		Vicars, Robert, Marrickville Woollen Mills, Marrickville.
1935		Vickery, Joyce Winifred, M.Sc., Botanic Gardens, Sydney; p.r. 17 The Promenade, Cheltenham.
1933	P 6	Voisey, Alan Heywood, D.Sc., Lecturer in Geology and Geography, New England University College, Armidale.
1903	P 10	‡Vonwiller, Oscar U., B.Sc., F.Inst.P., Emeritus Professor of Physics in the University of Sydney; p.r. " Withington," Castle Hill-road, Castle Hill. (President, 1930.)
1948		Walker, Donald Francis, Surveyor, 13 Beauchamp-avenue, Chatswood.
1943		Walker, James Foote, Company Secretary, 11 Brucedale-avenue, Epping.
1919	P 2	Walkom, Arthur Bache, D.Sc., Director, Australian Museum, Sydney; p.r. 45 Nelson-road, Killara. (Member from 1910-1913. President, 1943-44.)
1950		Warburton, William Kingston, B.Sc., Research Officer, McMaster Laboratory, Glebe.
1913	P 5	‡Wardlaw, Hy. Sloane Halcro, D.Sc. *Syd.*, F.R.A.C.I., c/o Kanematsu Institute, Sydney Hospital, Macquarie Street, Sydney. (President, 1939.)
1944		Warner, Harry, A.S.T.C., Chemist, 6 Knibbs-street, Turner, Canberra, A.C.T.
1919	P 1	Waterhouse, Lionel Lawry, B.E. *Syd.*, " Rarotonga," 42 Archer-street, Chatswood.
1919	P 7	Waterhouse, Walter L., M.C., D.Sc.Agr., D.I.C., F.L.S., Research Professor of Agriculture, University of Sydney; p.r. " Hazelmere," Chelmsford-avenue, Lindfield. (President, 1937.)
1944		Watkins, William Hamilton, B.Sc., Industrial Chemist.
1911	P 1	‡Watt, Robert Dickie, M.A., B.Sc., Gladswood House, Gladswood Gardens, Double Bay.
1921		Watts, Arthur Spencer, "Araboonoo", Glebe-street, Randwick.
1947		Webb, Gordon Keyes, A.F.I.A., A.C.I.S., Accountant, c/o Max Wurcker (1930) Pty. Ltd., 99 York-street, Sydney.
1947		Werner, Ronald Louis, Industrial Chemist, 25 Dine-street, Randwick.
1949		Westheimer, Gerald, B.Sc., F.S.T.C., F.I.O., Optometrist, 727 George-street, Sydney.
1946		Weston, Margaret Crowley, B.A., 41 Bulkara-road, Bellevue Hill.
1943		Whiteman, Reginald John Nelson, M.B., Ch.M., F.R.A.C.S., 143 Macquarie-street, Sydney.
1949		Williams, Benjamin, A.S.T.C., 97 McMichael-street, Maryville, N.S.W.
1949		Williamson, William Harold, Hughes-avenue, Ermington.
1945		Willis, Jack Lehane, B.Sc., Flat 5, " Narooma", Hampden-street, North Sydney.
1943		Winch, Leonard, B.Sc., 26 Boonah-street, Griffith, N.S.W.
1940		Wogan, Samuel James, Range-road, Sarina, North Queensland.
1936	P 12	Wood, Harley Weston, M.Sc., A.Inst.P., F.R.A.S., Government Astronomer, Sydney Observatory, Sydney. (President, 1949.)
1906	P 12	‡Woolnough, Walter George, D.Sc., F.G.S., c/o Mr. W. L. Woolnough, " Callabonna ", 8 Park-avenue, Gordon.
1916		‡Wright, George, Company Director, c/o Hector Allen, Son & Morrison, 7 Wynyard-street, Sydney; p.r. 22 Albert-street, Edgecliff.
1946		Wyndham, Norman Richard, M.D., M.S. (*Syd.*), F.R.C.S. (*Eng.*), F.R.A.C.S., Surgeon, 225 Macquarie-street, Sydney.
1950		Zehnder, John Oscar, B.Sc., Geologist, c/o Australasian Petroleum Coy., Port Moresby, Papua.
1948		Zingel, Judith, B.Sc., 68 Upper-street, Bega, 7C.

HONORARY MEMBERS.

Limited to Twenty.

Elected.	
1949	Burnet, Frank Macfarlane, M.D., Ph.D., F.R.S., Director of the Walter and Eliza Hall Research Institute, Melbourne.
1951	Fairley, Sir Neil Hamilton, C.B.E., M.D., D.Sc., F.R.S., 73 Harley-street, London, W.1.
1949	Florey, Sir Howard, M.B., B.S., B.Sc., M.A., Ph.D., F.R.S., Professor of Pathology, Oxford University, England.
1914	Hill, James P., D.Sc., F.R.S., Professor of Zoology, University College, Gower-street, London, W.C.1, England.
1946	Jones, Sir Harold Spencer, M.A., D.Sc., F.R.S., Astronomer Royal, Royal Observatory, Greenwich, London, S.E.10.
1915	Maitland, Andrew Gibb, F.G.S., "Bon Accord," 28 Melville-terrace, South Perth, W.A.
1912	Martin, Sir Charles J., C.M.G., D.Sc., F.R.S., Roebuck House, Old Chesterton, Cambridge, England.
1948	Oliphant, Marcus L., B.Sc., Ph.D., F.R.S., Professor of Physics, The University, Edgbaston, Birmingham 15, England.
1948	Robinson, Sir Robert, M.A., D.Sc., F.C.S., F.I.C., F.R.S., Professor of Chemistry, Oxford University, England.
1946	Wood-Jones, F., D.Sc., M.B., B.S., F.R.C.S., L.R.C.P. (*Lond.*), F.R.S., F.Z.S., Professor of Anatomy, University of Manchester, England.

OBITUARY, 1950-51.

1913	Richard W. Challinor.
1913	William M. Doherty.
1949	Frank W. Follett.
1905	Mark Foy.
1920	Albert Sherbourne Le Souef.
1942	Arthur S. Lippmann.
1950	George Millar.
1921	Gustavus A. Waterhouse.
1928	Frederick A. Wiesener.

THE REV. W. B. CLARKE MEMORIAL FUND.

The Rev. W. B. Clarke Memorial Fund was inaugurated at a meeting of the Royal Society of N.S.W. in August, 1878, soon after the death of Mr. Clarke, who for nearly forty years rendered distinguished service to his adopted country, Australia, and to science in general. It was resolved to give an opportunity to the general public to express their appreciation of the character and services of the Rev. W. B. Clarke " as a learned colonist, a faithful minister of religion, and an eminent scientific man." It was proposed that the memorial should take the form of lectures on Geology (to be known as the Clarke Memorial Lectures), which were to be free to the public, and of a medal to be given from time to time for distinguished work in the Natural Sciences done in or on the Australian Commonwealth and its territories ; the person to whom the award is made may be resident in the Australian Commonwealth or its territories, or elsewhere.

The Clarke Memorial Medal was established first, and later, as funds permitted, the Clarke Memorial Lectures have been given at intervals.

CLARKE MEMORIAL LECTURES.

Delivered.

1906. "The Volcanoes of Victoria," and "The Origin of Dolomite" (two lectures). By Professor E. W. Skeats, D.Sc., F.G.S.
1907. "Geography of Australia in the Permo-Carboniferous Period" (two lectures). By Professor T. W. E. David, B.A., F.R.S.
"The Geological Relations of Oceania." By W. G. Woolnough, D.Sc.
"Problems of the Artesian Water Supply of Australia." By E. F. Pittman, A.R.S.M.
"The Permo-Carboniferous Flora and Fauna and their Relations." By W. S. Dun.
1918. "Brain Growth, Education, and Social Inefficiency." By Professor R. J. A. Berry, M.D., F.R.S.E.
1919. "Geology at the Western Front," By Professor T. W. E. David, C.M.G., D.S.O., F.R.S.
1936. "The Aeroplane in the Service of Geology." By W. G. Woolnough, D.Sc. (This Journ., 1936, *70*, 39.)
1937. "Some Problems of the Great Barrier Reef." By Professor H. C. Richards, D.Sc. (This Journ., 1937, *71*, 68.)
1938. "The Simpson Desert and its Borders." By C. T. Madigan, M.A., B.Sc., B.E., D.Sc. (Oxon.). (This Journ., 1938, *71*, 503.)
1939. "Pioneers of British Geology." By Sir John S. Flett, K.B.E., D.Sc., LL.D., F.R.S. (This Journ., 1939, *73*, 41.)
1940. "The Geologist and Sub-surface Water." By E. J. Kenny, M.Aust.I.M.M. (This Journ., 1940, *74*, 283.)
1941. "The Climate of Australia in Past Ages." By C. A. Sussmilch, F.G.S. (This Journ., 1941, *75*, 47.)
1942. "The Heroic Period of Geological Work in Australia." By E. C. Andrews, B.Sc.
1943. "Australia's Mineral Industry in the Present War." By H. G. Raggatt, D.Sc.
1944. "An Australian Geologist Looks at the Pacific." By W. H. Bryan, M.C., D.Sc.
1945. "Some Aspects of the Tectonics of Australia." By Professor E. S. Hills, D.Sc., Ph.D.
1946. "The Pulse of the Pacific." By Professor L. A. Cotton, M.A., D.Sc.
1947. "The Teachers of Geology in Australian Universities." By Professor H. S. Summers, D.Sc.
1948. "The Sedimentary Succession of the Bibliando Dome : Record of a Prolonger Proterozoic Ice Age." By Sir Douglas Mawson, O.B.E., F.R.S., D.Sc., B.E.
1949. "Metallogenetic Epochs and Ore Regions in Australia." By W. R. Browne, D.Sc.
1950. "The Cambrian Period in Australia." By F. W. Whitehouse, Ph.D., D.Sc.

AWARDS OF THE CLARKE MEDAL.

Established in memory of
The Revd. WILLIAM BRANWHITE CLARKE, M.A., F.R.S., F.G.S., etc.
Vice-President from 1866 *to* 1878.

The prefix * indicates the decease of the recipient.

Awarded.

1878 *Professor Sir Richard Owen, K.C.B., F.R.S.
1879 *George Bentham, C.M.G., F.R.S.
1880 *Professor Thos. Huxley, F.R.S.
1881 *Professor F. M'Coy, F.R.S., F.G.S.
1882 *Professor James Dwight Dana, LL.D.

Awarded.	
1883	*Baron Ferdinand von Mueller, K.C.M.G., M.D., Ph.D., F.R.S., F.L.S.
1884	*Alfred R. C. Selwyn, LL.D., F.R.S., F.G.S.
1885	*Sir Joseph Dalton Hooker, O.M., G.C.S.I., C.B., M.D., D.C.L., LL.D., F.R.S.
1886	*Professor L. G. De Koninck, M.D.
1887	*Sir James Hector, K.C.M.G., M.D., F.R.S.
1888	*Rev. Julian E. Tenison-Woods, F.G.S., F.L.S.
1889	*Robert Lewis John Ellery, F.R.S., F.R.A.S.
1890	*George Bennett, M.D., F.R.C.S. *Eng.*, F.L.S., F.Z.S.
1891	*Captain Frederick Wollaston Hutton, F.R.S., F.G.S.
1892	*Sir William Turner Thiselton Dyer, K.C.M.G., C.I.E., M.A., LL.D., SC.D., F.R.S., F.L.S.
1893	*Professor Ralph Tate, F.L.S., F.G.S.
1895	*Robert Logan Jack, LL.D., F.G.S., F.R.G.S.
1895	*Robert Etheridge, Jnr.
1896	*The Hon. Augustus Charles Gregory, C.M.G., F.R.G.S.
1900	*Sir John Murray, K.C.B., LL.D., SC.D., F.R.S.
1901	*Edward John Eyre.
1902	*F. Manson Bailey, C.M.G., F.L.S.
1903	*Alfred William Howitt, D.SC., F.G.S.
1907	*Professor Walter Howchin, F.G.S., University of Adelaide.
1909	*Dr. Walter E. Roth, B.A.
1912	*W. H. Twelvetrees, F.G.S.
1914	Sir A. Smith Woodward, LL.D., F.R.S., Keeper of Geology, British Museum (Natural History), London.
1915	*Professor W. A. Haswell, M.A., D.SC., F.R.S.
1917	*Professor Sir Edgeworth David, K.B.E., C.M.G., D.S.O., M.A., SC.D., D.SC., F.R.S., F.G.S.
1918	*Leonard Rodway, C.M.G., Honorary Government Botanist, Hobart, Tasmania.
1920	*Joseph Edmund Carne, F.G.S.
1921	*Joseph James Fletcher, M.A., B.SC.
1922	*Richard Thomas Baker, The Crescent, Cheltenham.
1923	*Sir W. Baldwin Spencer, K.C.M.G., M.A., D.SC., F.R.S.
1924	*Joseph Henry Maiden, I.S.O., F.R.S., F.L.S., J.P.
1925	*Charles Hedley, F.L.S.
1927	Andrew Gibb Maitland, F.G.S., " Bon Accord," 28 Melville Terrace, South Perth, W.A.
1928	*Ernest C. Andrews, B.A., F.G.S., 32 Benelong Crescent, Bellevue Hill.
1929	Professor Ernest Willington Skeats, D.SC., A.R.C.S., F.G.S., University of Melbourne, Carlton, Victoria.
1930	L. Keith Ward, B.A., B.E., D.SC., Government Geologist, Geological Survey Office, Adelaide.
1931	*Robin John Tillyard, M.A., D.SC., SC.D., F.R.S., F.L.S., F.E.S., Canberra, F.C.T.
1932	*Frederick Chapman, A.L.S., F.R.S.N.Z., F.G.S., Melbourne.
1933	Walter George Woolnough, D.SC., F.G.S., Department of the Interior, Canberra, F.C.T.
1934	*Edward Sydney Simpson, D.SC., B.E., F.A.C.I., Carlingford, Mill Point, South Perth, W.A.
1935	*George William Card, A.R.S.M., 16 Ramsay-street, Collaroy, N.S.W.
1936	Sir Douglas Mawson, KT., O.B.E., F.R.S., D.SC., B.E., University of Adelaide.
1937	J. T. Jutson, B.SC., LL.B., 9 Ivanhoe-parade, Ivanhoe, Victoria.
1938	*Professor H. C. Richards, D.SC., The University of Queensland, Brisbane.
1939	*C. A. Sussmilch, F.G.S., F.S.T.C., 11 Appian Way, Burwood, N.S.W.
1941	Professor Frederic Wood Jones, M.B., B.S., D.SC., F.R.S., Anatomy Department, University of Manchester, England.
1942	William Rowan Browne, D.SC., Reader in Geology, The University of Sydney, N.S.W.
1943	Walter Lawry Waterhouse, M.C., D.SC.AGRIC., D.I.C., F.L.S., Reader in Agriculture, University of Sydney.
1944	Professor Wilfred Eade Agar, O.B.E., M.A., D.SC., F.R.S., University of Melbourne, Carlton, Victoria.
1945	Professor William Noel Benson, B.A., D.SC., F.G.S., F.R.G.S., F.R.S.N.Z., F.G.S.AM., University of Otago, Dunedin, N.Z.
1946	Black, J. M., A.L.S. (*honoris causa*), Adelaide, S.A.
1947	*Hubert Lyman Clark, A.B. D.SC., Ph.D., Hancock Foundation, U.S.C., Los Angeles, California.
1948	Walkom, Arthur Bache, D.SC., Director, Australian Museum, Sydney.
1949	Rupp, Rev. H. Montague, 24 Kameruka-road, Northbridge.
1950	Mackerras, Ian Murray, B.SC., M.B., Ch.M., The Queensland Institute of Medical Research, Brisbane.

AWARDS OF THE JAMES COOK MEDAL.

Bronze Medal.

Awarded annually for outstanding contributions to science and human welfare in and for the Southern Hemisphere.

1947 Smuts, Field-Marshal The Rt. Hon. J. C., P.C., C.H., K.C., D.T.D., LL.D., F.R.S., Chancellor, University of Capetown, South Africa.
1948 Houssay, Bernado A., Professor of Physiology, Instituto de Biologia y Medicina Experimental, Buenos Aires, Argentina.
1949 No award made.
1950 Fairley, Sir Neil Hamilton, C.B.E., M.D., D.Sc., F.R.S., 73 Harley-street, London, W.1.

AWARDS OF THE EDGEWORTH DAVID MEDAL.

Bronze Medal.

Awarded annually for Australian research workers under the age of thirty-five years, for work done mainly in Australia or its territories or contributing to the advancement of Australian Science.

1948 Giovanelli, R. G., M.Sc., Division of Physics, National Standards Laboratory, Sydney. } Joint Award.
Ritchie, Ernest, M.Sc., University of Sydney, Sydney.
1949 Kiely, Temple B., D.Sc.Agr., Caroline-street, East Gosford.
1950 Berndt, Ronald M., B.A., Dip.Anthr., University of Sydney. } Joint Award.
Berndt, Catherine H., M.A., Dip.Anthr., University of Sydney.

AWARDS OF THE SOCIETY'S MEDAL AND MONEY PRIZE.

Money Prize of £25.

Awarded.
1882 John Fraser, B.A., West Maitland, for paper entitled "The Aborigines of New South Wales."
1882 Andrew Ross, M.D., Molong, for paper entitled "Influence of the Australian climate and pastures upon the growth of wool."

The Society's Bronze Medal.

1884 W. E. Abbott, Wingen, for paper entitled "Water supply in the Interior of New South Wales."
1886 S. H. Cox, F.G.S., F.C.S., Sydney, for paper entitled "The Tin deposits of New South Wales."
1887 Jonathan Seaver, F.G.S., Sydney, for paper entitled "Origin and mode of occurrence of gold-bearing veins and of the associated Minerals."
1888 Rev. J. E. Tenison-Woods, F.G.S., F.L.S., Sydney, for paper entitled "The Anatomy and Life-history of Mollusca peculiar to Australia."
1889 Thomas Whitelegge, F.R.M.S., Sydney, for paper entitled "List of the Marine and Freshwater Invertebrate Fauna of Port Jackson and Neighbourhood."
1889 Rev. John Mathew, M.A., Coburg, Victoria, for paper entitled "The Australian Aborigines."
1891 Rev. J. Milne Curran, F.G.S., Sydney, for paper entitled "The Microscopic Structure of Australian Rocks."
1892 Alexander G. Hamilton, Public School, Mount Kembla, for paper entitled "The effect which settlement in Australia has produced upon Indigenous Vegetation."
1894 J. V. De Coque, Sydney, for paper entitled the "Timbers of New South Wales."
1894 R. H. Mathews, L.S., Parramatta, for paper entitled "The Aboriginal Rock Carvings and Paintings in New South Wales."
1895 C. J. Martin, D.Sc., M.B., F.R.S., Sydney, for paper entitled "The physiological action of the venom of the Australian black snake (*Pseudechis porphyriacus*)."
1896 Rev. J. Milne Curran, Sydney, for paper entitled "The occurrence of Precious Stones in New South Wales, with a description of the Deposits in which they are found."
1943 Edwin Cheel, Sydney, in recognition of his contributions in the field of botanical research and to the advancement of science in general.
1948 Waterhouse, Walter L., M.S., D.Sc.Agr., D.I.C., F.L.S., Sydney, in recognition of his valuable contributions in the field of agricultural research.
1949 Elkin, Adolphus P., M.A., Ph.D., Sydney, in recognition of his valuable contributions in the field of Anthropological Science.
1950 Vonwiller, Oscar U., B.Sc., F.Inst.P., Sydney, in recognition of his valuable contributions in the field of Physical Science.

AWARDS OF THE WALTER BURFITT PRIZE.

Bronze Medal and Money Prize of £75.

Established as the result of a generous gift to the Society by Dr. W. F. Burfitt, B.A., M.B., Ch.M., B.Sc., of Sydney, which was augmented later by a gift from Mrs. W. F. Burfitt. Awarded at intervals of three years to the worker in pure and applied science, resident in Australia or New Zealand, whose papers and other contributions published during the past six years are deemed of the highest scientific merit, account being taken only of investigations described for the first time, and carried out by the author mainly in these Dominions.

Awarded.
1929 Norman Dawson Royle, M.D., Ch.M., 185 Macquarie Street, Sydney.
1932 Charles Halliby Kellaway, M.C., M.D., M.S., F.R.C.P., The Walter and Eliza Hall Institute of Research in Pathology and Medicine, Melbourne.
1935 Victor Albert Bailey, M.A., D.Phil., Associate-Professor of Physics, University of Sydney.
1938 Frank Macfarlane Burnet, M.D. (*Melb.*), Ph.D. (*Lond.*), The Walter and Eliza Hall Institute of Research in Pathology and Medicine, Melbourne.
1941 Frederick William Whitehouse, D.Sc., Ph.D., University of Queensland, Brisbane.
1944 Hereward Leighton Kesteven, D.Sc., M.D., c/o Allied Works Council, Melbourne.
1947 John Conrad Jaeger, M.A., D.Sc., University of Tasmania, Hobart.
1950 Martyn, David F., D.Sc. (*Lond.*), F.R.S., Radio Research Board, c/o Commonwealth Observatory, Mount Stromlo, Canberra, A.C.T.

AWARDS OF LIVERSIDGE RESEARCH LECTURESHIP.

This Lectureship was established in accordance with the terms of a bequest to the Society by the late Professor Archibald Liversidge. Awarded at intervals of two years, for the purpose of encouragement of research in Chemistry. (This Journal, Vol. LXII, pp. x-xiii, 1928.)

Awarded.
1931 Harry Hey, c/o The Electrolytic Zinc Company of Australasia, Ltd., Collins Street, Melbourne.
1933 W. J. Young, D.Sc., M.Sc., University of Melbourne.
1940 G. J. Burrows, B.Sc., University of Sydney.
1942 J. S. Anderson, B.Sc., Ph.D. (*Lond.*), A.R.C.S., D.I.C., University of Melbourne.
1944 F. P. Bowden, Ph.D., Sc.D., University of Cambridge, Cambridge, England.
1946 Briggs, L. H., D.Phil. (*Oxon.*), D.Sc. (*N.Z.*), F.N.Z.I.C., F.R.S.N.Z., Auckland University College, Auckland, N.Z.
1948 Ian Lauder, M.Sc., Ph.D., University of Queensland, Brisbane.
1950 Hedley R. Marston, F.R.S., C.S.I.R.O., Adelaide.

Royal Society of New South Wales

REPORT OF THE COUNCIL FOR THE YEAR ENDING 31st MARCH, 1951.

Presented at the Annual and General Monthly Meeting of the Society, 4th April, 1951 (Rule XXVI).

The membership of the Society at the end of the period under review stood at 369, an increase of eight. Twenty-nine new members were elected during the year. However, 11 members were lost by resignation, and one, who was in arrears with his subscription, was removed from the register. Nine members have been lost to the Society by death since 1st April, 1950 :

Richard W. Challinor (1913).
William M. Doherty (1913).
Frank W. Follett (1949).
Mark Foy (1905).
Albert Sherbourne Le Souef (1920).
Arthur S. Lippmann (1942).
George Millar (1950).
Gustavus A. Waterhouse (1921).
Frederick A. Wiesener (1928).

During the year nine General Monthly Meetings were held, at which the average attendance was thirty. Thirty-one papers were accepted for reading and publication by the Society, thirteen papers less than the previous year.

The following Exhibits were discussed on dates as under :

3rd May :

" Demonstration of the Bourdillon Air Sampler ", by Dr. P. M. Rountree.

6th September :

" Demonstration of Coal Dust Inflammability Apparatus ", by Mr. H. A. J. Donegan.

" Demonstration of Stresses Produced by Shearing Viscous Liquids ", by Dr. R. C. L. Bosworth.

6th December :

" Manila Hemp ", by Dr. C. J. Magee.

At the meeting held on the 2nd August, the film " Clouds and their Formation " was shown. This had been made possible by the kindness of Dr. E. B. Kraus, who also presented a splendid commentary.

In thanking Dr. Kraus for the loan of this interesting film, the Chairman moved a vote of thanks to Captain Silcock and Lieutenant Simpson for having made available the necessary equipment for the screening of the film, and to Sergeant Brown for his valuable assistance on this occasion.

The meeting devoted to the commemoration of great scientists was held on the 4th October, at which the following addresses were given :

" Descartes ", by Mr. W. B. Smith-White.
" Gay Lussac ", by Dr. D. P. Mellor.
" W. M. Davis ", by Dr. W. R. Browne.

At the meeting held on the 1st November, the President welcomed members and their friends to the Conversazione. The evening was devoted to Exhibits and Films of Scientific Interest. This programme had been made possible through the courtesy of the following :

The Australian Museum,
The Chemistry Department, University of Sydney,
The Mining Museum,
The Museum of Technology and Applied Science.

Lecturettes given during the year were as follows :

3rd May : " Moulds and Mildews ", by Dr. C. J. Magee.
7th June : " Fleece Growth and Problems of Climatic Adaptation in Sheep ", by Mr. H. B. Carter.
5th July : " Heard Island ", by Mr. A. J. Lambeth.

Five Popular Science Lectures were delivered during the year and were appreciated by members of the Society and the public :

18th May : " Pharmacology in the New Age ", by Professor R. H. Thorp.

15th June : " Clouds and their Formation ", by Dr. E. B. Kraus.

17th August : " Recent Developments in Town and Country Planning ", by Professor D. Winston.

21st September : " Coal ", by Professor C. E. Marshall.

4th October : " Storms on the Sun ", by Dr. R. G. Giovanelli.

The Annual Dinner of the Society was held in the New Bevery of the University Union on the 29th March, 1951. There were present 60 members and friends.

The Council of the Society held eleven ordinary meetings during the year, at which the average attendance was eight.

On Science House Management Committee the Society was represented by Messrs. H. O. Fletcher and F. R. Morrison, with substitute representatives Dr. R. L. Aston and Mr. H. H. Thorne.

On Science House Extension Committee the Society was represented by Drs. R. L. Aston and A. Bolliger.

The Clarke Memorial Lecture for 1950 was delivered by Dr. F. W. Whitehouse on the 20th July, the title being " The Cambrian Period in Australia ".

The Liversidge Research Lecture for 1950 was delivered by Mr. Hedley R. Marston, F.R.S., on the 15th November, and was entitled " Energy Transactions in Homeothermic Animals ".

The Clarke Memorial Medal for 1951 was awarded to Dr. Frank Leslie Stillwell of Melbourne for outstanding petrological and mineralogical research.

The Walter Burfitt Prize for 1950 was awarded to Dr. David F. Martyn, F.R.S., Radio Research Board, for outstanding contributions in the field of Ionospheric Research.

The Medal of the Royal Society of New South Wales for 1950 was awarded to Professor O. U. Vonwiller in recognition of his valuable contributions in the field of physical science.

The Edgeworth David Medal for 1950 was awarded to Ronald M. Berndt conjointly with Catherine H. Berndt in recognition of the outstanding contributions made by them in the field of anthropological science.

The James Cook Medal for 1950 was awarded to Sir Neil Hamilton Fairley in recognition of his work on malaria.

On the 8th December the President and members of Council entertained at afternoon tea Professor Dirk Brouwer, Director of Yale University Observatory, on the occasion of his visit to this city.

The financial position of the Society, as disclosed by the Annual Audit, is not a satisfactory one. The deficit which was £436 in 1949-50 has now grown to £687. To meet heavy current expenses the Hon. Treasurer has been forced to sell Treasury Bonds amounting to £1,000.

By far the most serious drain on the Society's finances comes from the rapidly mounting costs of printing the Society's Journal and Proceedings. In spite of the fact that the Council accepted thirteen papers fewer this year, the cost of the Journal was £921.

This represents approximately a 30% increase in the cost per page on the last Journal (44 papers at a cost of £1,001). A small portion of this cost will, it is true, ultimately be offset by a grant obtained from the Commonwealth Scientific Publications Committee towards the cost of printing two valuable papers. However, this does not represent the total cost to the Society of the printing of the Journal, as this year an additional sum of £140 was spent on reprints as against a sum of £23 for the previous year.

The outgoing Council desires particularly to draw the attention of the new Council and of members in general to this serious state which has arisen in connection with the financing of the Journal.

A recent advice from the printer informs us that the unit cost—already 167% above the 1940 cost—rose further from £2 per page to £2 15s. per page—a further 37·5% increase. While a thorough examination and vigorous exploitation of other possible sources of revenue—of publication grants, publication fees, assistance from outside bodies ultimately to benefit from the information published in our Journal, etc.—may do much to help, it appears that economies are imperative and some form of restriction on publication expenses must be contemplated.

The Society has published its first Monograph, entitled " The Structural Evolution of the Hunter-Manning-Myall Province, New South Wales ", by G. D. Osborne, D.Sc.

The Society's share of the profits from Science House for the year was £450, an increase of £50 on the previous year.

The grant of the Government of New South Wales has been received. The continued interest of the Government in the work of the Society is much appreciated.

The Library. The amount of £77 3s. 9d. has been spent on the purchase of periodicals, and £33 17s. on binding. Extra shelving was placed in the library during the year, the cost of this being £46 0s. 10d.

Exchange of publications is maintained with 420 societies and institutions, an increase of 21 over the previous year.

The number of accessions entered in the catalogue during the year ended 28th February, 1951, was 2,718 parts of periodicals.

The number of books, periodicals, etc., borrowed by members, institutions and accredited readers was 252.

Among the institutions which made use of the library through the inter-library borrowing scheme were: Commonwealth Observatory, Taubmans Ltd., McMaster Laboratories, Fisher Library, Plant Industry and Entomological Laboratories, Waite Agricultural Research Institute, National Standards Laboratories, Melbourne University, Snowy Mountains Hydro-Electric Authority, Colonial Sugar Refining Co. Ltd., Elliotts and Australian Drug Co., Adelaide University, Sydney Technical College, Timbrol Ltd., School of Public Health and Tropical Medicine Museum of Applied Arts and Sciences, C.S.I.R.O. Fisheries, Institution of Engineers, University of Tasmania, Food Preservation Laboratories, Sydney Hospital, Australian Paper Manufacturers, Water Conservation and Irrigation Commission, Department of Works and Housing, Royal Society of Tasmania, Public Library of Victoria, Forestry Commission of N.S.W.

F. R. MORRISON,
President.

THE ROYAL SOCIETY OF NEW SOUTH WALES.

BALANCE SHEET AS AT 28th FEBRUARY, 1951.

LIABILITIES.

1950.		1951.					
£		£	s.	d.	£	s.	d.
470	Accrued Expenses				274	14	4
33	Subscriptions Paid in Advance				35	14	0
107	Life Members' Subscriptions—Amount carried forward				97	16	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	1,926	2	10			
	Walter Burfitt Prize	1,126	10	11			
	Liversidge Bequest	721	18	9			
	Monograph Capital Fund	3,733	0	6			
7,401					7,507	13	0
25,580	ACCUMULATED FUNDS				24,886	2	9
	Contingent liability (in connection with perpetual leases).						
£33,591					£32,802	0	1

ASSETS.

1950.		1951.					
£		£	s.	d.	£	s.	d.
403	Cash at Bank and in Hand				633	15	9
	Investments—Commonwealth Bonds and Inscribed Stock, etc.—at Face Value—						
	Held for—						
	Clarke Memorial Fund	1,800	0	0			
	Walter Burfitt Prize Fund	1,000	0	0			
	Liversidge Bequest	700	0	0			
	Monograph Capital Fund	3,000	0	0			
	General Purposes	3,660	0	0			
11,160					10,160	0	0
	Debtors for Subscriptions	58	6	6			
	Deduct Reserve for Bad Debts	58	6	6			
—					—		
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
360	Furniture—At Cost—*less* Depreciation				342	0	0
26	Pictures—At Cost—*less* Depreciation				25	0	0
7	Lantern—At Cost—*less* Depreciation				6	0	0
£33,591					£32,802	0	1

TRUST AND MONOGRAPH CAPITAL FUNDS.

	Clarke Memorial.			Walter Burfitt Prize.			Liversidge Bequest.			Monograph Capital Fund.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Capital at 28th February, 1950 ..	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0
Revenue—												
Balance at 28th February, 1950	157	1	1	90	12	5	33	5	3	620	3	4
Interest for twelve months ..	67	12	6	37	12	3	26	7	3	112	17	2
	224	13	7	128	4	8	59	12	6	733	0	6
Deduct Expenditure	98	10	9	1	13	9	37	13	9	—		
Balance at 28th February, 1951 ..	£126	2	10	£126	10	11	£21	18	9	£733	0	6

ACCUMULATED FUNDS.

	£	s.	d.	£	s.	d.
Balance at 28th February, 1950				25,579	11	3
Less—						
Increase in reserve for bad debts	£0	9	6			
Deficit for twelve months (as shown by Income and Expenditure Account)	686	13	0			
Bad Debts written off	6	6	0			
				693	8	6
				£24,886	2	9

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on the 28th February, 1951, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Public Accountants.

Prudential Building,
39 Martin Place,
Sydney, 27th March, 1951.

INCOME AND EXPENDITURE ACCOUNT.

1st March, 1950, to 28th February, 1951.

1949-50.						1950-51.					
£						£	s.	d.	£	s.	d
1,002	To	Printing and Binding Journal—Vol. 83				920	15	6			
520	,,	Salaries				578	15	4			
113	,,	Library—Purchases and Binding				199	8	7			
102	,,	Printing—General				117	6	10			
68	,,	Miscellaneous				108	13	9			
58	,,	Postage and Telegrams				77	11	2			
54	,,	Rent—Science House Management Committee				59	4	2			
16	,,	Entertainment Expenses				4	6	1			
36	,,	Cleaning				36	0	0			
21	,,	Depreciation				20	0	0			
15	,,	Telephone				21	4	3			
24	,,	Insurance				23	10	9			
19	,,	Audit				31	10	0			
5	,,	Electricity				13	0	1			
13	,,	Repairs				0	1	7			
	,,	Reprints—									
		Expenditure	£335	2	9						
		Less Received	194	6	9						
23						140	16	0			
	,,	Annual Dinner—									
		Expenditure	£89	10	7						
		Less Received	76	12	6						
18						12	18	1			
£2,107									£2,365	2	2

1949-50.			1950-51.		
£			£	s.	d.
599	By	Membership Subscriptions	623	14	0
400	,,	Government Subsidy	400	0	0
400	,,	Science House—Share of Surplus	450	0	0
162	,,	Interest on General Investments	183	4	2
90	,,	Proceeds Sale of Old Library Books	—		
11	,,	Other Receipts	12	2	0
9	,,	Proportion of Life Members' Subscriptions	9	9	0
1,671			1,678	9	2
436	,,	Deficit for Twelve Months	686	13	0
£2,107			£2,365	2	2

ABSTRACT OF PROCEEDINGS

OF THE SECTION OF

GEOLOGY

Chairman : G. D. Osborne, D.Sc. (Syd.), Ph.D. (Camb.).

Honorary Secretary : N. C. Stevens, B.Sc.

Eight meetings were held during the year 1950, the average attendance being eighteen members and eight visitors.

Meetings :

April 21st.—Annual Meeting. Election of Office-bearers for 1950 : Chairman, Dr. G. D. Osborne, and Honorary Secretary, Mr. N. C. Stevens.
Address by Dr. Dorothy Carroll, " Methods in Sedimentary Petrology ".

May 19th.—Lecturettes : " Recent Work of the New South Wales Geological Survey ", by Officers of the Survey—including a general outline by Mr. C. St. J. Mulholland ; faults in coalfields area by Mr. F. N. Hanlon ; felspar, beryl and mica deposits near Broken Hil by Mr. J. M. Rayner ; and the Snowy Mountains Hydro-Electric Scheme by Mr. L. R. Hall

June 23rd.—Address by Dr. W. R. Browne : " On the Geology of the Mittagong-Bowral District."

July 21st.—Address by Associate Professor F. W. Whitehouse : " Sedimentation in the Great Artesian Basin." Exhibit by Mr. R. O. Chalmers of pebbles with flattened sides from Giligulgul, Q.

August 18th.—Notes and Exhibits : By Mr. A. S. Ritchie : Ancient river gravels of the Hunter River near Newcastle. By Miss F. M. Quodling : Sphalerite and galena from Clwydd and Hassan's Walls. By Dr. W. R. Browne : The occurrence and distribution of Ordovician rocks in New South Wales. By Dr. Ida A. Browne : Soft-bodied organisms from the Middle Cambrian Burgess shales, Canada. By Mr. A. V. Jopling : Lantern slides of photomicrographs. By Mr. T. G. Vallance : Highly metamorphosed sediments from west of Adelong, New South Wales. By Mr. N. C. Stevens : Ores from the wolfram mines at Frogmore, New South Wales, including cuproscheelite surrounding wolframite. By Mr. R. O. Chalmers : Calcareous deposits in water pipes from Hawkesbury sandstone country. By Dr. L. E. Koch : The water supplies of Teheran (Persia).

September 15th.—Address by Mr. A. J. Lambeth : " A Geologist on Heard Island and Kerguelen's Land."

October 20th.—Address by Dr. G. D. Osborne : " Evidence against Extensive Granitization in Large Unstressed Bathyliths."

November 17th.—Notes and Exhibits : By Dr. W. R. Browne : Wind-blown sand from Lake George. By Mr. C. St. J. Mulholland : A draft copy of map symbols used by the Bureau of Mineral Resources. By Miss F. M. Quodling : A dichroscope, and mica sheets with flattened garnets from Central Australia. By Mr. N. C. Stevens : Notes on Ordovician strata from the Walli district, New South Wales. By Dr. G. D. Osborne : Fine-grained microsyenite from the south-western chilled margin of the Mt. Gibraltar intrusion, Bowral.

Obituary

Richard Westman Challinor, who died on February 3rd, 1951, was born in 1874. Educated in Sydney, he became a demonstrator in chemistry under Professor Liversidge at Sydney University. In 1898 he was appointed to the Chemistry staff of the Sydney Technical College, and later became head teacher of Organic Chemistry, which position he held until his retirement in 1938. Challinor took a keen personal interest in his students, the majority of whom maintained close bonds of friendship with him after completing their courses of study. He was actively associated with the growth and development of Technical Education in New South Wales from 1900 onwards.

He became a Fellow of the Institute of Chemistry by examination in 1910, and was an original member of the Australian Chemical Institute, in which he held the offices of President and Secretary respectively of the New South Wales branch. He was one of the founders of the Sydney Technical College Chemical Society in 1913. He joined this Society in 1913, occupied the Presidential Chair in 1933, and was for many years a Councillor. Until recent years he rarely missed a meeting of the Society, and was keenly interested in all of its activities.

Frank William Follett, who died on October 25th, 1950, was born in Sydney in 1892 and trained as a Civil Engineer. In World War I he joined the Royal Flying Corps and served with the rank of Captain in England and France.

After his return to Australia he held the position of Superintendent of Aircraft in the Department of Civil Aviation for eight years.

As one of the founders of Adastra Airways and afterwards its Managing Director, Captain Follett played a leading part in the development of civil aviation, commercial aerial surveying and photogrammetry in Australia. He was elected a member of this Society in 1949.

Mark Foy, who died on November 15th, 1950, at the age of 85 years, was a successful business man in Sydney. He was a leading sportsman, and in 1892 founded the Sydney Flying Squadron. He was a member of this Society since 1905.

Albert Sherbourne Le Souef was born in Melbourne in 1877, and died on March 31st, 1951. He was Secretary and later Assistant Director of the Melbourne Zoological Gardens between 1896 and 1903, when he was appointed Director of the Zoological Gardens at Moore Park, Sydney.

He was responsible for much of the organization connected with the transfer of the Gardens to their present site, and became the first Director of the Taronga Park Zoological Gardens.

Mr. Le Souef was a Corresponding Member of the Zoological Society of London and a Councillor of the Zoological Society of New South Wales for about 50 years. He was the author of numerous scientific papers on zoology. He had been a member of this Society since 1920.

Arthur S. Lippmann was born in 1884 at Hamburg, Germany, and took his medical degree in 1908. He became Physician-in-Chief to the Medical Section of St. George Hospital, Hamburg, in 1916.

He arrived in Australia in 1939, and built a large medical practice in Macquarie Street, Sydney. He published a number of papers in medical journals, and joined this Society in 1942.

Both in Germany and in Australia Dr. Lippmann was regarded as an outstanding scientist, and was held in high esteem by his fellow scientists. He died on July 5th, 1950.

George Millar, who died on September 2nd, 1950, was born in Scotland in 1891 and arrived in Australia during his boyhood. After serving in the first world war, he became a chartered accountant, and will be remembered for his outstanding honorary services to the Surf Life Saving Association of N.S.W. Although he had been interested in the activities of this Society for some years, he had been enrolled as a member only a few days before his death.

Gustavus Athol Waterhouse was born in Sydney in 1877 and died on July 29th, 1950. He graduated from the University of Sydney as B.Sc. in 1899 and B.E. in 1900, and was awarded the D.Sc. in 1924. From 1900 he was on the assay staff of the Royal Mint until it closed in 1926.

Dr. Waterhouse took a very active interest in scientific societies in the State. He was a Special Life Member of the Royal Entomological Society of London and held executive positions on the Councils of the Linnean Society of New South Wales (Hon. Treasurer 1926-43), the Royal Zoological Society of N.S.W., the Naturalists' Club and the Sydney University Engineering Society. He was Hon. General Treasurer of A.N.Z.A.A.S. and the Australian National Research Council, and a Trustee and Hon. Entomologist of the Australian Museum, Sydney.

His scientific work consisted of research on Lepidoptera, on which he was a world authority. Some years ago he presented his large collection of butterflies to the Australian Museum. He was the author of numerous papers and two books on butterflies.

He was a member of this Society since 1921.

Frederick Abbey Wiesener, who died on April 15th, 1950, was educated at Sydney High School and Sydney University. He graduated in Medicine in 1923 and for two years continued post-graduate studies abroad, chiefly in London and Vienna.

On his return to Sydney he practised as an eye specialist in Macquarie Street, Sydney, until his retirement a few years ago. He travelled extensively in Europe and elsewhere. He held a number of honorary positions at hospitals in Sydney.

Dr. Wiesener was a member of this Society since 1928 and frequently attended the meetings of the Geology Section.

PRESIDENTIAL ADDRESS

By F. R. Morrison.

Delivered before the Royal Society of New South Wales, April 4, 1951.

GENERAL.

This Annual Meeting of the Society brings us to a period in the world's history which is probably best described by the opening words of Charles Dickens' "A Tale of Two Cities", "It was the best of times, it was the worst of times . . ." Judged in terms of money, Australia, America and a number of other countries are experiencing an unprecedented period of prosperity. Our primary products are fetching record prices in the world's markets, unemployment is nil, and time for enjoyment of leisure is increasing. Indeed, signs are not wanting that some difficulties are being experienced by many in efforts to take full advantage of that leisure. Unfortunately, owing to a number of factors, demand in general is greater than supply as far as both the essentials and luxuries of life are concerned, and our apparent prosperity assumes a different aspect as the spiral of income and expenditure winds rapidly upwards.

Our own Society is naturally affected by these circumstances. The Annual Report reveals a substantial loss on the year's activities in spite of the Hon. Treasurer's watchful eye on the Society funds and the exercise of economy wherever possible. Our most important function is the printing of research papers in the Journal, and this is the cause of our losses. Ways and means of meeting the rising costs have been discussed very earnestly by your Council during the past year, and will be continued by the incoming Council, until a solution is found. Of one thing members may be certain, namely, that the acceptance and printing of the results of research by members, and in certain cases by non-members, will be the Society's principal function while its funds are able to meet the cost.

Some restriction of printing may be necessary as a temporary measure, but no effort will be spared to meet the situation. I feel sure that a way out of our difficulties will be found.

To return to world conditions, we find that, in contrast to the apparent prosperity of a few nations, a grim and desolate state of affairs exists in many other lands. War, threats of aggression, terrorism, the growing pains of newly created nations, cries of distress from starving populations, especially children (legacies from World War II), hysteria, doubt and worry are rampant. There is so much of international politics involved in the world situation today that a society such as the Royal Society of New South Wales is not in a position, nor is it appropriate for it, to express opinions and offer advice on what are regarded as controversial matters ; at the same time it might point out, without fear of an accusation of partiality, that the simple scientific attitude might be more fully employed in attacking some of the problems urgently awaiting solution. Science remains as always, based on the search for truth, and its application to many international issues would surely eliminate many misunderstandings. Perhaps if those who guide the destinies of nations were chosen from amongst the scientifically trained and philosophical thinkers, there might exist a clearer understanding between peoples of all nations, irrespective of colour or creed. It is true that " a science may attain to fullness, her disciples never ", nevertheless the followers of science are always striving for that goal, consequently they should constitute a powerful influence for peace and understanding. As members of a senior scientific body with tradition and experience as guides, each one of us has an obligation to look beyond our own boundaries to the greater world problems. I am convinced that if each individual living in a democracy realized the obligations of self-discipline and personal responsibility which a democratic way of life imposes, there would be little fear of facing the future with confidence, and there would exist a greater degree of tolerance and sympathetic understanding of the problems of the less fortunate and so-called backward peoples of the world. A study, or even a regular perusal, of UNESCO publications and newspapers, furnishes sufficient evidence of the necessity for a broad and intelligent background of knowledge of other peoples and of their ways of life. I feel there is need for a revival of philosophical discussions at our meetings, as something a little broader and more thought-provoking than the specialized papers. Specialization in science cannot be avoided under present circumstances, but we would do well to remember that " the object of the Royal Society of New South Wales is to encourage studies . . . and to publish original papers on Science, Art, Literature and Philosophy . . . " This Society is one which opens its doors to all seekers after knowledge, and the dissemination of philosophy in its broadest aspects should be our objective.

In the opening remarks of his Presidential Address last year, Mr. Harley Wood commented on the need for " semi "-popular presentation of papers on specialized subjects, in order that members not conversant with the particular field of science might be able to gain an idea of the purpose and/or the results of the research. My own experience during the past year has confirmed this opinion. I should like to impress upon authors of papers the wisdom of putting themselves in the place of the audience, and then, of applying the golden rule, " Do unto others . . . " I am convinced that if an author devotes himself to the task, the principal parts of his paper can be presented in a manner both interesting and profitable to any audience. An abstruse mathematical, physical or chemical paper may interest those who specialize in the respective branch of science, but its probable application to industry, or its advantage over previous finds, is of some interest to all. A complex chemical reaction may mean very little if described by words and formulæ, but a demonstration which produces a red or blue precipitate is appreciated by all observers.

I take this opportunity of thanking those who have helped to make my term of office an enjoyable and profitable experience. Members of Council have proved most cooperative. The Honorary Secretaries have carried out their duties with efficiency and zeal. Dr. I. A. Browne, the Hon. Editorial Secretary, has brought up to date the printing of the Society's Journal, an outstanding achievement. Dr. R. C. L. Bosworth's term of office as Hon. Correspondence Secretary has been characterized by " neatness and despatch " and he takes over the Presidential Chair with a sound knowledge of the Society's affairs. The work of Dr. C. J. Magee as Hon. Treasurer has been arduous, especially in view of his having to budget for a loss on the year's undertakings. He has carefully guarded the Society's interests, and his courage and tenacity in continuing as Hon. Treasurer augur well for the Society's future financial position. To the Hon. Librarian, Mr. F. N. Hanlon, thanks are due for his careful oversight of library activities and his untiring efforts to preserve an orderly arrangement of volumes, etc. As one of the Society's representatives on Science House Management Committee, I should like to state that the Committee is carrying out its duties very efficiently. When it is realized that the rentals of Science House tenants have never been increased, and the charges for meeting halls only once since pre-war days, whereas maintenance, repairs, cleaning, etc., costs have increased greatly during those years, the fact that the Society's share of profit was greater than that of the previous year is very gratifying, and a tribute to the work of the Secretary, Mr. N. B. Walker.

Thanks are due to those who contributed to the Society's meetings. Scientific papers reached a high standard, lecturettes, exhibits and films were of particular interest to all present, and furnished evidence of careful preparation and attention on the part of contributors. The Popular Science Lectures were well attended, and the lecturers, who devoted much time and thought to their preparation, deserve the gratitude of members of the public who heard them, and the Society, which sponsored them. Finally, I wish to express appreciation of the cooperation of members who took part in meetings and other activities of the Society during my term of office.

THE SCIENCE MUSEUM—ITS DUTIES AND ITS DUES.

The appelation "Science Museum" is here used to describe the prototype of the Science Museum of South Kensington, London, England, and more specifically the Museum of Applied Arts and Sciences, Sydney, New South Wales, Australia, with which latter institution the speaker has been associated for over 30 years. In this address it is intended to say something of science museums in general and of the present and future outlook of Australian science museums in particular.

For a considerable time it has been realized that the ultimate fate of museums and similar educational institutions in Australia will depend on appropriate action to keep them up to date, and thus enable them to perform the functions and fulfil the aims for which they were established. A Museum of Applied Arts and Sciences must keep abreast of the world's progress and developments in science and its industrial applications, as well as in applied arts and craftsmanship. Its resources, financial and otherwise, should enable it to illustrate by appropriate exhibits and displays the latest advances in research, as well as ideas and suggestions inspired by such researches. The public, for which the institutions exist, would thus reap the fruits of the world's knowledge with a minimum of delay. Such an objective is the ideal to which all museums should aspire. The means by which it can be attained are not easy of definition, and the path is beset with many obstacles. These are often very discouraging, especially when hard work and enthusiasm on the part of the personnel concerned are the principal resources of the institution.

The Present Position of Science Museums in Australia.

It might surprise, and perhaps shock, many people to learn that in spite of maximum effort and enthusiasm our science museums may be in many respects from one to two decades "behind the times" compared with science museums in Europe and North America. The principal obstacle is lack of finance for buildings, equipment and trained personnel. These remarks are not intended as criticism of any authority. It is realized that so far as the individual States of Australia are concerned, it is doubtful if the educational finances could cope with the demands of a modern science museum. It would appear that a common pool of finance should be involved, and the Commonwealth Treasury is the logical source. Perhaps the advent of the Commonwealth Jubilee Celebrations makes the suggestion appropriate in this year of grace 1951.

The question might well be asked, Is it essential that a museum strive to attain the objective previously mentioned? If it is apparently serving the needs of the public and no complaints are heard, why press for further aid? The answer is that if, in spite of continual efforts to keep pace with progress in applied arts and sciences, there is a lag between information received by the institution and its being made available to the public, neither of the parties receives its dues. The museum is aware of its deficiency, while the public may or may not be cognisant of its lack of up-to-date information.

With all the goodwill and sympathy of which the States of Australia are capable, it is perhaps too much to expect, and certainly too much to hope, that finance will be available to conduct science museums in a manner befitting their importance. The cost appears to be one to spread over the resources of the Commonwealth of Australia, and all States should share in the benefits which the Federal Government is able to bestow.

Importance of the public service rendered by the museums of the various States should be the deciding factor in the allotment of assistance. The logical authority to make recommendations is a committee, responsible to parliament, consisting of personnel with an intimate knowledge of the obligations and requirements of museums. If constituted on a pattern similar to that of the Standing Commission on Museums and Galleries set up in London in 1931, each institution would have the benefit of careful investigation from time to time into its resources and requirements, and recommendations for assistance would be placed before the appropriate government authority without delay. Impartial judgments would guarantee that the institutions were given assistance in direct proportion to their services to the public. A perusal of the Third Report of the abovementioned Commission, issued in 1948, reveals on the one hand the necessity for such investigations and subsequent recommendations, and on the other a recognition by the British Treasury that National Museums and Galleries " are the fountain heads of knowledge, and it is their duty to provide the indispensable material for study in almost every domain of learning ". The following were the terms of reference of the Standing Commission :

(1) To advise generally on questions relevant to the most effective development of the National Institutions as a whole, and on any specific questions which may be referred to them from time to time.

(2) To promote cooperation between the National Institutions themselves, and between the National and Provincial Institutions ; and

(3) to stimulate the generosity and direct the efforts of those who aspire to become public benefactors.

In view of the success that has attended the work of that commission in England and Scotland, a similar commission in Australia might function as follows :

(1) To investigate the existing conditions of the various collections in the National Museums with special reference to the Applied Science Museums.

(2) To consider to what extent these Museums lag behind the great Science Museums of Europe, the United Kingdom and North America.

(3) To take steps to deal with the immediate practical needs of the National Museums :

    (*a*) Building requirements,

    (*b*) Financial requirements.

It is felt that the activities of the Standing Commission would be the only practical method of preventing long periods of stagnation, which finally call for sudden and costly remedial measures.

It does not appear to be generally recognized in Australia that modern science museums are not only great instruments of technical, as well as of popular, instruction, but are in reality symbols of national efficiency. This has been strikingly demonstrated in the great industrial countries such as the United Kingdom, the United States of America and Germany, where the great science museums are the envy of the world. However, despite this general lack of recognition, our experience has shown that the services which a science museum renders to the public are greatly appreciated by those who take advantage of them. In passing, it might be mentioned that frequently enquirers for information are surprised to learn that such an institution exists, until they have been directed to the museum as the source of such information. After the first introduction, we can count on a lasting acquaintance, and most likely, friendship, with the institution and its staff.

Overseas Visits by Senior Technical Officers.

The benefits to be derived from interstate and overseas visits by senior technical officers need no emphasis. The study of appropriate current literature, together with correspondence, furnishes much information, but nothing surpasses personal contacts and discussions with fellow scientific workers in other lands. At least one scientific officer should travel overseas every five years. Apart from information relative to exhibits and displays, contact with other research workers is invaluable to the institution. Unfortunately, the financial resources of most Australian museums do not allow of such activities, and overseas visits have depended almost entirely on the generosity of funds established in the U.S.A. In view of the overseas travel facilities offered by Australian Federal Government organizations, implementation of the suggestions regarding Federal responsibility for science museums would probably solve this problem. The members of the Standing Commission on Museums and Galleries, London, " are convinced of the value of constant visits from all members of the higher technical staffs of a museum or art gallery to other institutions. Such visits should be not only to other national institutions in this country, but also to museums and galleries in the provinces and overseas, and they should be made at the public expense."

The Duties of a Science Museum.

It is not my intention to describe in detail the activities of a science museum ; books have been published and papers covering every phase of museum work, methods of display, etc., presented to appropriate organizations by competent authorities. Rather do I wish to record some opinions and conclusions based on our own experiences during a period of over 30 years, in the belief that first-hand information will add something, however small, to what has already been published by previous writers.

Broadly speaking, the duties of a science museum may be stated as follows :

(1) An educational service in the form of exhibits and displays for the benefit of all sections of the community.

(2) An information service on questions of applied science.

(3) The carrying out of scientific research.

Much has been written about the exact rôle that a museum plays in education. The museum should be " a fountain head of knowledge " in the broadest sense of the word. My own opinion is that a modern science museum provides a broad liberal education for all sections of the community, both children and adults, which cannot be obtained from other educational sources. It bridges the gaps between other forms of education, from kindergarten to university or technical college, and constitutes a series of stepping stones to knowledge beyond the realm of systematic teaching. The value of visual education cannot be too strongly stressed, and of all forms, the three-dimensional presentation is the ideal teacher. Our world is a three-dimensional one, and it is logical that museum displays should transcend other media in conveying information and inspiration. " In its own way, the museum may, better than any other media of study, offer to people experiences which in the past were acquired by the growing generation through observation of events in their environment. A carefully selected set of specimens in a museum may act as a semblance of an environment to be viewed or to be used as a scene for activities " (Wittlin, 1949). But all this is conditional on the museum realizing its responsibilities and of performing its duties in accordance with its aims and objects. To quote Dr. Douglas A. Allan (1949), " what is demanded is thoughtful preparation and inspired presentation—the fundamentals of Visual Education ".

In addition to its duty of illustrating by displays the progress and applications of science, the museum is able to bring before the public the sociological implications of applied science as well as those of industrial development and progress. Thus the citizen learns that a foreign nation develops synthetic materials to replace natural materials previously imported, because of its inability to pay for them. Such knowledge leads to a better understanding of the underlying motives of national and international issues, and breeds tolerance and understanding. It gives the academically trained student a broader and practical grasp of applied principles, and helps the business man to understand the underlying facts upon which his business is based. It is important to note that UNESCO recognizes the part which museums are playing in world affairs, especially in regard to visual educational facilities for backward peoples. Particularly is the educational value of the museum exemplified in the case of the adult who has been unable, or unwilling to take advantage of the usual educational facilities in his youthful days. He is probably convinced that " it is too late to start now ", but also realizes that living in a democracy carries with it the obligation of self-discipline, and that, in order to take an interest in the affairs of the country and in the activities of its leaders, which he helped to put in power, he must have an intelligent understanding of the " how " and " why " of familiar everyday happenings. The science museum has replies to many of the questions an average child or adult asks himself from time to time. The fundamental principles of physics, chemistry, engineering, biology and other sciences and their applications are illustrated by exhibits, many of which have moving parts, labelled simply and as briefly as possible, consistent with scientific accuracy.

We have found that, if the exhibit has the approval of the intelligent twelve-year-old child, the average adult will be quite satisfied with its message of information. At the same time, there is need for a planned project to provide the environment and equipment for children of all ages to learn how to live, and to satisfy that curiosity which is the birthright of all healthy minds. I am of the opinion that the solution of the world's sociological and political problems lies in the liberal education of the growing child. If he or she be given the opportunity to learn voluntarily in the open atmosphere of scientific knowledge, we need have no fear that the mind will remain unsatisfied. The spirit of adventure and the search for satisfying knowledge will accomplish the desired ends. The result will be healthy-minded children, and eventually citizens with a sense of responsibility to themselves, to their fellows, and to the world.

It is the duty of a museum to set aside a section entirely for children. It should be " given " to them to use as they please. Naturally, appropriate equipment and exhibits must be provided for their enjoyment and instruction. If the child is able to take an active part in the working of, say, a model railway locomotive, or in manipulating the controls of an aeroplane, his ego is satisfied, and the lesson is absorbed not only without effort, but with keen enjoyment.

The static display calls for careful thought and labelling by personnel well acquainted with the needs and wishes of children.

It should be remembered that the founding of the Museum of Science and Industry, Chicago, U.S.A., sprang from a boy's interest in machines that move. Julius Rosenwald, father of the boy, was determined that his and other fathers' sons should have a museum similar to the great Deutsches Museum at Munich. He realized his ambition after having contributed five million dollars to the project. Full-scale engines, electric generating plant, etc., are a feature of this museum, also an apparently full-scale coal mine.

Exhibits and displays of applied art are an essential feature of a museum of applied arts and sciences. As in the case of applied science displays, the setting up and labelling must convey the story simply and concisely. The objective is to introduce the visitor to a subject which he probably feels is beyond his ability to comprehend. The background of fundamental knowledge regarding such objects as ceramic ware, antique metalware and ivory carvings may be acquired without much mental effort if care and thought are exercised in presentation and labelling. It might be mentioned here that opinions differ in regard to labels. Some think the printed label is best. Our preference is for good lettering by a ticket-writer, well trained in our requirements. A handwritten label, in our opinion, enlivens and gives " sympathy " to an exhibit.

THE VISITOR.

The duties of a museum towards the visitor must be kept in mind by each member of the staff. In a past era there was sometimes a tendency to regard the visitor as an interloper, and to assume that the institution—which belonged to the public—had been erected for the purpose of providing employment for a curator and several attendants. The museum of today, and especially the applied science museum, should be a dynamic and colourful institution, offering attractions and a hearty welcome to all who enter its doors. The casual visitor, as distinct from the one who has a definite objective, is often slightly bewildered when he arrives. A word of welcome from the Chief Attendant, who should always be present at the entrance, is sufficient to set the visitor at ease, and to dissipate any " official " atmosphere.

A published guide or catalogue of exhibits may be available for purchase, but we have found that a free one-page leaflet, indicating a limited number—ten, precisely—of the " highlights " to be found on each of our three display floors, is a very satisfactory introduction to the museum. The visitor quickly realizes that an attempt to " see everything " on one visit would produce " mental indigestion ", and physical fatigue. On the other hand, if he obeys the brief directions in the leaflet to go straight from one exhibit to the next mentioned, he will find that he has actually made a survey of the museum and its contents within a comparatively short period of time. During his movements from one exhibit to another, he has seen other exhibits which interest him, and he makes a mental resolve that a further visit must be paid. Thus his appetite for knowledge has been whetted, which is exactly what the museum intended. The detailed guide to exhibits will almost certainly be purchased as the visitor leaves.

It should be the aim of museums to impress the visitor as he steps inside the door. A vestibule, of circular, hexagonal or octagonal shape makes an impressive and dignified " reception room ". Here it is necessary to avoid making the transition from busy street to museum too severe or awesome. Without sacrifice of scientific accuracy or of æsthetic effect, the vestibule or entrance hall can be made a place of welcome, with even a " homely " touch to prepare the mind for instruction. A modern building, windowless and air-conditioned, needs but little aid to comfort, but the older buildings must be provided with the best that is available, consistent with financial resources.

Our own entrance hall contains an inlaid marble table of Florentine mosaic, a terra cotta group, two Japanese hand-embroidered silk and satin curtains, and a silk needlework picture. The wall is opposite the main stairway and floodlights illuminate the exhibits. The group of five exhibits is attractive and pleasing to the eye.

Amenities for Visitors.

A modern museum should possess all the facilities for ease of movement and comfort for the visitor. These include lifts, retiring rooms, a lounge or reading room, a restaurant and milk bar. The location of the restaurant requires careful consideration: while to many the grilling of a steak produces a sweet savour, the odour of cooking cabbage is not an appropriate accompaniment to the contemplation of an exquisite piece of Chinese porcelain or ivory carving. Where other comforts are lacking, ample seating at least should be provided. Small leatherette cushioned armchairs have proved satisfactory, and provide both rest and a vantage point from which to study the exhibits.

Drinking water should be available on each floor, and during the summer months iced water dispensers should be provided.

The Value of Captions.

" How to drink Sea-Water and Live ! " captures both the eye and the imagination. Is it possible that the Ancient Mariner's cry of despair, " Water, water everywhere, nor any drop to drink " has been disproved ? The exhibit of ion-exchange synthetic resins furnishes affirmative evidence.

Demonstrations of Working Exhibits.

In cases where a variety of demonstrations is given daily, efforts should be made to avoid clashing, in order that country, interstate and overseas visitors may be able to see all if desired. Demonstrations and working exhibits must always be in order if the public is to be served efficiently, and any sudden breakdown should be given immediate attention. This necessitates the presence of skilled artisans and tradesmen on the spot. Casual assistance cannot be relied on if the institution wishes to keep faith with the public. It is one of the small irritations besetting the administrative staff that such breakdowns generally occur an hour before the week-end break, or on the eve of a public holiday.

Ventilation and Lighting.

None of the museums in Australia is fitted with air-conditioning, consequently adequate ventilation is a problem. Dust and acid fumes, as well as soot and ash from city smoke stacks, are the arch enemies of museum exhibits, and prevailing winds must be studied during the year in order that the opening of windows, doors and fanlights may be regulated with discretion and commonsense.

Apart from internal lighting of cases by fluorescent lamps, many of the exhibits are illuminated by external sources of light. A certain amount of daylight may be utilized in a building with windows, but difficulties are experienced in excluding direct sunlight and in regulating the admission of diffused light. During the winter months the general lighting within the building must be supervised by the attendant staff in order that all exhibits may be visible to visitors at all times. It would appear that the lighting of museums is still a problem, and that windowless, air-conditioned buildings are the answer. The labour involved in the cleaning of windows and venetian blinds is also costly, and difficult to obtain at the present time.

Floors.

Our experience has shown that for general service and comfort for visitors a thick linoleum appears to offer advantages over other flooring materials. Where floors are rough or other than wooden, a composition or plywood should first be put down, and the linoleum laid over this material.

Replacement of Displays.

As the years pass it is necessary to review some displays, and probably to remove them altogether, since they have outlived their usefulness. The interior of our building consists of a series of bays each $18' \times 15'$, the walls being constructed of brick. Some years ago it was necessary to clean down the brickwork and apply paint. A careful selection of cream and green surface finishes of the enamel type, produced surprisingly attractive effects, the bays being transformed into " new " rooms for the reception of up-to-date exhibits. At the present time, the withdrawal of an exhibit from a bay provides the opportunity for lining the walls with wall board, fibre board or similar cellulose composition, and this may be finished with appropriate tints of colour according to the type of display.

Special Exhibits and Displays.

These are usually of a temporary nature, and are a means of furnishing up-to-date information to the public, at the same time keeping the activities of the museum before them. We set aside several cases for individual exhibits of outstanding interest and/or beauty. At the moment a fine example of Chinese carved ivory in an appropriate setting is displayed in one of these cases. Such exhibits prove a drawcard for the introduction of visitors to the museum, and are an added attraction for the regular visitor.

" The Exhibit of the Month " provides the opportunity for an exhibit to be removed from its associated exhibits, and to be studied and appreciated as an individual specimen.

Displays on a larger scale are placed in a room reserved for the purpose, and are designed to furnish information on subjects of topical interest, or to illustrate the properties and industrial applications of recently developed materials. At the present time, the latest types of synthetic fibres are being displayed, in addition to various types of plastics, in order to show their appropriate applications according to type.

Disposition of Exhibits.

Lack of space at times forces us to display a variety of exhibits close to each other. Such an arrangement sometimes calls for criticism. While it is conceded that a smooth transition from one type of exhibit to another is preferable, a contrast is at time not without value. In the older buildings it is not always practicable to place a new exhibit in its appropriate section. In that case care should be taken to avoid placing, say, an industrial exhibit or a piece of mechanism in the same line of vision as a delicate piece of ceramic ware. The point to be made is that, when space is available, it is advisable to make use of it, in order that delay may not be incurred between receipt of the material and its display. This does not excuse its exhibition without regard to its importance, and simply for the sake of giving it a safe resting place. It would be better to place it in the " recently acquired exhibits " case, until such time as it can be incorporated in the appropriate section.

GUIDE LECTURES.

Up to the present time we have not had the service of guide lecturers. We believe they can be very useful if their work is performed with the exercise of discretion and commonsense, but feel that a good deal of supervision is necessary to ensure freedom from the monotony of repetition. Recorded talks on such working exhibits as the Strasburg Clock model, television demonstration unit, and the recently installed Spitz Planetarium have proved successful to date. There is room for differences of opinion on this matter, but much will depend upon the nature of the exhibit and the need for a degree of dramatization in certain descriptions. Some demonstrations require the personal human factor to gain the necessary effect.

RESEARCH.

Most national museums have specialists in various branches of science, whose efforts are directed largely to the planning of displays but who also carry out original research. In an applied science museum, similar conditions exist, with the emphasis on applied research. The Museum of Applied Arts and Sciences established research laboratories over fifty years ago, and the classical researches on the essential oils of Australian flora by Baker and Smith have been continued up to the present time. As a result of these researches the institution is regarded as the authority on the chemistry and technology of Australian essential oils. As members are aware, results of the large majority of this work have been published in the Society's Journal and Proceedings. It may be mentioned that many of these oils had no commercial value or application before their composition and properties were determined. Subsequently, uses were found, and these products of the Australian bushland have been, for many years, in demand for therapeutic, industrial and perfumery purposes respectively. The great genus *Eucalyptus* and some of the " Tea Tree " genera are still under investigation by a team of botanists and chemists, and the present work has as its objectives :

(*a*) Solving the problem of so-called " physiological forms ", *i.e.* plants which are botanically identical, but which contain in their foliage essential oils of different composition.

(*b*) Determining the origin and rôle of essential oils in living plants.

(*c*) Extending the uses of major constituents present in commercial eucalyptus oils.

(*d*) Producing by selection and breeding, plants containing maximum yields of high quality essential oils.

For the purposes of objective (*d*) experimental plantations were established at the National Park and Castle Hill, each about thirty miles from Sydney, about ten years ago, and already promising results have been obtained with a number of species. Results of investigations having an economic bearing, but which are not entirely suitable for the Society's Journal, are published by the Museum.

It cannot be too strongly emphasized that research is the life-blood of a science museum. If the spirit of research be absent, the museum may truly be described as a " dead " place. By its very nature, a science museum is a research institution, and only in an atmosphere of active inquiry can its functions be maintained. Research contributes largely to the reservoir from which flows the information service to the public and to industry. Specialized displays are dependent upon the results of the institution's research, *e.g.* that illustrating the development of the eucalyptus oil industry of Australia. Incidentally, the laboratories are ideal training grounds for students or for scientific cadets taking science courses at teaching institutions. There is a variety of jobs to be done, from receiving and weighing foliage, distilling the oil therefrom, analysing the oils and identifying the constituents, according to the qualifications and experience of the worker. On the botanical side, genetical studies are proceeding, in collaboration with the chemists, and valuable field experience is thus available. The scientific officers, of course, may contribute advice and assistance, if required by the Keeper of Exhibits, in the setting up of displays. The information service provides an excellent training ground for students, who, under the guidance of senior officers, find that " learning by teaching " is a source of knowledge and satisfaction.

THE INFORMATION SERVICE.

This duty of a science museum is one which probably establishes a closer contact with the public and with industry and commerce than its other activities. The personal interview between enquirer and museum officer is a means of developing an association of mutual understanding, confidence and benefit. Information is furnished on the applications of chemistry, botany, art and craftmanship by the appropriate officers. Although our museum has furnished assistance to industry and to individuals for a period of over fifty years, there are still many who express surprise when directed to the institution.

The developments in technology and applied science during World War I resulted in a greater interest and appreciation of the value of science to industry, and the services of the museum were sought in regard to these matters. In 1930, the economic depression and resulting unemployment, in addition to tariff restrictions on imports, stimulated keen interest in the exploitation of Australia's natural resources. Manufacturers were compelled to produce articles previously imported, and in many cases had only a vague idea of the fundamental principles involved.

The Museum was able to furnish information quickly, and by lending a sympathetic and understanding ear to the problems, enabled the enquirers to grasp the principles on which the respective industries were based. It is not our purpose to provide detailed information or to carry out extensive investigations on behalf of enquirers. We merely " help industry to help itself ". The answer to a question probably adds the link to a chain of applied thought and experiment that puts the inquirer on the right track. The larger industrial organizations employ their own scientists and technologists, but the smaller industrialist is dependent upon the private consultant and the science museum for advice and guidance. Private consultants often require advice regarding alternative or newly developed materials on behalf of their clients, and they usually look to the science museum for this information.

The outbreak of World War II called for an increased demand for technical information, and the experience gained by the Museum during World War I and the economic depression proved invaluable. Many of the problems submitted were basically similar to those dealt with previously, and enabled the answers to be made with expedition. A service that is appreciated by inquirers is the interpretation of information acquired from a library. The latter institution has placed a research of technical literature before an inquirer and he has studied it to the best of his ability. His lack of fundamental scientific knowledge, however, results in some confusion, and he turns to the science museum, which he feels will handle his queries with sympathy and understanding. The gratitude of these people is ample reward for the effort involved, and must be experienced to be appreciated. The science museum has also become a clearing house where buyers and sellers are brought into contact with one another, because the museum has a wide knowledge of industry and its personnel. This service proved of great value during World War II when the armed forces, as well as industry, were seeking sources of supply of both raw and manufactured materials.

It is fitting to mention here that membership of scientific societies is of great advantage to museum officers, apart from the fellowship which they enjoy. Indeed, the privileges and obligations of membership are the stimulus to mutual help gladly given. I am sure that all members of this Society have at times been able to gain profitable information from a fellow member on a subject outside his or her domain in order to assist in the solution of some problem. This should not be the prime reason for a member wishing to join a scientific society, but is an important incidental that follows admission to membership.

Many industrialists are diffident about releasing information to government officials on methods of manufacture, or new techniques in production, but adopt an entirely different attitude to officers of a science museum. This confidence is born of mutual assistance, and the relationship thus enjoyed is part of the background that has helped us to help industry for so many years.

Conclusion.

It would be presumptious on my part to imply that this address embodies a description of the whole of the duties of a Science Museum, or, for that matter, all of its dues. The hope is expressed, however, that the suggestions and ideas set down may contribute to a better understanding and a greater sense of responsibility on the part of Australians, towards that national and somewhat neglected institution—the Science Museum.

Acknowledgements.

In the preparation of this address I have had frequent discussions with the Director, Mr. A. R. Penfold, and the Keeper of Exhibits, Mr. H. L. Brown, and I desire to express my thanks for their cooperation.

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OCCULTATIONS OBSERVED AT SYDNEY OBSERVATORY DURING 1950.

By W. H. Robertson, B.Sc.

(Communicated by the Government Astronomer.)

Manuscript received, December 20, 1950. Read, April 4, 1951.

The following observations of occultations were made at Sydney Observatory with the 11½-inch telescope. A tapping key was used to record the times on a chronograph, with the exception of 208, which was an eye and ear observation. The reduction elements were computed by the method given in the Occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. The necessary data were taken from the *Nautical Almanac* for 1950, the Moon's right ascension and declination (hourly table) and parallax (semi-diurnal table) being interpolated therefrom. No correction was applied to the observed times for personal effect, but a correction of —0·00076 hours was applied before entering the ephemeris of the Moon. This corresponds to a correction of —1″·5 to the Moon's mean longitude.

Table I.

Serial No.	N.Z.C. No.	Mag.	Date.	U.T.	Observer.
				h m s	
202	3332	7·2	Jan. 21	9 50 44·4	R
203	1189	5·0	Feb. 1	12 27 56·2	R
204	824	6·2	Feb. 26	11 09 18·0	W
205	1252	7·4	Mar. 1	8 57 21·3	R
206	1576	5·3	May 25	7 46 42·7	W
207	1814	7·0	May 27	14 06 19·0	W
208	2017	6·4	June 25	13 04 37·1	W
209	1925	1·2	Aug. 18	6 19 57·1	R
210	1925	1·2	Aug. 18	7 30 11·4	R
211	2645	6·0	Sept. 19	10 38 22·3	W
212	2644	6·3	Sept. 19	10 41 57·0	W
213	···	8·9	Sept. 19	10 47 33·8	W
214	2660	6·1	Sept. 19	12 53 31·9	W
215	3307	4·9	Nov. 17	11 35 12·8	R

Table I gives the observational material. The serial numbers follow on from those of the previous report (Robertson, 1951). The observers were H. W. Wood (W) and W. H. Robertson (R). In all cases the phase observed was disappearance at the dark limb, with the exception of 210, which was a reappearance at the bright limb. Table II gives the results of the reductions which were carried out in duplicate. The N.Z.C. numbers given are those of the Catalog of 3539 Zodiacal Stars for the Equinox 1950·0 (Robertson, 1940), as recorded in the *Nautical Almanac*.

TABLE II.

Serial No.	Lunation.	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of	
										$\Delta\alpha$	$\Delta\delta$
							″	″	″		
202	335	+ 93	+38	86	+35	14	−0·6	−0·6	−0·2	+ 9·8	+0·75
203	335	+ 99	+17	97	+17	3	0·0	0·0	0·0	+13·4	−0·04
204	336	+ 94	+34	88	+32	12	0·0	0·0	0·0	+11·9	+0·41
205	336	+100	+ 1	100	+ 1	0	+1·0	+1·0	0·0	+13·1	−0·25
206	339	+ 81	−59	65	−48	35	−0·2	−0·2	+0·1	+ 6·7	−0·89
207	339	+ 97	+26	93	+25	7	+0·8	+0·8	+0·2	+14·6	−0·23
208	340	+ 35	+94	12	+33	88	−0·9	−0·3	−0·8	+10·2	+0·71
209	342	+ 79	−61	63	−48	37	+0·6	+0·5	−0·4	+ 6·4	−0·90
210	342	− 96	−27	93	+26	7	+0·8	−0·8	−0·2	−14·5	+0·19
211	343	+ 77	−64	59	−49	41	+0·6	+0·5	−0·4	+10·4	−0·61
212	343	+ 72	+69	52	+50	48	−1·2	−0·9	−0·8	+ 9·2	+0·72
213	343	+ 67	+74	45	+50	55	−0·4	−0·3	−0·3	+ 8·4	+0·77
214	343	+ 73	−69	53	−50	47	+1·4	+1·0	−1·0	+10·0	−0·65
215	345	+ 95	+32	90	+30	10	−1·4	−1·3	−0·4	+10·4	+0·71

The star involved in occultation 213 was not included in the *Nautical Almanac* list; it is C.D. −28° 14412. Its apparent place was R.A. $18^{h}\,14^{m}\,22^{s}{\cdot}74$, Dec. −28° 17′ 13″·1 (Yale, 1943).

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AN ELEMENTARY NON-CONSERVATIVE ELECTRICAL SYSTEM.

By W. B. Smith-White,
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Introduction and Summary.

Recently I have shown (Smith-White, 1949 ; 1950) that the general electrostatic system containing deformable dielectrics is not mechanically conservative. As may be expected, the recognition of this fact is of the first importance in the construction of electrical theory. In this paper I discuss an elementary electrostatic system which shows in the simplest way the difference between the point of view taken by me and that implied by the so-called " energy method " in the theory of dielectric forces.

Briefly, I have said that the mechanical force acting on the dielectric is to be inferred directly from elementary electrical principles, ultimately, Coulomb's law ; and, when the proper expression is taken for this force, it appears that an electrostatic system is generally non-conservative if deformation of the dielectric bodies in it is allowed. For the energy method, on the other hand, an energy function U is derived for the system, assuming that the dielectrics in it are held rigid. It is then asserted that the mechanical forces acting on the dielectric are to be found by assuming that the system is conservative, with energy function U, when deformation of the dielectric bodies in it is allowed.

Consider for a moment a system consisting of a volume distribution of electric charge in the neighbourhood of a dielectric body. The dielectric will become polarised, and we regard it simply as a volume distribution of electric moment. To form my elementary system I replace the volume charge by a single point charge and the polarised region by a pair of point dipoles. To imitate the simplest dielectric systems I suppose these dipoles to be " inductive " ; *i.e.* the strength of each dipole will be proportional to the strength of the electric field in which it lies. The coefficients in this proportionality will correspond in some way to the dielectric constant $k=\frac{K-1}{4\pi}$. Finally I suppose that these coefficients depend upon the separation between the dipoles, and this corresponds roughly to the feature that k may depend on the material density of the dielectric body.

The System Considered.

Take a point charge e and two point dipoles p_1 and p_2 movable in a line OX. The dipole moments are supposed to be parallel to OX and to be estimated positive in the direction from O to X. Suppose that the abscissae of e, p_1 and p_2 are x, x_1 and x_2 and $x<x_1<x_2$.

Let φ be the electric potential at e, and let E_1, E_2 be the electric field intensities at p_1, p_2. Write

$$p_1=\lambda_1 E_1,\ p_2=\lambda_2 E_2\ ; \qquad \text{(1)}$$

$$\left.\begin{aligned} r_1&=x_1-x,\ r_2=x_2-x\ ; \\ s&=x_2-x_1=r_2-r_1. \end{aligned}\right\} \qquad \text{(2)}$$

Here λ_1, λ_2 may be functions of s.

Now

$$\left.\begin{aligned} \varphi&=-\frac{p_1}{r_1{}^2}-\frac{p_2}{r_2{}^2}, \\ E_1&=\frac{e}{r_1{}^2}+\frac{2p_2}{s^3}, \\ E_2&=\frac{e}{r_2{}^2}+\frac{2p_1}{s^3}. \end{aligned}\right\} \qquad \text{(3)}$$

Substitute from (3) in (1) and solve for p_1, p_2. Then

$$\left.\begin{aligned} p_1&=\frac{\lambda_1 e}{Dr_1{}^2}+\frac{2\lambda_1\lambda_2 e}{Ds^3r_2{}^2}, \\ p_2&=\frac{\lambda_2 e}{Dr_2{}^2}+\frac{2\lambda_1\lambda_2 e}{Ds^3r_1{}^2}, \end{aligned}\right\} \qquad \text{(4)}$$

where

$$D=1-\frac{4\lambda_1\lambda_2}{s^6}. \qquad \text{(5)}$$

If F, F_1 and F_2 be the mechanical forces acting on e, p_1, p_2 reckoned positive in the direction from O to X, then

$$\left.\begin{aligned} F\ &=\frac{2ep_1}{r_1{}^3}+\frac{2ep_2}{r_2{}^3}, \\ F_1&=-\frac{2ep_1}{r_1{}^3}+\frac{6p_1p_2}{s^4}, \\ F_2&=-\frac{2ep_2}{r_2{}^3}-\frac{6p_1p_2}{s^4}, \end{aligned}\right\} \qquad \text{(6)}$$

so that

$$F+F_1+F_2=0.$$

Substituting from (4) in (6),

$$\left.\begin{aligned} F\ &=\frac{2\lambda_1 e^2}{Dr_1{}^5}+\frac{2\lambda_2 e^2}{Dr_2{}^5}+\frac{4\lambda_1\lambda_2 e^2}{Ds^3}\cdot\frac{r_1+r_2}{r_1{}^3r_2{}^3}, \\ F_1&=-\frac{2\lambda_1 e^2}{Dr_1{}^5}-\frac{4\lambda_1\lambda_2 e^2}{Ds^3r_1{}^3r_2{}^2}+\frac{6\lambda_1\lambda_2 e^2}{D^2s^4}\left(\frac{2-D}{r_1{}^2r_2{}^2}+\frac{2\lambda_1}{s^3r_1{}^4}+\frac{2\lambda_2}{s^3r_2{}^4}\right), \\ F_2&=-\frac{2\lambda_2 e^2}{Dr_2{}^5}-\frac{4\lambda_1\lambda_2 e^2}{Ds^3r_1{}^2r_2{}^3}-\frac{6\lambda_1\lambda_2 e^2}{D^2s^4}\left(\frac{2-D}{r_1{}^2r_2{}^2}+\frac{2\lambda_1}{s^3r_1{}^4}+\frac{2\lambda_2}{s^3r_2{}^4}\right). \end{aligned}\right\} \qquad \text{(7)}$$

It may be seen that the forces (7) cannot in general be derived from an energy principle and then the system considered is non-conservative. In a differential displacement of the system the work done by these forces is

$$dW=Fdx+F_1dx_1+F_2dx_2=F_1dr_1+F_2dr_2. \qquad \text{(8)}$$

The expression (8), where F_1, F_2 have the values (7), is a perfect differential if and only if λ_1, λ_2 are constants. In fact, writing λ_1', λ_2', $(\lambda_1\lambda_2)'$ for derivatives with respect to s, and

$$\left.\begin{aligned} A_1&=\frac{\lambda_1'}{D}+\frac{4\lambda_1(\lambda_1\lambda_2)'}{D^2s^6},\\ A_2&=\frac{\lambda_2'}{D}+\frac{4\lambda_2(\lambda_1\lambda_2)'}{D^2s^6},\\ B&=\frac{(\lambda_1\lambda_2)'}{D^2s^3},\end{aligned}\right\} \tag{9}$$

a straightforward calculation gives

$$\frac{\partial F_2}{\partial r_1}-\frac{\partial F_1}{\partial r_2}=\frac{2e^2A_1}{r_1^5}+\frac{2e^2A_2}{r_2^5}+4e^2B\,\frac{r_1+r_2}{r_1^3r_2^3} \tag{10}$$

The right-hand side of (10) vanishes if λ_1, λ_2 are constants. Conversely, if the right-hand side of (10) vanishes identically in a domain of values of r_1, r_2 and we put $z=r_2+r_1$, $s=r_2-r_1$, we see that

$$\frac{2^6e^2}{(z^2-s^2)^5}\{A_1(z+s)^5+A_2(z-s)^5+4Bz(z^2-s^2)^2\}$$

is identically zero in z, s. It follows that B, A_1, A_2 must vanish identically in s, and then by (9), $(\lambda_1\lambda_2)'=0$, $\lambda_1'=0$, $\lambda_2'=0$.

Thus, when λ_1, λ_2 are not constants the system considered is not mechanically conservative.

THE ENERGY METHOD.

Instead of deriving the forces acting on the dipoles directly as in the preceding section, the "energy method" would assume the system to be mechanically conservative and would derive these forces by differentiation of the energy function. The force on the charge e would be taken from the first formula in (7) and the energy would be

$$U=-\int_{-\infty}^{x}Fdx=-\frac{2\lambda_1e^2}{D}\int_{r_1}^{\infty}\frac{dr_1}{r_1^5}-\frac{2\lambda_2e^2}{D}\int_{r_2}^{\infty}\frac{dr_2}{r_2^5}-\frac{128\lambda_1\lambda_2e^2}{Ds^3}\int_{z}^{\infty}\frac{zdz}{(z^2-s^2)^3}$$

where $z=r_2+r_1$. Evaluating the integrals,

$$U=-\frac{\lambda_1e^2}{2Dr_1^4}-\frac{\lambda_2e^2}{2Dr_2^4}-\frac{2\lambda_1\lambda_2e^2}{Ds^3r_1^2r_2^2} \tag{11}$$

The forces acting on the dipoles would now be taken as

$$F_1^{(h)}=-\frac{\partial U}{\partial r_1},\quad F_2^{(h)}=-\frac{\partial U}{\partial r_2}. \tag{12}$$

Calculating these derivatives and comparing with (7) we find

$$\left.\begin{aligned} F_1^{(h)}-F_1&=-\frac{e^2A_1}{2r_1^4}-\frac{e^2A_2}{2r_2^4}-\frac{2e^2B}{r_1^2r_2^2},\\ F_2^{(h)}-F_2&=\frac{e^2A_1}{2r_1^4}+\frac{e^2A_2}{2r_2^4}+\frac{2e^2B}{r_1^2r_2^2}.\end{aligned}\right\} \tag{13}$$

These formulae show that the mechanical forces in the system, according to the energy method, may be obtained from those derived directly by introducing an additional mutual repulsion between the dipoles of amount

$$\frac{e^2A_1}{2r_1^4}+\frac{e^2A_2}{2r_2^4}+\frac{2e^2B}{r_1^2r_2^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

From (3) and (9) we see that expression (14) is the same as

$$\tfrac{1}{2}E_1^2\lambda_1'+\tfrac{1}{2}E_2^2\lambda_2'. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

DIELECTRIC FORCES.

Any suggestion that the spurious repulsive force (14), between the dipoles of the elementary system, should be regarded seriously would probably be dismissed as fantastic. What I wish to make plain here is that precisely such a force is generally accepted in the commonly presented theory of dielectric forces due to Helmholtz. In the case of a fluid dielectric the force per unit volume, derived directly, is

$$\mathbf{F}=\tfrac{1}{2}k\nabla E^2,$$

and that given by the energy method is

$$\mathbf{F}^{(h)}=-\tfrac{1}{2}E^2\nabla k+\tfrac{1}{2}\nabla\left(E^2\tau\frac{\partial k}{\partial\tau}\right),$$

where $1+4\pi k$ is the dielectric constant, and τ is the density of the fluid. The difference between these expressions is

$$\mathbf{F}^{(h)}-\mathbf{F}=\tfrac{1}{2}\nabla\left(E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right)\right). \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

This formula corresponds exactly with the formula (13) above.

The following remarks may serve to elaborate the last statement. In a continuous isotropic medium the dipole element is $k\mathbf{E}dv$, where dv is an element of volume. If, to allow for dilatation of the medium, we use τ_0, dv_0 to denote undeformed or initial density and volume of an element, then $\tau_0dv_0=\tau dv$, so that

$$\mathbf{p}=\frac{k\tau_0}{\tau}dv_0\mathbf{E}.$$

Accordingly we may suppose $(k/\tau)\tau_0dv_0$ to correspond with the coefficient λ of the elementary system. Again we may associate τ of the dielectric with $1/s$ of the elementary system; we take τ/τ_0 to correspond with s_0/s, where s_0 is an initial value of s. Then to $s_0\dfrac{d\lambda}{ds}=d\lambda/d\left(\dfrac{s}{s_0}\right)$ will correspond

$$\frac{\partial}{\partial(\tau_0/\tau)}\left(\frac{k}{\tau}\tau_0dv_0\right)=-dv_0\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right).$$

Substituting (15) for the right-hand side of (13) and noting that

$$\lambda_1'=\frac{d\lambda_1}{ds}=-\frac{\partial\lambda_1}{\partial x_1},\ \lambda_2'=\frac{d\lambda_2}{ds}=\frac{\partial\lambda_2}{\partial x_2}$$

we have

$$F_1^{(h)}-F_1=\tfrac{1}{2}E_1^2\frac{\partial\lambda_1}{\partial x_1}-\tfrac{1}{2}E_2^2\frac{\partial\lambda_2}{\partial x_2}.$$

We now replace the right-hand side successively by

$$-\tfrac{1}{2}(x_2-x_1)\frac{\partial}{\partial x}\left(E^2\frac{\partial\lambda}{\partial x}\right),\quad -\tfrac{1}{2}s_0\frac{\partial}{\partial x}\left(E^2\frac{d\lambda}{ds}\right),$$

$$-\tfrac{1}{2}\frac{\partial}{\partial x}\left(E^2 s_0\frac{d\lambda}{ds}\right),\quad \tfrac{1}{2}dv_0\frac{\partial}{\partial x}\left(E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right)\right).$$

Finally, reckoning the force per unit volume, and replacing the last expression by the corresponding vector form we get

$$\mathbf{F}^{(h)}-\mathbf{F}=\tfrac{1}{2}\nabla\left(E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right)\right),$$

which is (16).

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THE ANALYSIS OF INFINITELY LONG BEAMS UNDER NORMAL LOADS.

By C. A. M. Gray, B.Sc., B.E.

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Introduction.

The determination of the stresses and displacements in an infinitely long beam under normal loads has been made by Filon and Th. v. Karman. Their solutions, however, were obtained by using Fourier integral expansions of the loads, and their results are expressed as definite integrals, which are rather difficult to interpret.

In this paper, the theory of the complex variable is used to develop the solution as a complex power series, giving a direct solution of the problem. Use is made of some general results given by Muscelisvili, in which he has reduced the solution of two dimensional problems in elasticity to the determination of two analytic functions, given, for simply connected areas, by two integral equations.

These integral relations are applied quite generally to the problem of a long beam, and it is shown that their solution is reduced to solving an infinite set of simultaneous equations. The solution of these equations is quite practicable by an iteration process, and a simple example already considered by Filon is given to illustrate this point.

Fundamental Equations.

Consider a two-dimensional elastic system in which the z or x,y plane is the plane of the applied forces. Define the two analytic functions $\Omega(z)$ and $w(z)$ of the complex variable z by

$$\left.\begin{aligned}\widehat{xx}+\widehat{yy}&=R_{\text{eal.}}\,\Omega'(z),\\ 2(\widehat{xx}-\widehat{yy}+2i\widehat{xy})&=-(z\bar{\Omega}''(\bar{z})+\bar{w}''(\bar{z})),\end{aligned}\right| \quad \ldots\ldots\ldots\ldots(1)$$

where the dashes (″) denote differentiation, the bars (—) the conjugates and the quantities $\widehat{xx}$, $\widehat{yy}$, $\widehat{xy}$ the stresses. Then, when the boundary loads are given, Muschelisvili (1933) has shown that they may be expressed as

$$\Omega(z_{\mathrm{B}})+z_{\mathrm{B}}\bar{\Omega}'(\bar{z}_{\mathrm{B}})+\bar{w}'(\bar{z}_{\mathrm{B}})=4i\int_0^s(X_\nu+iY_\nu)ds; \quad \ldots\ldots\ldots\ldots (2)$$

where X_ν and Y_ν are the components of the surface tractions along the x and y axes respectively, z_{B} is the boundary value of z, and the line integral is taken in the positive sense around the contour of the loaded body. Further, if the area in the z plane is conformally transformed to the unit circle γ: $|\zeta|<1$ in the ζ plane by the relation $z=f(\zeta)$, equation (2) becomes

$$\Omega\{f(\sigma)\}+f(\sigma)\bar{\Omega}'_{z}(\bar{\sigma})+\bar{w}'(\bar{\sigma})=F_1+iF_2; \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

the value of ζ on the boundary of γ being denoted by $\sigma=e^{i}\theta$ and the subscript z in the second term denoting that the differentiation is with regard to z.

Multiplying both sides of (3) by $d\sigma/2\pi i(\sigma-\zeta)$, integrating round the contour γ and applying Cauchy's Theorem, Muschelisvili then obtains (from (3)) the integral relation

$$2\pi i\Omega\{f(\zeta)\}=\int_\gamma (F_1+iF_2)d\sigma/(\sigma-\zeta)-\int_\gamma f(\sigma)\overline{\Omega}'_z(\bar{\sigma})d\sigma/(\sigma-\zeta)+\text{constant}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

and from the conjugate of (4)

$$2\pi iw'\{f(\zeta)\}=\int_\gamma (F_1-iF_2)d\sigma/(\sigma-\zeta)-\int_\gamma \bar{f}(\bar{\sigma})\Omega'_z(\sigma)d\sigma/(\sigma-\zeta)+\text{constant} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The solution of these equations is quite simple if the mapping function $f(\zeta)$ is rational, but, in general special consideration must be given to the second integral on the R.H.S. of (4) and (5). In the next section, the particular case of the mapping of an infinitely long rectangle on the unit circle is considered and, it will be shown, that if $\Omega'_z(\zeta)$ is given by the power series $\sum\limits_{r=0} b_r\zeta^r$ equation (4) can be replaced by an infinite set of simultaneous equations for the b's.

GENERAL SOLUTION FOR INFINITELY LONG BEAMS.

The transformation $z=-(2ih/\pi)\log_e(1+\zeta)/(1-\zeta)$ transforms the infinite strip $x=\pm h$, $-\infty<y<\infty$ into the unit circle in the ζ plane (refer Fig. (1)).

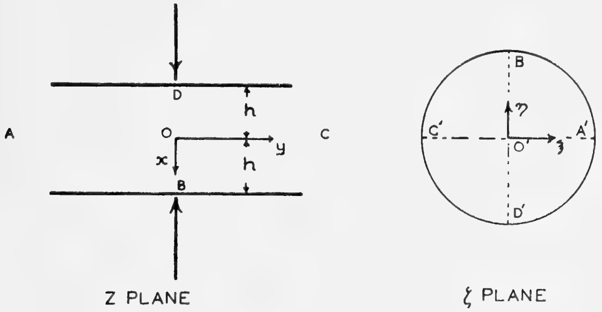

Fig. 1.

Hence from (4) we have

$$\Omega\{f(\zeta)\}=(1/2\pi i)\int_\gamma (F_1+iF_2)d\sigma/(\sigma-\zeta)$$
$$+(h/\pi^2)\int_\gamma [\log_e(1+\sigma)/(1-\sigma)]\overline{\Omega}'_z(\bar{\sigma})d\sigma/(\sigma-\zeta) \quad \ldots\ldots \quad \textbf{(4a)}$$

In this equation the first integral is known and the second integral can be determined as follows :

Consider $\int_c \overline{\Omega}'_z(1/u)\log(1-u)du/(u-\zeta)$ where C is the dotted contour and ζ is any point internal to γ.

Now if Ω'_z is analytic for $|u|<1$, $\overline{\Omega}'_z(1/u)$ will be analytic for $|u|>1$.

Hence,

$$\int_C \bar{\Omega}'_z(1/u) \log (1-u)du/(u-\zeta)=0\,;$$

$$\therefore -\int_\gamma \bar{\Omega}'_z(1/\sigma) \log (1-\sigma)d\sigma/(\sigma-\zeta)+ \int_C^D \bar{\Omega}'_z(1/\xi) \log (1-\xi)d\xi/(\xi-\zeta)$$

$$+\int_\Gamma \bar{\Omega}'_z(1/\sigma') \log (1-\sigma')d\sigma'/(\sigma'-\zeta)+\int_A^B \bar{\Omega}'_z(1/\xi) \log (1-\xi)d\xi/(\xi-\zeta)$$

$$=0\,;$$

where the contour integrals are taken in the positive sense.

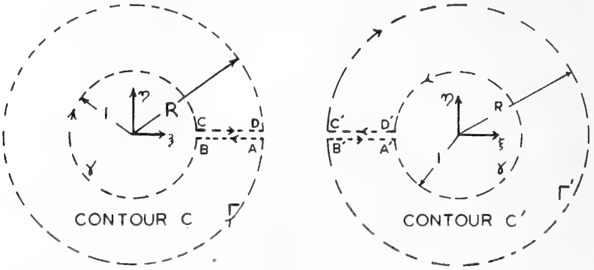

Fig. 2.

Now, along CD, $\xi=\rho$; and along AB, $\xi=\rho e^{2i\pi}$.

$$\therefore \int_1^R \bar{\Omega}'_z(1/\xi) \log (1-\xi)d\xi/(\xi-\zeta)+\int_R^1 \bar{\Omega}'_z(1/\xi) \log (1-\xi)d\xi/(\xi-\zeta)$$

$$=-2i\pi\int_1^R \bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta).$$

$$\therefore \int_\gamma \bar{\Omega}'_z(\bar{\sigma}) \log (1-\sigma)d\sigma/(\sigma-\zeta)=-2i\pi\int_1^R \bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)$$

$$+\int_\Gamma \bar{\Omega}'_z(1/\sigma') \log (1-\sigma')d\sigma'/(\sigma'-\zeta).$$

Similarly, we have for the contour C'

$$\int_\gamma \bar{\Omega}'_z(\bar{\sigma}) \log (1+\sigma)d\sigma/(\sigma-\zeta)=-2i\pi\int_{-1}^{-R} \bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)$$

$$+\int_{\Gamma^1} \bar{\Omega}'_z(1/\sigma') \log (1+\sigma')d\sigma'/(\sigma'-\zeta).$$

Hence,

$$\int_\gamma \bar{\Omega}'_z(\bar{\sigma}) \log (1+\sigma)/(1-\sigma)\,.\,d\sigma/(\sigma-\zeta)$$

$$=-2i\pi\int_{-1}^{-R} \bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)+2i\pi\int_1^R \bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)$$

$$+\int_{\Gamma 1} \bar{\Omega}'_z(1/\sigma') \log (1+\sigma')d\sigma'/(\sigma'-\zeta).$$

$$-\int_\Gamma \bar{\Omega}'_z(1/\sigma') \log (1-\sigma')d\sigma'/(\sigma'-\zeta).$$

Now, if Γ and Γ' increase indefinitely, and $\Omega'_z(u)$ is bounded for $u \rightarrow 0$, this becomes

$$(1/2\pi i)\int_{\gamma}\bar{\Omega}'_z(\bar{\sigma}) \log (1+\sigma)/(1-\sigma) \,.\, d\sigma/(\sigma-\zeta)=\int_{1}^{\infty}\bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)$$
$$-\int_{-1}^{-\infty}\bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta).$$

But,

$$\int_{1}^{\infty}\bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)=\int_{1}^{\infty}(\bar{b}_0+\bar{b}_1/\rho+\bar{b}_2/\rho^2 \ldots)d\rho/(\rho-\zeta)$$
$$=\bar{b}_0\int_{1}^{\infty}d\rho/(\rho-\zeta)-(\bar{b}_1/\zeta) \log (1-\zeta)-(\bar{b}_2/\zeta^2)[\log (1-\zeta)+\zeta] \ldots,$$

where $\Omega'_z(\zeta)=\sum\limits_{r=0} b_r\zeta^r$, for $|\zeta|<1$, since $\Omega'_z(\zeta)$ is analytic for $|\zeta|<1$.

Similarly,

$$\int_{-1}^{-\infty}\bar{\Omega}'_z(1/\rho)d\rho/(\rho-\zeta)=\bar{b}_0\int_{-1}^{-\infty}d\rho/(\rho-\zeta)-(\bar{b}_1/\zeta) \log (1+\zeta)$$
$$-(\bar{b}_2/\zeta^2)(\log (1+\zeta)-\zeta) \ldots$$

$$\therefore (1/2\pi i)\int_{\gamma}\bar{\Omega}'_z(\bar{\sigma}) \log (1+\sigma)/(1-\sigma) \,.\, d\sigma/(\sigma-\zeta)=\bar{b}_0 \log (1+\zeta)/(1-\zeta)$$
$$+(\bar{b}_1/\zeta) \log (1+\zeta)/(1-\zeta)+ \ldots$$

Now for $|\zeta|<1$,

$$\log (1+\zeta)/(1-\zeta)=2(\zeta+\zeta^3/3+\zeta^5/5 \ldots).$$

Hence,

$$(1/2\pi i)\int_{\gamma}\bar{\Omega}'_z(\bar{\sigma}) \log (1+\sigma)/(1-\sigma) \,.\, d\sigma/(\sigma-\zeta)=(2b_1+2\bar{b}_3/3 \ldots)$$
$$+2(\bar{b}_0+\bar{b}_2/3 \ldots)\zeta+2(\bar{b}_1/3+\bar{b}_3/5 \ldots)\zeta^2 \ldots$$

Again,

$$d\Omega/d\zeta=(d\Omega/dz)dz/d\zeta$$
$$=-(4ih/\pi)[b_0+b_1\zeta+(b_0+b_2)\zeta^2+\ldots].$$

Also $(1/2\pi i)\dfrac{d}{d\zeta}\displaystyle\int_{\gamma}(F_1+iF_2)d\sigma/(\sigma-\zeta)$ can be expressed as a power series $\sum\limits_{r=0} p_r\zeta^r$, for $|\zeta|<1$.

Hence differentiating both sides of (4A) with regard to ζ the following infinite set of equations is obtained to determine the b's:

$$\left.\begin{array}{l} b_0+(\bar{b}_0+\bar{b}_2/3+\bar{b}_4/5+\ldots) =ip_0\pi/4h \\ b_1+2(\bar{b}_1/3+\bar{b}_3/5+\bar{b}_5/7 \ldots) =ip_1\pi/4h \\ b_0+b_2+3(\bar{b}_0/3+\bar{b}_2/5+\bar{b}_4/7 \ldots)=ip_2\pi/4h \\ \qquad\qquad\qquad\qquad\text{etc.} \end{array}\right| \quad \ldots\ldots\ldots \quad (6)$$

With the b's determined, Ω'_z can be computed by either of two methods. We have directly by definition $\Omega'_z=\sum\limits_{r=0} b_r\zeta^r$, however, sometimes it is more convenient to obtain an expression from (4A). Differentiating both sides of (4A) with regard to z we have:

$$4h.\Omega'_{\mathrm{z}}=i\pi(1-\zeta^2)\Big[(1/2\pi i)\frac{d}{d\zeta}\int_\gamma(F_1+iF_2)d\sigma/(\sigma-\zeta)$$
$$+(4ih/\pi)[(i\pi p_0/4h-b_0)+(i\pi p_1/4h-b_1)\zeta+\ldots]\Big].$$

To complete the solution we require $w'(z)$. From equation (5) and carrying out the second integration in a similar fashion as for the corresponding integral in (4),

$$2\pi iw'(z)=\int_\gamma(F_1-iF_2)d\sigma/(\sigma-\zeta)-\int_\gamma\Omega'_{\mathrm{z}}(\sigma)\bar{f}(\sigma)d\sigma/(\sigma-\zeta)$$
$$=c_0+c_1\zeta+c_2\zeta^2\ldots;$$

where

$$c_1=q_1-(4ih/\pi)[b_2+b_6/5+b_{10}/9\ldots],$$
$$c_2=q_2-(4ih/\pi)[b_3+b_5/3+b_7/5\ldots],$$
$$c_3=q_3-(4ih/\pi)[b_4+b_6/3+b_8/5\ldots],$$

etc.

and

$$(1/2\pi i)\int_\gamma(F_1-iF_2)d\sigma/(\sigma-\zeta)=q_0+q_1\zeta+q_2\zeta^2\ldots$$

As an example consider the infinite beam loaded with two equal opposing normal forces placed at corresponding points of the two edges (refer to Fig. 1). Then, along BCD, $F_1+iF_2=-4i$, $F_1-iF_2=4i$,
and along DAB, $F_1+iF_2=0$, $F_1-iF_2=0$.

Hence, $(1/2\pi i)\int_\gamma(F_1+iF_2)d\sigma/(\sigma-\zeta)=(-2/\pi)\log(\sigma_{\mathrm{D}}-\zeta)/(\sigma_{\mathrm{B}}-\zeta)$.

$$\therefore\frac{d}{d\zeta}\int_\gamma(F_1+iF_2)d\sigma/(\sigma-\zeta)=-8(1-\zeta^2+\zeta^4-\zeta^6+\ldots).$$

Similarly,

$$(1/2\pi i)\int_\gamma(F_1-iF_2)d\sigma/(\sigma-\zeta)=(2/\pi)\log(\sigma_{\mathrm{D}}-\zeta)/(\sigma_{\mathrm{B}}-\zeta)$$
$$=(2/\pi)[\log\sigma_{\mathrm{D}}/\sigma_{\mathrm{B}}-2i\zeta+2i\zeta^3/3\ldots]$$

Equations (6) then become

$$2b_0+b_2/3+b_4/5+b_6/7\ldots=-h^{-1}$$
$$2b_0+1\cdot6b_2+0\cdot428571b_4+0\cdot333333b_6+\ldots=h^{-1}$$
$$2b_0+1\cdot71084b_2+1\cdot55555b_4+0\cdot454545b_6+\ldots=-h^{-1}$$
$$2b_0+1\cdot77778b_2+1\cdot63636b_4+1\cdot53846b_6+\ldots=h^{-1}$$

etc.

These equations can be solved by iteration, and Table I gives the results of seven iterations together with the accepted values.

Hence,

$$\Omega'_{\mathrm{z}}=\left\{-\frac{1-\zeta^2}{1+\zeta^2}+0\cdot341-0\cdot21\zeta^2-0\cdot05\zeta^4-0\cdot043\zeta^6\ldots\right\}h^{-1}.$$

$$4h^2\,.\,d\Omega'_{\mathrm{z}}/dz=i\pi\zeta(1-\zeta^2)[4/(1+\zeta^2)^2-0\cdot42-0\cdot2\zeta^2-0\cdot26\zeta^4\ldots].$$

$$dw'(z)/dz=-(1-\zeta^2)[-(1+\zeta^2)^{-1}-0\cdot7854(1-\zeta^2)/(1+\zeta^2)$$
$$+3\cdot1416\zeta^2/(1+\zeta^2)^2-0\cdot55014+0\cdot215\zeta^2+0\cdot215\zeta^4\ldots]h^{-1}.$$

TABLE I.

Iteration.	$b_0 \times h$.	$b_2 \times h$.	$b_4 \times h$.	$b_6 \times h$.	$b_8 \times h$.	$b_{10} \times h$.
0	—	—	—	—	—	—
1	—	—	—	—	—	—
2	—0·61207	1·76415	—1·80009	1·32181	—	—
3	—0·708431	1·71731	—2·00701	1·72058	—1·34823	—
4	—0·634263	1·82678	—2·00593	1·90613	—1·77065	1·33048
5	—0·703277	1·75369	—2·07246	1·92217	—1·94988	1·75816
6	—0·64225	1·82921	—2·02635	1·96914	—1·97449	1·97113
7	—0·69795	1·76036	2·07620	1·94526	—2·01862	2·0286
Accepted values	—0·659	1·79	—2·05	1·957	—2	2

The stresses can now be calculated from (1) and the distributions along OX and OY are shown in Figure 3. As a check on the approximation the values calculated by Filon (1900) are shown.

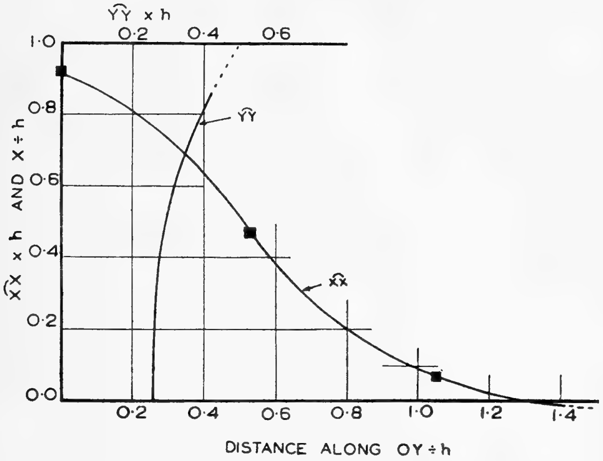

Fig. 3.

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OF
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Containing the Clarke Memorial Lecture for 1951 and Papers read in July and August, 1951

Pp. 26-81, Plates I-VI

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IDA A. BROWNE, D.Sc.

Honorary Editorial Secretary

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CLARKE MEMORIAL LECTURE

THE ORE MINERALS AND THEIR TEXTURES.*

By A. B. EDWARDS, D.Sc., Ph.D., D.I.C.

With Plates I-IV and three text-figures.

I. COMMEMORATIVE.

We are gathered tonight in commemoration of the Reverend W. B. Clarke, one of the founders of Australian geology.

William Branwhite Clarke was born in Suffolk in 1798. He entered Jesus College, Cambridge, in 1817, where he studied under Professor Sedgwick, received the degree of Bachelor of Arts in 1821, and the Master's degree in 1824. He was ordained a minister of the Church of England in 1821, and in that capacity he migrated in 1839 to New South Wales, where he continued his ministrations until his retirement in 1870 at the age of 72 years.

He began his geological studies soon after his arrival, and continued them until his death in 1878. They are preserved for us in more than 50 papers published in the Journal of this Society and in the Quarterly Journal of the Geological Society, and in his book, " Remarks on the Sedimentary Formations of New South Wales ", which ran to four editions in his lifetime.

His interests embraced the whole field of geology. He was the first, after Strzelecki, to discover gold in the colony, in 1841, and the first to discover tin, in 1849. He made the first records of Silurian and Cretaceous fossils in Australia, and many of the formations of this country received their names at his hand, such as your familiar Hawkesbury Sandstone. His chief contribution, however, was in determining the structure, succession and age of the Permian coalfields of New South Wales, in the face of vigorous controversy.

In 1876 he was elected a Fellow of the Royal Society—still a rare distinction for scientists in this country—and in 1877 the Geological Society of London gave further recognition to his work by awarding him its Murchison Medal.

It is pleasing to record that he was not without honour in his own country, and that in the very year of his death, 1878, the Clarke Memorial Medal was founded in his honour.

His annual commemoration has been extended to include a public lecture, which it is my duty tonight to present to you. It is a considerable honour to have been chosen to do this, and I trust you will forgive me in that my subject does not relate very closely to William Clarke's work. Nowadays we are forced to be more restricted in our geological interests, and I have thought it proper that on this occasion I should review some aspects of the subject of which I have most first-hand experience, namely " The Ore Minerals and their Textures ". My subject is the more apposite in that the Clarke Memorial Medal for 1951 has been awarded to my chief and colleague, Dr. Frank Leslie Stillwell, in recognition, among other things, of his work with the ore minerals. Dr. Stillwell has done more than any other to promote the study of the ore minerals in this country, and much of what I have to say is based on his labours and teaching.

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* Delivered to the Royal Society of New South Wales, June 14, 1951.

II. The Ore Minerals and Their Textures.

The ore minerals, or as they may be termed equally, the opaque minerals, are in some respects simpler in their atomic structures than the common rock minerals, but paradoxically from this simplicity comes a complexity within themselves that is revealed in their textures.

They comprise three groups : (i) the *sulphides*, with which may be included arsenides, antimonides and tellurides, and which comprise by far the greater variety of the ore minerals, (ii) the *opaque oxides*, which are few in number but of greater economic importance, as a source of iron and the ferro-alloys, and (iii) the *native metals*, equally few in number, but also of considerable economic importance.

The sulphides are most distinctive compounds. They are predominantly covalent (or homopolar) structures. The only essentially ionic sulphides are those of the alkalis and the alkaline-earths, which are water-soluble, and are not found as discrete minerals.

The predominantly covalent character of the sulphides probably arises from the fact that the large sulphur atoms, and in particular the S^{2-} ions, are highly polarizable structures. This could explain the selective association, found under natural conditions, of sulphur with the B sub-group elements of the Periodic Table—the so-called *chalcophile* elements—which are all strongly polarizing, 18-electron shell-type elements, and with certain of the transition metals, which approximate to 18-electron shell-type elements. An association of sulphur with a chalcophile element appears to satisfy the polarizing characters of both, more effectively than other associations can ; and the intensity of the resulting polarization is apparently such that these sulphide molecules, once formed, are indifferent, even in a melt, to a silicon-oxygen environment. They become immiscible in a silicate melt, so that they fail to be incorporated in silicate minerals.

Many of the sulphides in addition possess metallic characteristics, indicating some degree of metallic bonding. This arises from their high metal content, and the fact that in most of them the metal atoms occur in well defined planes from which non-metallic elements are excluded.

Structures of the Sulphides.

As a result of these features the sulphides form a variety of more or less close packed crystal structures that include infinite three-dimensional complexes, layer structures and chain structures, in a general way comparable with silicate structures, but mutually exclusive. The structures of the main sulphide groups are described in W. L. Bragg's " Atomic Structure of Minerals " (1937) and in numerous papers in the journals. Their chemical aspects are discussed in A. F. Well's " Structural Inorganic Chemistry " (1945) and R. C. Evans' " Introduction to Crystal Chemistry " (1948), and need not be considered here. Brief reference to the forms of some of these sulphide structures is necessary, however, to explain the peculiar textures and relationships of the ore minerals.

Table 1 (from Wells, p. 386) summarizes the chief types of crystal structure shown by the simple sulphides. The antifluorite type of sulphide structure does not concern us, because these compounds are not found as minerals.

Of the sulphides crystallizing with a *rock salt structure* (Text-fig. 1 (a)), one, galena, PbS, is of great importance as an ore mineral. The lead and sulphur atoms are arranged alternately at the corners of a set of cubes, the atoms of either kind forming a face-centred cubic lattice. Each lead atom is surrounded by six sulphur atoms, and each sulphur by six lead atoms. Few other of the common sulphides assume this form, which accounts for the " aloofness " of galena in assuming relationships with other minerals.

The crystallization of galena with the rock salt structure does not imply ionic bonding of the crystal, as is apparent from the physical properties of galena, which is opaque, with a brilliant metallic lustre, quite unlike the colourless and transparent ionic sulphides.

The pyrite structure (Text-fig. 1 (b)) (*after* Bragg, p. 71 ; Wells, p. 390) may be regarded as a variant of the rock-salt or galena structure, if we suppose the Fe atoms to replace the Pb atoms, and a double S group to replace the single S atoms of the galena structure. These dumb-bell shaped S_2 groups are so oriented that each of the eight small cubes into which the unit cube is divided in Text-fig. 1 (b) has only *one group* pointing towards its centre. Each of the S atoms is linked to one S atom on one side, and to a triad of Fe atoms on the other, so that the S_2 group, considered as a unit, lies between six metal atoms, like the S atoms in PbS, and each Fe atom touches six sulphur atoms. The distance between the S atoms is 2·10 A. This is much less than twice the radius of a sulphur atom, which would be about 3·5 A., and indicates that the S atoms are linked by covalent (homopolar) bonds.

TABLE 1.

The Crystal Structures of Some Sulphides.

(*From* Wells, *Structural Inorganic Chemistry*, p. 386.)

Type of Structure.	Coordination Numbers of M and S.	Name of Structure.	Examples.
Infinite 3 - dimensional complexes.	4 : 8	Antifluorite.	Li_2S, Na_2S, K_2S, Rb_2S.
	6 : 6	Rock-salt.	MgS, CaS, SrS, BaS, MnS, PbS.
	6 : 6	Nickel arsenide.	FeS, CoS, NiS.*
	6 : 6†	Pyrites or Marcasite.	FeS_2, CoS_2, NiS_2, MnS_2, OsS_2, RuS_2.
	4 : 4	Zinc-blende.	BeS, ZnS, CdS, HgS‡
		Wurtzite.	ZnS, CdS, MnS.
	4 : 4	Cooperite.	PtS.
Layer structures	6 : 3	Cadmium iodide.	TiS_2, ZrS_2, SnS_2, PtS_2.
	6 : 3	Molybdenum sulphide.	MoS_2, WS_2.
Chain structures ..			Sb_2S_3, Bi_2S_3, SiS_2.
Molecular structures			All sulphides consisting of finite molecules.

* Also the millerite structure (5 : 5 coordination).

† The coordination numbers here are those of Fe by S and of S_2 groups by Fe (or other metal).

‡ Metacinnabarite—also the hexagonal cinnabar structure.

Closely related to the pyrite structure is the structure of minerals of the *ulmannite class*, viz. ulmannite (NiSbS), gersdorffite (NiAsS), cobaltite (CoAsS). In ulmannite a nickel atom takes the place of each iron atom of the pyrite, while an SbS group replaces each S_2 group. Comparable substitutions occur with gersdorffite and cobaltite.

The *marcasite structure* (Text-fig. 1 (c)) (*after* Bragg, p. 74 ; Wells, p. 390) is closely related to the pyrite structure. In the marcasite structure the Fe atoms lie at the corners and centre of an ortho-rhombic cell. The inclined S_2 groups are centred midway between the Fe atoms in the *c*-direction, and lie on reflection planes. As in the pyrite structure, each S atom is linked to an S atom on one side and to a triad of Fe atoms on the other side, and each Fe atom touches six S atoms.

Arsenic substitutes readily for sulphur in this structure, giving either arsenopyrite (FeAsS), with AsS groups, or lollingite ($FeAs_2$) with As_2 groups. This explains the ready replacement of lollingite by arsenopyrite, observed in many ores, e.g. at Broken Hill (Stillwell and Edwards, 1939) (Plate I, fig. 1). By replacement I mean " the dissolving of one mineral and the simultaneous deposition of another mineral in its place, without the intervening development of appreciable open spaces, and commonly without change of volume ". The replacement of lollingite by arsenopyrite involves solid diffusion of an S atom into the lattice and simultaneous outward diffusion of an As atom, without any change in the crystal structure, and as can be seen from Plate I, fig. 1, the inward diffusion of the replacing atoms and the outward diffusion of the substituted atoms follows the crystallographic directions of the lollingite.

Another important sulphide structure is the *nickel arsenide structure* (Text-fig. 1 (d)). Minerals that crystallize with this structure are niccolite (NiAs), breithauptite (NiSb) and pyrrhotite (FeS). In niccolite the nickel atoms lie on a simple hexagonal lattice (Text-fig. 1 (d)). Every arsenic atom lies between six nickel atoms, and every nickel atom lies between six arsenic atoms, and *also* between two nickel atoms which are so close that they must be regarded as nearest neighbours.

The arsenic atoms, as may be seen from Text-fig. 1 (d), lie on two hexagonal lattices, which are roughly in the position of hexagonal closest packing with respect to one another.

With pyrrhotite Fe atoms take the place of Ni atoms, and S atoms take the place of As atoms.

Compounds of this structure are metallic in appearance, and tend to be of variable composition. The variable composition of pyrrhotite is well known. It almost always contains S in excess of the formula FeS, and a variety of formulae ranging from Fe_6S_7 to $Fe_{11}S_{12}$ have been proposed to cover this variation. X-ray examination has established that the variability arises not from variable sulphur content but from the fact that a variable proportion of the iron positions in the structure are *vacant*, so that in the sulphur-rich varieties the number of iron atoms present is below normal (Hägg and Sucksdorff, 1933). This is demonstrated in Text-fig. 1 (e) (*after* Bragg, p. 67), which shows the observed densities of pyrrhotites of a range of composition, plotted as circles, against the calculated curves of density variation to be expected from (i) substituting sulphur for iron, and (ii) withdrawing iron atoms from some of the lattice points. As Bragg comments, " the verdict is clearly for the withdrawal of iron ".

The well-known tendency for some pyrrhotites to react with oxygen, and thereby retard the dissolution of gold in cyanide solutions, is probably related to this habit of lattice defect, which is also shared by pyrite. Pyrite, like pyrrhotite, is notably non-stoichiometric, its composition ranging from $FeS_{1\cdot94}$ to $FeS_{2\cdot04}$, with a corresponding variation in such properties as density and electrical conductivity (Smith, 1942).

There is some tendency for atoms of foreign metals to lodge in the vacant iron sites in these structures, giving a form of limited solid solution. Thus occurrences of gold apparently in solid solution in high temperature pyrite are known from various epithermal gold ores, a notable example being the pyrite of the Dolphin East Lode, at Vatukoula, Fiji, where concentrations of gold as high as 25 ounces (780 grammes) of gold per ton of pyrite have been encountered, the gold being invisible at the highest magnification, though detectable with the spectroscope (Stillwell and Edwards, 1946).

If pyrite containing such " invisible " gold is annealed at 600° C. for several hours, the gold aggregates into particles of visible size (1 to 2 microns). The visible particles so formed resemble many natural occurrences of fine-grained

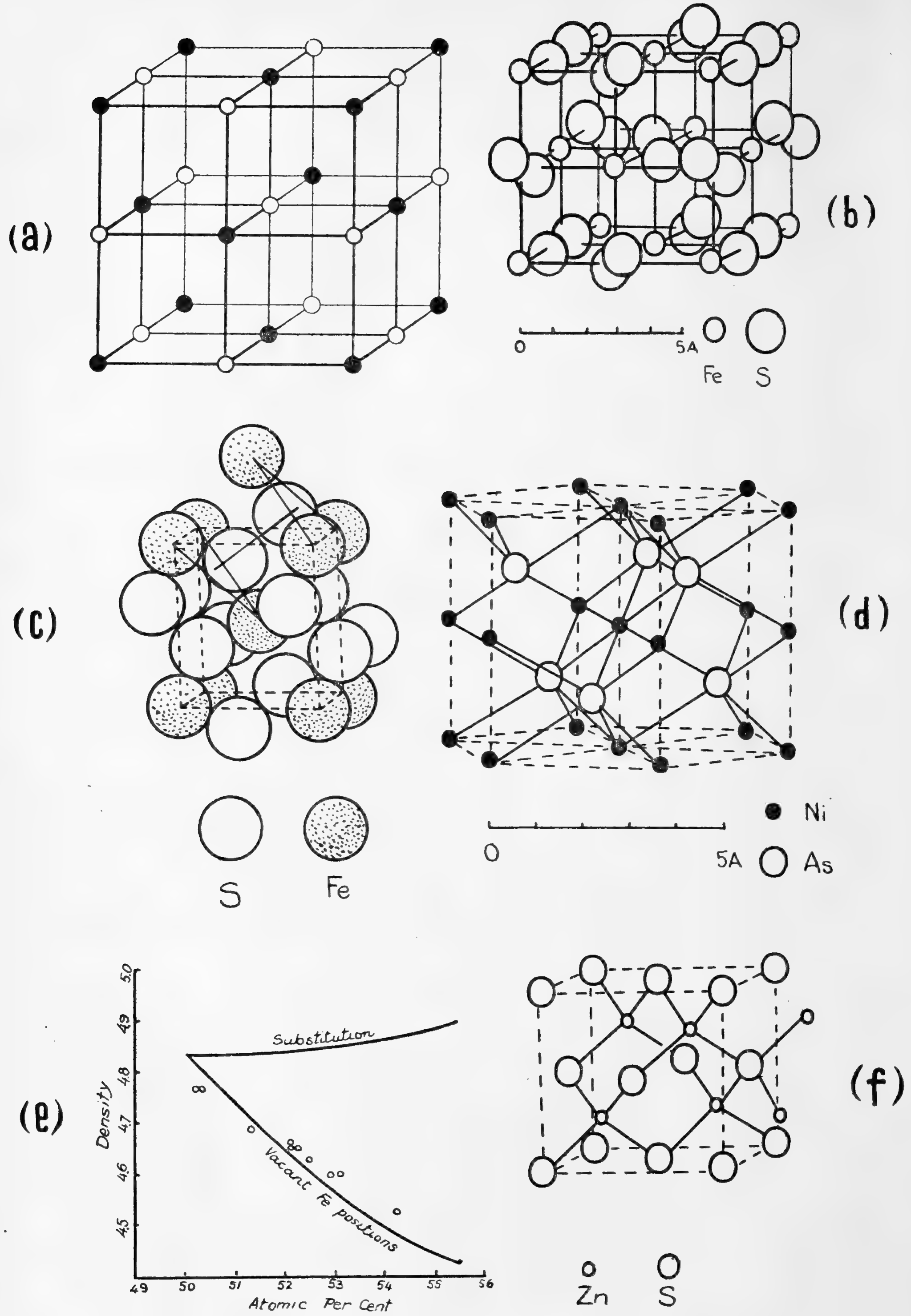
(a)
(b)
0
5A
Fe
S
(c)
S
Fe
(d)
Ni
0
5A
As
(e)
Density
5.0
4.9
4.8
4.7
4.6
4.5
49
50
51
52
53
54
55
56
Atomic Per Cent
Substitution
Vacant Fe positions
(f)
Zn
S

Fig. I.

gold (Plate I, fig. 2), which may have resulted from the unmixing and segregation of gold in solid solution, during the auto-annealing, i.e. the slow cooling, of the ore deposits concerned (Maslinitsky, 1944). Alternatively it might derive from the spontaneous breakdown of Au_2S_3, which is stable only at high temperatures, under a high pressure of sulphur vapour (Maslinitsky, 1944).

Gordon Smith (1947) has made an ingenious attempt to use the lattice defects of pyrite as a measure of its temperature of formation. His *pyrite geothermometer* consists of a pair of hot and cold electrodes, connected through a sensitive galvanometer, that measures the potential difference set up when the two electrodes are applied simultaneously to the surface of a pyrite crystal. The greater the number of defects the lower the potential difference that results. The theory is that high temperature crystals are most nearly perfect, and that the number of lattice defects increases as the temperature of crystallization decreases. While this seems true for pure substances, it fails to take account of the effects of impurities and foreign atoms in minerals, so that some pyrites give anomalous results.

In the *zinc blende structure* (Text-fig. 1 (f)) (*after* Wells, p. 83), which characterizes sphalerite and a number of other sulphide minerals, the metal atoms lie in a face-centred cubic lattice, and the sulphur atoms are arranged in a similar lattice. Thus in sphalerite (ZnS) each S atom is surrounded by four Zn atoms at the corners of a tetrahedron, all the tetrahedra being similarly oriented, and each Zn atom is surrounded similarly by four S atoms at the corners of a tetrahedron.

Chalcopyrite ($CuFeS_2$) has a very similar structure in which the Zn atoms of ZnS are replaced by alternate Cu and Fe atoms, but the unit cell of chalcopyrite is twice as large as that of ZnS (Text-fig. 2 (a)) (*after* Wells, p. 395). The difference in size of the Cu and Fe atoms compared with the Zn atoms causes the tetrahedral arrangement of the metal atoms in $CuFeS_2$ to be slightly irregular, so that $CuFeS_2$ is tetragonal, but with its angles very close to those of the cubic system.

In stannite (Cu_2FeSnS_4) the same structure is retained, but half of the Fe atoms are replaced by Sn atoms. A further difference is that in the stannite all the copper atoms occupy planes by themselves, parallel to 001, with the Sn and Fe atoms occupying alternate positions in the intervening metal planes (Text-fig. 2 (a)).

Clearly there is opportunity for extensive isomorphous substitution of Cu, Fe, Sn and Zn for one another in these structures, that is, for solid solution between these minerals. The relationships are more complex in that tetrahedrite (Cu_3SbS_3) and tennantite (Cu_3AsS_3) also have this structure. The

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References to Fig. 1.

Text-Fig. 1 (a).—The structure of galena (rock-salt structure) (black circles = lead, open circles = sulphur). Translation can occur either along a (111) plane or parallel to a cube plane (001), provided the movement is in the direction of a cube-diagonal (110), without bringing like-charged atoms opposite one another in adjacent planes. Movement in the (001) plane is preferred because the (001) planes are the most widely spaced in the lattice.

Text-Fig. 1 (b).—The pyrite structure, with the S–S distance reduced to accentuate the resemblance to the galena or rock-salt structure. *After* Wells.

Text-Fig. 1 (c).—The marcasite structure. The iron atoms (shaded) outline the unit cell. The position of the S_2 group between two iron triads is shown. *After* Bragg.

Text-Fig. 1 (d).—The nickel arsenide structure, NiAs. The central nickel atom is surrounded by six arsenic atoms and two nickel atoms. *After* Bragg.

Text-Fig. 1 (e).—The circles show the observed variation of density of pyrrhotite with composition. Their proximity to the lower curve proves that variation occurs by withdrawal of iron atoms from lattice positions. *After* Bragg.

Text-Fig. 1 (f).—The zinc-blende structure, ZnS. *After* Wells.

Cu atoms substitute for three-quarters of the Zn atoms in the ZnS structure, and the Sb or As atoms for the remaining Zn atoms, but since both Sb and As form only three strong bonds, one-quarter of the S positions are left unoccupied.

Solid Solutions.

With increasing temperature the possibilities of solid solution are enhanced, in that the radius of vibration of each atom is increased, so that the space that it occupies is enlarged, and this makes easier any substitution of a foreign metal atom of different size than the normal metal atom of the structure without causing undue distortion of the lattice (Buerger, 1934).

Order-Disorder Transformations.

Solid solution between a number of the sulphide minerals is further promoted in that high temperature introduces disorder in their crystal structures. The sulphur lattices remain sensibly perfect, but the metal lattices become more or less completely disordered, so that the metal atoms are distributed statistically through the crystal structure, as in a liquid. This behaviour has been established for the silver and copper selenides, and for argentite (Ag_2S) and hessite (Ag_2Te) by Rahlfs (1936), for chalcocite (Cu_2S) and digenite (Cu_9S_5) by N. W. Buerger (1941), and more recently for chalcopyrite ($CuFeS_2$), stannite (Cu_2FeSnS_4) and bornite (Cu_4FeS_5) by Frueh (1950), and it is probably to be found in any sulphide minerals which show inversion twinning, like hessite (Plate I, fig. 3), stannite and matildite. The symmetry of the ordered form is a sub-group of that of the disordered form, so that inversion twinning commonly develops with a return to order.

If a crystal contains two or more chemically different kinds of atoms, A and B, which play similar roles in the crystal lattice, e.g. Cu and Fe in chalcopyrite, Cu, Fe and Sn in stannite, at high temperatures disorder may prevail among these atoms, so that instead of occurring in strictly ordered positions relative to one another in the crystal structure, they may proxy for each other indistinguishably (Buerger, 1948, p. 101). In a disordered state an excess of A relative to B can be accepted into the structure ; but with a return to order the excess A must be rejected.

When in a state of disorder, i.e. at high temperatures, extensive solid solution is possible between those groups of minerals which have similar crystal structures, and in which the S atoms, or their equivalents, are more or less equally spaced. Thus extensive mutual solid solution is possible between ZnS, FeS, $CuFeS_2$, Cu_2FeSnS_4, Cu_3SbS_3 and Cu_3AsS_3.

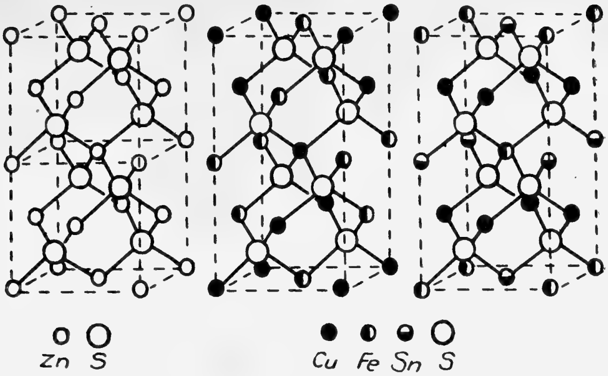
Unmixing.

With the cooling of such a solid solution there occurs (i) a general shrinkage of the structure, and (ii) a return to the ordered state. Both changes cause precipitation of the solute atoms (Buerger, 1934, p. 444 ; 1948, p. 101).

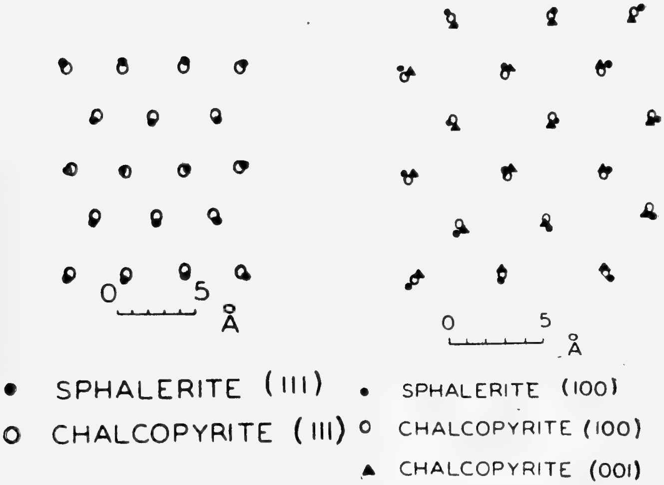
The precipitates appear as minerals intimately intergrown with the solvent mineral or host, and generally these intergrowths are oriented parallel to certain favoured crystallographic directions of the host (Plate I, fig. 5).

In such oriented intergrowths the contact planes between the two minerals are planes in which (i) the atoms in the plane consist of an element common to both minerals, and (ii) in which the atomic spacings are similar for both minerals so that the linear differences in spacing of the atoms of this element in the equivalent planes of the two minerals does not exceed 10% of the spacing of the larger of the two structures concerned (Gruner, 1929, p. 227). The contact plane thus fits equally well into the structure of each of the minerals in the intergrowth and is *shared* by them, so that no structural break is involved at the interface. Text-fig. 2 (b) shows the spacing of S atoms in the (111) and (100)

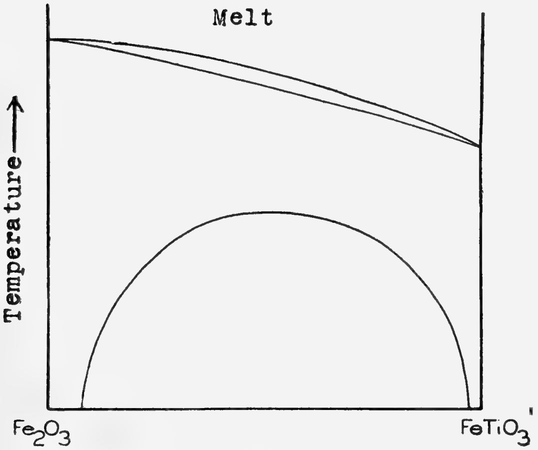
(a)



(b)



(c)



Text-Fig. 2 (a).—Crystal structures of ZnS showing two cell units, $CuFeS_2$ and Cu_2FeSnS_4. *After* Wells.

Text-Fig. 2 (b).—Spacing of S atoms in the (111) and (100) planes of sphalerite and chalcopyrite. (*After* Gruner, *Amer. Mineral.*, 14, 1929.)

Text-Fig. 2 (c).—Diagram to represent the phase relations of hematite and ilmenite. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 110, 1938.)

planes of sphalerite and chalcopyrite. The close coincidence of the S atoms permits these two minerals to share their S planes in intergrowths.

Where there is only one set of planes of such pronounced chemical and structural similarity common to both minerals, lamellar intergrowths occur (Plate I, fig. 5). Where there are two or more sets of planes that can be shared lamellar intergrowths may occur, or the solute mineral may form skeletal crystals (Plate I, fig. 4), or more or less globular bodies distributed through the host as droplets in an emulsion (Plate II, fig. 1).

Under favourable conditions, naturally occurring intergrowths of this kind can be tested by heat treatment, and the temperature at which unmixing (precipitation) occurs can be determined, thereby providing a point on the geological thermometer.

Segregation.

Unmixing at high temperatures, with slow cooling, is accompanied by more or less rapid solid diffusion of the precipitated phase out of unfavourable structure, leading to segregation of the solute mineral (precipitate) in the grain boundaries of the host. If the amount of precipitated mineral is small, it will accumulate as a network of narrow curving seams in the grain boundaries of its former host (Plate I, fig. 6), when the original relationship between the two minerals can be recognized.

If, however, the proportions of solvent and precipitate mineral are more equal, segregation may lead to a coarse intergranular texture, from which it is difficult to find evidence of former solid solution (Plate II, fig. 2).

Progressive Unmixing.

Some solid solutions unmix more or less completely at a particular temperature at which inversion from the disordered to the ordered state occurs abruptly, as when matildite and galena, both with rock-salt structure, unmix almost completely at 210° C., the inversion temperature of matildite (Ramdohr, 1938).

If, however, the disorder level rises with temperature, on cooling a *progressive unmixing* occurs. Commonly the initial unmixing is into two partial solid solutions, which segregate by solid diffusion, and then continue to unmix in their turn with further slow cooling.

A further complication is introduced where more than one mineral is precipitated from a single host. The rates of unmixing of the several precipitate minerals, and of their segregation, varies with temperature and concentration, so that though one solute mineral may begin to precipitate before another, the unmixing of the latter may be completed first.

Oxide Minerals.

The opaque oxides show a parallel behaviour. Provided that two oxide minerals have similar crystal structures, extensive substitution of the metal atoms of the one in the metal lattice of the other is possible. The " foreign " atom must be of similar size to the metal atom for which it substitutes, and of the same valency. Generally the extent of substitution increases with rise in temperature and unmixing occurs on cooling. With a few minerals the substitution is so perfect that the solid solutions remain stable at normal temperatures. Tantalite ($FeTa_2O_6$) and columbite ($FeNb_2O_6$) are such a pair, forming a continuous solid solution series in which Nb^{5+} can substitute for Ta^{5+}. They have identical crystal structures, and the two elements have nearly identical ionic radii, Ta^{5+} 0·68 A, Nb^{5+} 0·69 A, and similar chemical properties, being adjacent to each other in Group V of the Periodic Table.

Ilmenite and Hematite.

Ilmenite ($FeTiO_3$) and hematite (Fe_2O_3) form a continuous solid solution at temperatures of about 600° C., and if rapidly cooled the solid solution may be retained in a metastable state. If slowly cooled it unmixes into two partial solid solutions, a ferriferous ilmenite and a titaniferous hematite, both of which unmix progressively on further cooling. Their phase relationships are indicated diagrammatically in Text-fig. 2 (c) (Edwards, 1947, p. 60). The final products of unmixing are ilmenite containing about 4·2% Fe^{3+} still in solid solution and hematite containing about 7·5% Ti^{3+} still in solid solution (" titanhematite ").

Plate II, fig. 3, shows the type of microtexture that results from unmixing of an ilmenite-hematite solid solution. Ex-solution bodies of titanhematite are distributed in a base of ilmenite. The hematite bodies are all oriented with their long axes parallel to one another, and to the (0001) direction of both the ilmenite and the hematite. The earlier precipitated ex-solution bodies are distinctly larger than the later-formed ones. The irregular shapes of the hematite bodies arise from their growth *in situ* by solid diffusion. The plane of the section is inclined to the (0001) plane of the intergrowth. If it were normal to the (0001) plane, the hematite bodies would appear as parallel straight blades, and their duplex nature would not be apparent.

Between the rows of coarse hematite bodies are rows of smaller hematite bodies in *seriate* arrangement (Plate II, fig. 4), resulting from progressive precipitation at more and more competing centres of crystallization, as the concentration of the solute, and the temperature (and hence the rate of solid diffusion) declined.

Similarly, the coarse hematite bodies contain rows of ilmenite ex-solution bodies with a similar seriate arrangement (Plate II, fig. 5), illustrating the progressive unmixing of the two partial solid solutions.

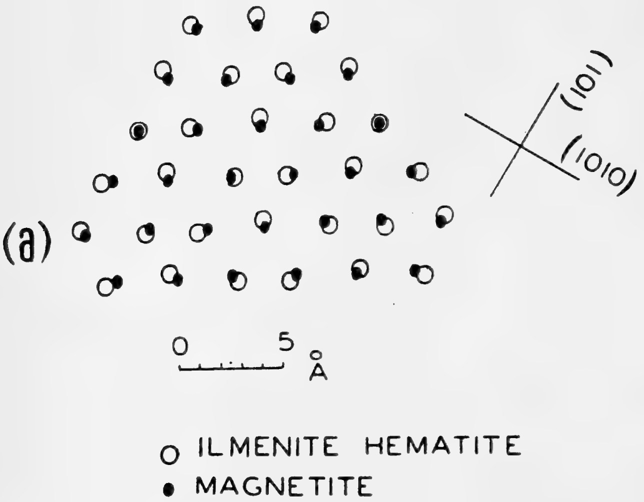
The capacity of these two minerals to form such extensive solid solution is explained by their crystal structures (Bragg, 1937, pp. 93-6 ; Barth and Posnjak, 1934, p. 165). In the unit cell of hematite the oxygen atoms are arranged in approximately hexagonal closest spacing in such a way that each Fe atom falls between six oxygen atoms arranged octahedrally. The ilmenite structure is identical, but with Ti atoms replacing half of the Fe atoms in an ordered sequence. Magnesium, if present, occupies the position of an iron atom. The unit cell of hematite has $a = 5 \cdot 42$ A. and $\alpha = 55° 17'$, that of ilmenite has $a = 5 \cdot 40$ A, $\alpha = 55° 1'$. The orientation of the intergrowth that forms on unmixing reflects the presence in both structures of oxygen planes parallel to their (0001) directions, in which the spacings of the oxygen atoms are practically identical.

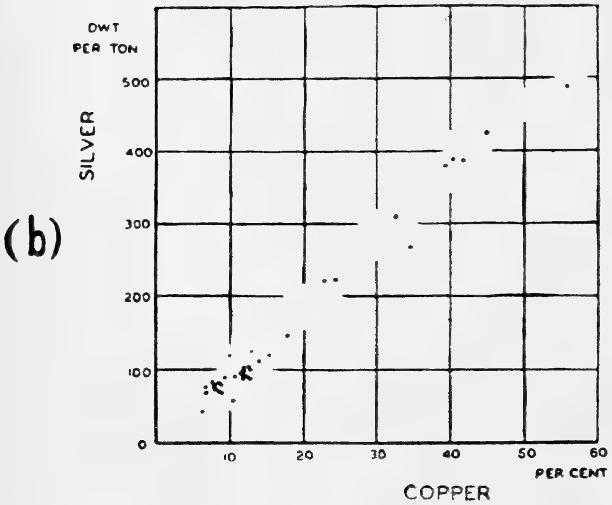
Magnetite-Ilmenite.

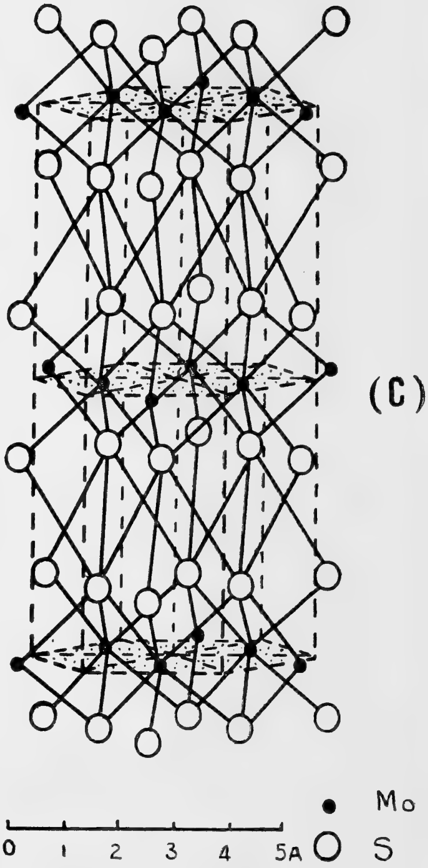
Ti can substitute for Fe in magnetite at high temperatures, forming a homogeneous mineral which is weakly anisotropic, and is intermediate in optical properties between magnetite and ilmenite, while retaining intense magnetism. This mineral is metastable, and natural occurrences are restricted to basalts and other rapidly chilled rocks that formed at high temperatures.

With moderate cooling rates, this solid solution unmixes. If magnetite predominates, the ilmenite is precipitated as blades (lamellae) which are elongated parallel to their (0001) direction, and are oriented in the (111) planes of the magnetite, giving a triangular lattice pattern intergrowth (Plate II, fig. 6). If ilmenite predominates, lamellae of magnetite are precipitated parallel to the (0001) plane of the ilmenite, and similarly oriented blades of magnetite are found in some specimens of ilmenite-hematite intergrowths.

This orientation arises from a sharing of oxygen planes. In the magnetite structure every third and seventh (111) plane consists of oxygen ions only, while in ilmenite every third (0001) plane consists of oxygen only. The spacing of the oxygen ions in these planes is such that if the planes are superimposed on one another the oxygen positions in the two planes practically coincide (Text-fig. 3 (a)).







Text-Fig. 3 (a).—The (0001) plane of oxygen atoms of ilmenite or hematite superimposed on an oxygen plane (111) of magnetite. (*After* Gruner, *Amer. Mineral.*, 14, 1929.)

Text-Fig. 3 (b).—Relative proportions of silver and copper in assays of Pine Vale ore and mill products.

Text-Fig. 3 (c).—The layer lattice structure of molybdenite, MoS_2. (*After* Bragg.)

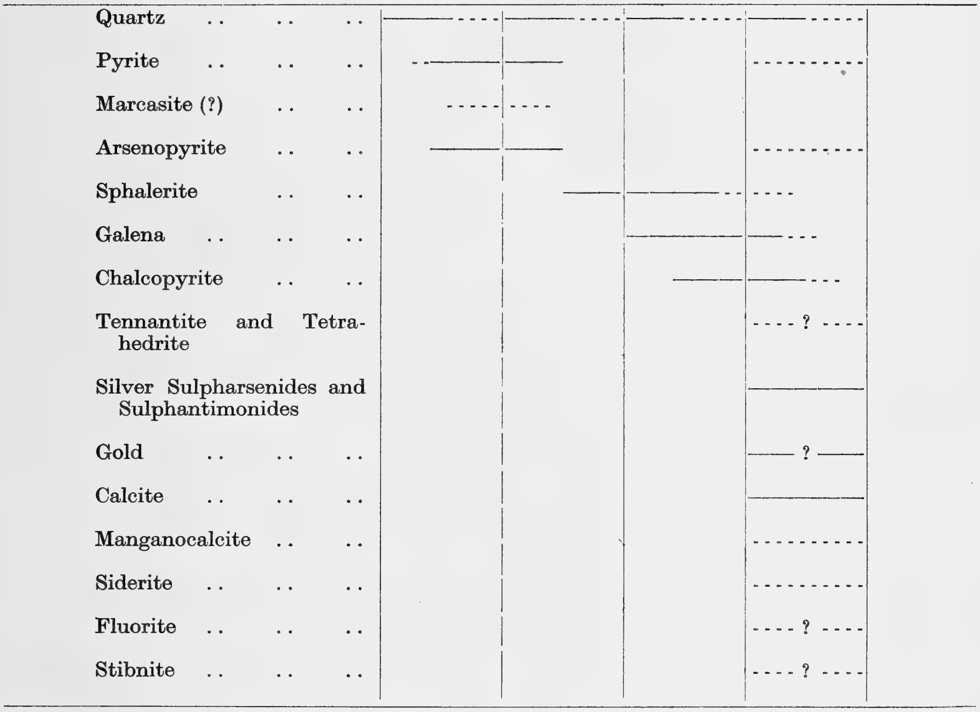
With slow cooling, segregation of the precipitate occurs, resulting in a granular association of ilmenite and magnetite (Plate III, fig. 1). This illustrates a simple application of textural studies of such ores. Titaniferous magnetite ore that has unmixed to a granular texture, such as this one, are readily freed from excessive titanium by magnetic concentration after crushing. Intimate intergrowths such as that in Plate II, fig. 6, defy physical separation.

A few polished sections can save or guide a great deal of testing work.

Paragenesis.

Such complex relationships make it difficult to determine a precise sequence of deposition of the minerals of an ore. Even the most reliable texture indicating sequence, the cross-cutting relationship of a vein, is suspect under certain conditions. Thus if fracturing occurs *during or before* the unmixing of a solid solution, the precipitate will sepregate in the fracture, forming a " segregation vein " (Plate III, fig. 2) (Edwards, 1951). Unless such a vein is recognized for what it is, a false impression of the sequence of deposition will result.

TABLE 2.
Typical Paragenesis Diagram.
PARAGENESIS OF HYPOGENE MINERALS.
(Vertical lines represent periods of fracturing.)



The paragenesis of an ore deposit is commonly expressed in a diagram such as Table 2, indicating a sequence of crystallization, of the various minerals present. Unless qualified, they present an over-simplified picture of a mineralization.

In most mineralizations the minerals tend to be deposited as *a series of solid solutions* of minerals of like crystal structure, which subsequently unmix. With slow cooling, segregation may be so complete as to destroy all evidence of the original solid solutions, but even so it is apparent that the minerals in an ore associate in groups of structurally-like minerals, and that the age relationships between such groups are readily distinguished, whereas the age relationships within the groups are complex.

The sequence of deposition of the minerals or solid solutions depends partly on their free energies of formation and partly on the concentrations of the elements concerned in the mineralizing solutions.

Pine Vale Ore.

A clear example of deposition in this manner is provided by the Pine Vale copper ore, near Mackay, Queensland. This orebody is a vein about three feet wide, at a granite contact. The ore minerals are bornite, chalcopyrite and tetrahedrite, in the proportions 92 : 7 : 1.

Bornite and chalcopyrite enter into extensive solid solution with one another above 475° (Schwartz, 1931 ; Merwin and Lombard, 1937), and chalcopyrite and tetrahedrite enter into solid solution at about 500° C. (Edwards, 1946), while a study of Pine Vale ore showed that tetrahedrite enters into solid solution in bornite above 275° C. (Edwards, 1946). Both bornite and chalcopyrite are in a state of disorder at high temperatures (Frueh, 1950).

In the Pine Vale ore the tetrahedrite occurs in an oriented ex-solution intergrowth with the bornite (Plate III, fig. 3), and a proportion of the chalcopyrite occurs in similar intergrowths (Plate III, fig. 4), though the greater part of it has segregated to form more or less granular areas. The unmixing of the chalcopyrite has overlapped the unmixing of the tetrahedrite, because some chalcopyrite bodies are moulded on unmixed tetrahedrite. Further confirmation that the three minerals were formerly a single solid solution is given by the fact that throughout the ore the silver content varies sympathetically with the copper content—1 per cent. copper is equivalent to 10 dwt. of silver. The silver occurs solely in the tetrahedrite, which is uniformly distributed throughout the bornite, but does not occur in the chalcopyrite. If the chalcopyrite was sporadically distributed or locally concentrated, the copper-silver relationship (Text-fig. 3 (b)) would not hold. To satisfy this relationship the chalcopyrite must be uniformly distributed through the bornite, and must originally have been in solid solution in the bornite, so that the three minerals were initially deposited as a single solid solution.

The Pine Vale ore is restored to its original condition, i.e. converted to a single homogeneous solid solution, by holding it at 480° to 500° C. for about 100 hours and then quenching it. If the homogenized solid solution is cooled slowly from this temperature, or is annealed at lower temperatures, chalcopyrite unmixes from it and segregates. The ore must have been deposited, therefore, at a temperature of about 500° C. or more.

The tetrahedrite dissolves in the bornite if the ore is held at about 285° C. for about 100 hours and is then quenched. If the homogenized bornite-tetrahedrite solid solution is slowly cooled from this temperature, or is annealed at between 250° C. and 275° C., the tetrahedrite is precipitated and segregates in the grain boundaries of the bornite in a matter of a few minutes. A similar segregation results if the natural ore is held at between 250° C. and 275° C. for a short period. For the natural intergrowth of the tetrahedrite in the bornite to have been preserved, the ore must, therefore, have been " frozen " at about 275° C.

This has an interesting implication. If the ore minerals were deposited at 500° C. and were " frozen " at 275° C., it follows that the mineralizing fluids were 200° to 250° C. *hotter than the country rock* when crystallization began.

General Sequence of Deposition.

In general sulphide mineralization begins with the deposition of minerals with the *pyrite* and *marcasite structures*, viz. pyrite and arsenopyrite or lollingite. Marcasite itself does not often form at this stage because it inverts to pyrite above 450° C. (Allen *et al.*, 1912). These minerals may carry significant amounts of Ni and Co in solid solution.

Minerals with the *nickel arsenide structure* tend to form next, especially pyrrhotite, which may carry nickel in solid solution. If iron is deficient in the mineralizing fluids, or when it becomes so, minerals with the *zinc blende structure* develop, as a complex solid solution, or a group of partial solid solutions, which will unmix, according to its composition to form sphalerite, pyrrhotite, chalcopyrite, stannite and even tetrahedrite or tennanite (Edwards, 1951). The sulphide of the most abundant metal will serve as host, and the others will precipitate from it. The order of unmixing varies with the concentrations of the various metals in solution, the temperature of their order-disorder transformations and the rate of cooling, and since the early unmixing is into partial solid solutions which tend to segregate and then unmix further, most complex sequences of deposition result.

Then follow minerals with the *rock salt structure*, notably galena, sometimes with various silver-bearing minerals and lead sulpho-salts in solid solution, and then the lead-arsenic, lead-antimony and lead-bismuth sulphides and the comparable silver minerals, which tend to possess more complex structures.

Replacement.

The paragenesis may be further complicated by the phenomena of replacement. In most ore bodies the earlier formed sulphides suffer some degree of replacement by the later formed sulphides. Plate I, fig. 1, shows lollingite being replaced by arsenopyrite, Plate II, fig. 2, shows pyrite being replaced by chalcopyrite and bornite. Plate III, fig. 5, shows pyrite being replaced by sphalerite, in Rosebery ore. The metals from the replaced mineral may be incorporated in the replacing mineral (metasome), as could have happened in this instance, where Fe could substitute for Zn, or may migrate in the residual mineralizing solutions, to be reprecipitated elsewhere. According to the composition of the residual solutions these redissolved elements may then be accommodated in later-formed, more complex minerals, or they may be forced to crystallize as a later, minor second generation of the early formed mineral, but only after they have again built up a sufficient concentration in the residual solutions. Plate III, fig. 6, shows early-formed cassiterite dissolving at a fairly late stage of mineralization, and the tin being reprecipitated as stannite.

Plate III, fig. 6, illustrates a relation that has significance in ore dressing. It is the practice when concentrating tin ores that contain sulphides to float off the sulphides, retaining the cassiterite in the flotation tailings, from which it is then recovered by gravity concentration. Rims of stannite, such as that shown in Plate III, fig. 6, will cause some cassiterite to float with the sulphides, causing losses of tin out of proportion to the amount of stannite in the ore.

Spontaneous Breakdowns.

Further complications are introduced where early-formed minerals dissociate with the changing conditions of the later stages of mineralization.

In ores in which the residual mineralizing fluids become enriched in carbonate or bicarbonate, pyrrhotite (FeS) spontaneously converts to marcasite (FeS_2), the excess iron being absorbed into carbonate minerals that are commonly intergrown lamellar fashion with the marcasite (Plate IV, fig. 1) or reprecipitated as a late generation of fine-grained magnetite, intergrown with the marcasite. Marcasite requires distinctly acid conditions for its formation. If the solutions are more or less neutral a late generation of fine-grained pyrite forms instead.

Any minerals which have precipitated from solid solution in the original pyrrhotite will be retained as fine inclusions in the marcasite, possibly with some reorientation.

Stannite, on reduction of the sulphur vapour pressure, while still hot, tends to dissociate, and fractures forming in stannite, while it is within some critical temperature range, not yet established, become filled with chalcopyrite and fine-grained cassiterite (" needle tin ") (Plate IV, fig. 2).

Metamorphism.

Where an ore deposit has been subject to movement or metamorphism, either during or after deposition, this is commonly revealed by distinctive textures in the ore minerals.

Contemporaneous Movements.

Many ores undergo differential movement during deposition. Minerals deposited before the movement, particularly the brittle minerals like pyrite and arsenopyrite, are fractured, the fractures being healed by minerals deposited subsequently. Plate IV, fig. 3, shows arsenopyrite fractured in this way, the fractures being filled with pyrrhotite, following movement at an early stage of mineralization. Plate IV, fig. 4, shows fractured pyrite, with the fractures filled, in part, with gold. This, incidentally, is a " free milling " ore. Crushing will expose the gold to the action of cyanide.

In some ores fracturing continues at intervals throughout deposition. An outstanding example is provided by the Mount Isa lead-zinc ores, where concomitant movements led to the formation of larger and larger fractures as the originally plastic shales were rendered more and more brittle by progressive impregnation and replacement by brittle sulphides (Edwards, 1947, p. 117). The earliest deposited minerals chiefly replaced crumpled finely banded shales, and were correspondingly fine-grained. Following the impregnation of the strata with pyrite, transverse fractures developed, extending across only a single shale bed a fraction of an inch across. These became filled with sulphides, rendering the rocks still more competent. Continuing movements led to the formation of still later fractures, extending for a few inches up to several feet, across groups of beds, and these were filled by the latest sulphides to be deposited, which were also the coarsest grained, presumably because the larger fractures coupled with falling temperature favoured crystal growth.

Flowage.

Soft minerals flow under pressure and become notably elongated. Deformation occurs by the slipping of one portion of the crystal relative to another in crystallographic directions that are parallel to rows or planes of consecutively like-charged atoms in the lattice (Buerger, 1928, 1930-45) :

$$\begin{array}{ccccc} - & - & - & - & - \\ + & + & + & + & + \end{array}$$

Movement in other directions would bring like-charged atoms opposite each other at some stage of the movement, and the resulting repulsion would cause disruption.

Movement is theoretically possible along any plane containing such a direction of possible translation, but is most favoured along those planes which in addition are planes of widest interplanar spacing, because the forces of interatomic attraction and friction, which oppose slippage, decrease rapidly with increasing width in the spacing of the planes.

Thus in galena (Text-fig. 1 (a)) translation could occur either along an octahedral (111) plane or along a cube face (001), provided that the movement is in the direction of a cube-face diagonal (110) plane. The (111) planes are the more obvious, but the wider spacing of the (001) planes renders them the preferred planes of movement.

Flowage also occurs easily in *layer lattice structures* like molybdenite (Text-fig. 3 (c)) in which a sheet of Mo atoms is sandwiched between two sheets of S atoms, parallel to the base of the hexagonal crystal, the three forming a " layer " of the structure. The atoms in the layer are firmly bound, but the force of attraction between adjacent layers is slight, and the crystals cleave with ease and are very responsive to pressure, even of quite local development. Clearly, however, the bonding between adjacent sulphur planes is different from that found between metal and sulphur atoms in galena, since molybdenite does not obey the " like-atom " repulsion rule.

Plate IV, fig. 5, shows typical flow or translation twinning in a crystal of molybdenite. Veinlets of native bismuth transecting the molybdenite have been reoriented at each passage from one twin band to the next, giving the appearance of miniature folding. The continuity of the bismuth veinlets across the twin bands, and their smooth edges indicate that they have undergone translation without rupture. The twin planes are the (0001) planes of the molybdenite crystal, and to account for the " folding " of the bismuth veinlets it is necessary to postulate a slipping movement in each adjacent layer plane structurally comparable with the twin plane, over the full width of each band, the direction of slip being reversed in adjacent bands.

Recrystallization.

If the deformation is pressed too far, in soft minerals, they recrystallize after the manner of metals. Molybdenite is so subject to flow that it does not readily recrystallize. Recrystallization is best seen in stibnite. The ready deformation of stibnite is again related to its crystal structure, which consists of a series of chains or bands of closely linked Sb and S atoms, which lie parallel to the *c*-axis of the crystal. The distance between Sb and S atoms in the chains is about 2·5 A., and the bonding is covalent (homopolar). Any two atoms belonging to different chains are at least 3·2 A. apart, and much less strongly bonded. Under pressure the chains slip over one another. With mild deformation stibnite crystals become greatly elongated, but beyond a certain stage of deformation recrystallization sets in and the whole mass recrystallizes as a mosaic of equigranular crystals which tend to absorb each other, building progressively larger crystals as in the recrystallization of metals.

Careful reading of such textures in an ore body will reveal whether it has been subject to contemporaneous movements during mineralization, or to subsequent pressure metamorphism, and in some circumstances will help to determine its geological age.

Temperatures.

The textures of the minerals, and particularly those resulting from unmixing of solid solutions and from inversions, afford a means of measuring the temperatures at which mineralizations occurred and the rate at which ore bodies cooled.

As indicated, the evidence of the Pine Vale copper ore suggests that the mineralizing fluids were several hundred degrees hotter than the country rock they invaded and that mineralization continued through a range of several hundred degrees. Most ores show these features. At Broken Hill mineralization commenced above 500° C. and finished somewhere below 350° C. At Kalgoorlie deposition began at about 500° C. and ceased between 180° C. and 150° C. At Vatukoula, Fiji, it began above 500° C. and ceased below 150° C.

Either we must postulate that mineralization is an extremely slow process, continuing over the time necessary for erosion to lower the isogeotherms by about 350° C. to permit the full range of mineralization, or we must assume with Lindgren (1933, p. 529) that the country rocks were heated up by igneous intrusions or emanations and then cooled slowly to normal temperatures as mineralization progressed, a process which Schneiderhöhn (1934, p. 471) has shown involves many thousands of years, or else we must assume that in general the mineralizing fluids reach their loci of deposition at temperatures well above that of the adjacent country rock.

In view of the ease and rapidity with which minerals precipitated from solid solution segregate into granular structures during laboratory experiments with natural ex-solution intergrowths, their preservation in ore deposits of Devonian or pre-Cambrian age forces me to accept the third conclusion, that the mineralizing fluids reach their seats of deposition at temperatures well above that of the country rocks, and that the preservation of ex-solution intergrowths is due to the resultant rapid cooling. It may be noted that ex-solution intergrowths are much more common in narrow veins than in large ore bodies, and this is particularly true of ex-solutions that occur round about 450° to 500° C.

It follows that the temperature of mineralizing fluids at their onset of crystallization bears little relation to the temperature of the country rock, i.e. the depth at which mineralization occurs but reflects the temperature of their (magmatic) source, the distance they have travelled from it, and the time involved in transit (Stillwell, 1951). Thus in the gold-telluride ores of Kalgoorlie, classed by Lindgren (1933, p. 678) as hypothermal, but perhaps better regarded as mesothermal as regards their depth of formation, and those of Vatukoula, Fiji, which are undoubtedly epithermal as regards their depth of formation, the temperature range was practically identical—from 500° C. at the onset to about 150° C. at completion.

This requires that we revise our meanings of the terms hypothermal, mesothermal and epithermal. Lindgren (1933, pp. 210, 212, 529, 640), in introducing these terms, gave them specific meaning as regards both depth (pressure) and temperature, viz.:

Epithermal: pressures equivalent to depths up to 5,000 ft., temperatures of 50° to 200° C.

Mesothermal: pressures equivalent to depths of 5,000 to 10,000 ft., temperatures of 200° to 300° C.

Hypothermal: pressures equivalent to depths in excess of 10,000 ft., temperatures of 300° to 500° C.

To get any measure of the temperature of the country rock at the locus of mineralization we must estimate the *temperature at which mineralization ceased.* If this can be determined, the *maximum depth* at which mineralization could have occurred can be estimated and can be checked against other estimates.

Our ideas as to the depth at which a mineralization occurred are qualitative and derive chiefly from the type of structure with which the mineralization is associated, possibly with support of stratigraphic data. Such estimates commonly rest on the assumption that mineralization was more or less concomitant with the development of the structures in which the ore body occurs. It could, of course, have occurred long subsequent, when erosion had brought pre-existing structures much closer to the surface.

Assuming a geothermal gradient of 1° C. increase per 100 ft. of depth, and a surface temperature of 10° C., the following depths are arrived at for the ore bodies just cited:

Ore Body.	Approximate Temperature of Cessation of Mineralization. (° C.)	Maximum Depth of Formation. (Ft.)
Pine Vale..	250	24,000
Vatukoula	150	14,000
Kalgoorlie	150	14,000
Broken Hill	c. 350	(?) 34,000

These figures are *over-estimates* in so far as (1) they over-estimate the final temperature of deposition, and (2) they ignore abnormal heating of the country rock by igneous intrusion or other factors. Thus, at Vatukoula it is possible that the brecciated basalt which serves as the country rock had not cooled to normal temperatures when the andesite intrusions and extrusions, with which the mineralization is associated genetically, occurred. At the time of mineralization the basalts had been buried beneath a considerable thickness of andesites and perhaps reheated.

Where proximity to contemporaneous igneous intrusions can be proved, calculations such as Schneiderhöhn's (1934) might permit an estimate of the temperature correction required to offset the heating effect of the intrusion. Thus at Pine Vale it is likely that the country rock was 100° to 200° C. above its normal temperature when mineralization occurred, so that the depth of deposition could have been as little as 5,000 ft. This only serves to emphasize the difference in temperature between the mineralizing fluids and the country rock.

Where a large positive discrepancy is established between a calculation of maximum possible depth on this basis and that based on other evidence, as at Pine Vale, we may have evidence of association in time between an ore body and an adjacent igneous intrusion or other source of abnormal heating of the country rock. A large negative discrepancy would suggest that the mineralization occurred long after the development of the structures with which it is associated. The ore of the Homestake gold mine, South Dakota, is possibly a case in point (Noble, 1950, p. 245).

Scale of Solid Diffusion.

In view of the emphasis placed on solid diffusion in this lecture, it is essential to keep a sense of proportion as to the scale of the movements involved. The ore minerals provide the most favourable structures for solid diffusion, far more so than the more rigid silicate structures. Moreover, they form under conditions likely to promote a maximum of solid diffusion.

Yet, in the *unmixing of solid solutions* the resultant linear movement of a given atom rarely exceeds a few millimetres, and is generally to be measured in microns ; and the growth in volume of a crystal of the precipitate is compensated by a corresponding reduction in volume of the residual host mineral, so that *while there is separation, there is no migration* away from the place of deposition. The forces promoting the separation are lacking at high temperatures. They develop only with falling temperatures, and the process is self-destroying in that segregation of the solute atoms brings increasing equilibrium to both crystal structures, so that solid diffusion occurs only within a limited range of temperature.

In *replacements* the scale on which solid diffusion operates is much the same, and the temperature range is similar. It is interesting to note that the metasome mineral is always less soluble in water than the host mineral, suggesting that the metasome has the more stable atomic structure.

In many ores the process of solid diffusion has been arrested in mid-stage and has remained in that arrested state for a period of the order of 500 to 1000 million years. In other words there has been no solid diffusion in these most favourable media since the ores cooled below a certain temperature, often a temperature above that of the invaded rocks.

These facts, combined with the probability that mineralizing fluids are at temperatures well above that of the surrounding country rock when they begin to crystallize, even at depths of five to ten miles, argue strongly against the likelihood that solid diffusion, leading to vast migrations of ions or atoms through miles of thickness of the crust, is the significant process in the formation of granite and related silicate rocks, as some workers would have us believe (Bugge, 1945 ; Ramberg, 1944). This is not to deny the likely efficacy of solid diffusion in metamorphic processes, where the conditions and the scale of movement are comparable with those found in ore deposits, or that solid diffusion operates in some silicate minerals, like ex-solution perthites, on a scale comparable with that found in ore minerals.

III. ACKNOWLEDGEMENTS.

My thanks are due to Dr. F. L. Stillwell, and to Mr. A. J. Gaskin, of the Geology Department, University of Melbourne, for stimulating criticism and suggestions during the preparation of this lecture.

The 23 photomicrographs of ore textures in Plates I-IV are reproduced by kind permission of the Australasian Institute of Mining and Metallurgy ; Text-figures 1*c*, 1*d*, 1*e* and 3*c* have been redrawn from W. L. Bragg's " Atomic Structure of Minerals " by kind permission of Cornell University Press ; and Text-figures 1*b*, 1*f* and 2*a*, together with Table 1, have been prepared from A. F. Well's " Structural Inorganic Chemistry," by kind permission of the Clarendon Press.

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EXPLANATION OF PLATES.

PLATE I.

Fig. 1.—Arsenopyrite replacing lollingite along crystallographic directions. Etched with $FeCl_3$. Broken Hill. ×42·5. (*From* Stillwell and Edwards, *Aust. Inst. Min. Met. Proc.*, 114, 1939.)

Fig. 2.—Two particles of gold (white) enclosed in pyrite in a cyanide residue. ×770. (*From* Edwards, *Textures of the Ore Minerals.*)

Fig. 3.—Characteristic patch lamellar inversion twinning of hessite that has inverted from the high-temperature to the low-temperature form. One set of lamellae appears as light bars, and is crossed by another set appearing as fainter dark bars. Kalgoorlie, crossed nicols. ×50. (*From* Stillwell, *Aust. Inst. Min. Met. Proc.*, 84, 1931.)

Fig. 4.—Skeletal crystals of tetrahedrite (dark) formed during the unmixing of a solid solution of tetrahedrite in chalcopyrite. New Thologolong, Vic. ×270. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 143-4, 1946.)

Fig. 5.—Lattice intergrowth of chalcocite (white) and bornite (dark) resulting from the unmixing of a solid solution of these two minerals. ×50. (*From* Van der Veen, *Mineragraphy and Ore Deposition.*)

Fig. 6.—" Network " texture resulting from the unmixing of a solid solution of pentlandite (light) in pyrrhotite (dark), with subsequent segregation of the pentlandite in the grain boundaries of the pyrrhotite. ×18·6. Sudbury, Ontario. (*From* Van der Veen, *Mineragraphy and Ore Deposition.*)

PLATE II.

Fig. 1.—" Emulsion " texture of chalcopyrite ex-solution bodies in sphalerite. New Thologolong, Vic. ×84. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 143-4, 1946.)

Fig. 2.—Residuals of pyrite (white), partly replaced by chalcopyrite (light grey) and bornite (dark grey). The bornite has possibly unmixed from solid solution in the chalcopyrite, and segregated by solid diffusion in the grain boundaries of the chalcopyrite. North Lyell Mine, Tas. ×290. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 114, 1939.)

Fig. 3.—Coarse ex-solution intergrowth of hematite (light) with ilmenite (dark). Olary, South Australia. ×134. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 110, 1938.)

Fig. 4.—The same, the ilmenite base magnified to show the seriate arrangement of smaller hematite ex-solution bodies between the rows of larger ex-solution bodies of hematite (lower edge). ×356. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 110, 1938.)

Fig. 5.—The same, a larger hematite ex-solution body magnified to show the seriate arrangement of ilmenite ex-solution bodies that have unmixed from it. ×356. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 110, 1938.)

Fig. 6.—Ex-solution intergrowth of ilmenite lamellae (dark grey) in the (111) planes of magnetite, now largely oxidized to hematite (white). Warramba, W.A. ×150. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 110, 1938.)

PLATE III.

Fig. 1.—Granular intergrowth of ilmenite (dark) and magnetite (now largely oxidized to hematite), resulting from the complete unmixing and segregation of an ilmenite-magnetite solid solution. Wannamal, W.A. ×70. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 110, 1938.)

Fig. 2.—Segregation veins of chalcopyrite (white) forming in an ex-solution intergrowth of chalcopyrite and sphalerite. Conrad, N.S.W. ×66.

Fig. 3.—Ex-solution intergrowth of tetrahedrite lamellae (white) in the (111) planes of bornite. Pine Vale, Q'ld. ×306. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 143, 1946.)

Fig. 4.—Ex-solution intergrowth of chalcopyrite lamellae (white) in the (111) planes of bornite. Pine Vale, Q'ld. ×88. (*From* Edwards, *Aust. Inst. Min. Met. Proc.*, 143, 1946.)

Fig. 5.—Corroded pyrite, with some traces of cubic form, partly replaced by enclosing sphalerite. Rosebery, Tas. ×210. (*From* Stillwell, *Aust. Inst. Min. Met. Proc.*, 94, 1934.)

Fig. 6.—Cassiterite crystals (hard medium grey) corroded and enclosed by stannite (light grey), in gangue. North Valley lode, Mt. Bischoff, Tas. ×57.

PLATE IV.

Fig. 1.—Lamellar intergrowth of marcasite (grey) and carbonate (black) formed from pyrrhotite which had undergone translation twinning (*cf.* Fig. 5, below). Consolidate Mine, Irvinebank, Qld. ×66. (*From* Edwards, *Textures of the Ore Minerals.*)

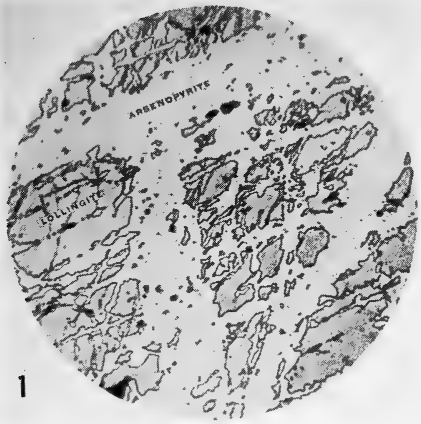
Fig. 2.—Segregation vein of ex-solved chalcopyrite traversing an ex-solution intergrowth of sphalerite (dark grey), stannite (medium grey) and chalcopyrite (white spots). Where the vein traverses the band of stannite bodies, it contains small areas of cassiterite (" needle tin ") formed by the breakdown of the stannite. Conrad Mine, N.S.W. ×66.

Fig. 3.—Pyrrhotite (grey) filling fractures in arsenopyrite (white). Dreadnought Lode, Renison Bell, Tas. ×110. (*From* Stillwell and Edwards, *Aust. Inst. Min. Met. Proc.*, Nos. 131-132, 1943.)

Fig. 4.—Gold veins (white) filling fractures in pyrite, and to some extent replacing the pyrite. La Mascotte Mine, Dart River, Vic. ×220. (*From* Edwards, *Textures of the Ore Minerals.*)

Fig. 5.—Veins of native bismuth (white) in molybdenite that has been twinned by pressure. Wolfram Camp, Q'ld. (*Cf.* Fig. 1, above.) ×70. (*From* Edwards, *Textures of the Ore Minerals.*)

Journal Royal Society of N.S.W., Vol. LXXXV, 1952, Plate I



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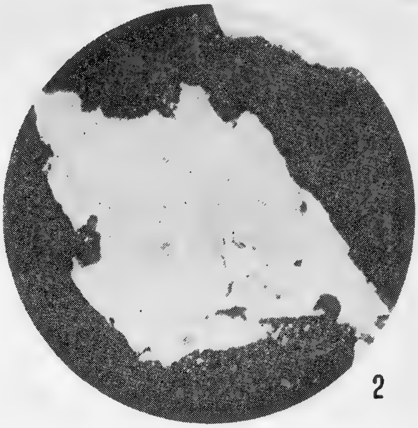

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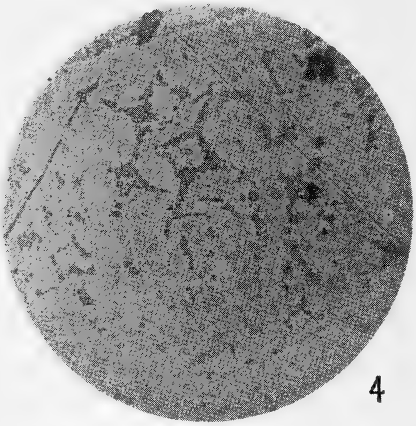

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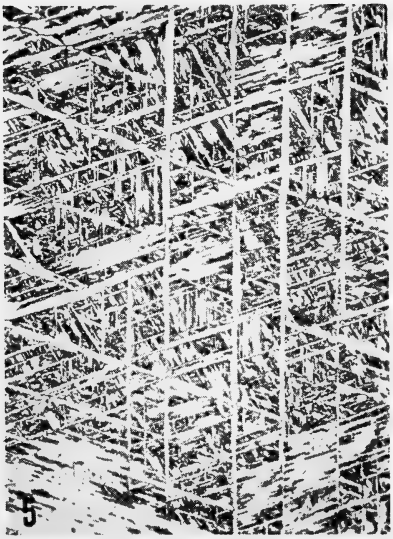

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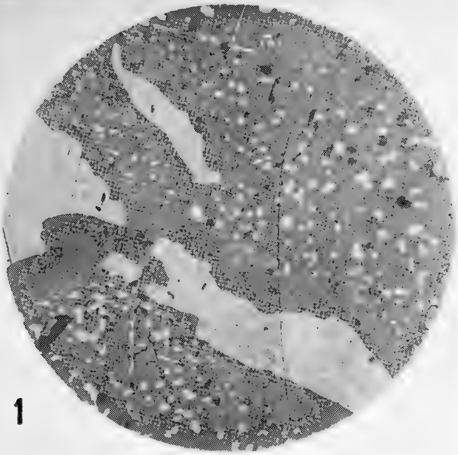
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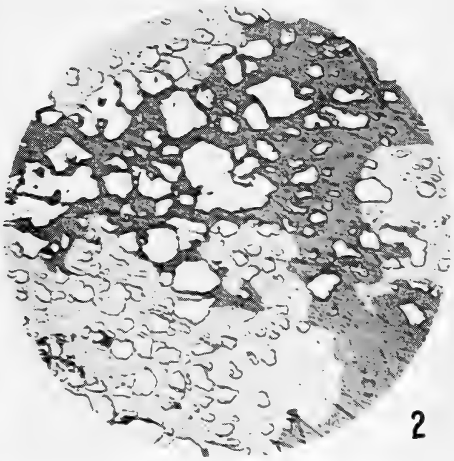
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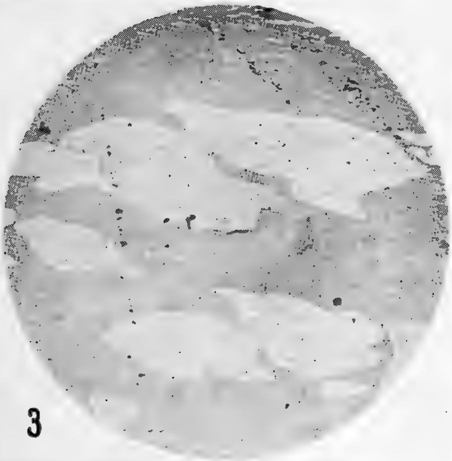
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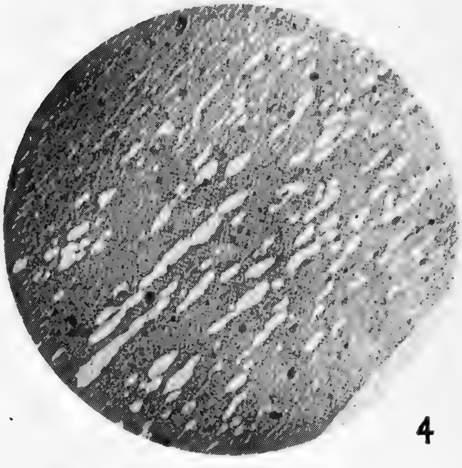
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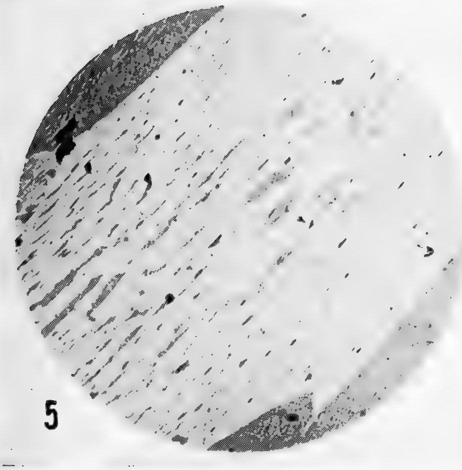
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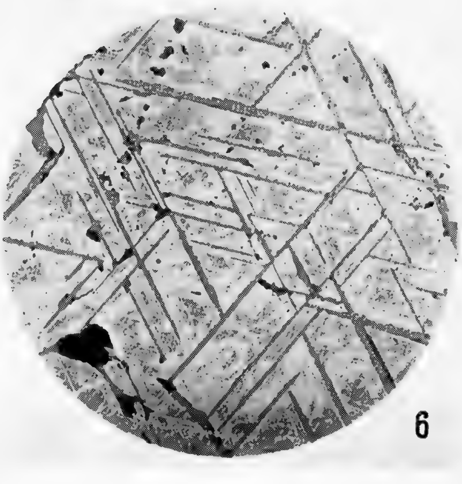
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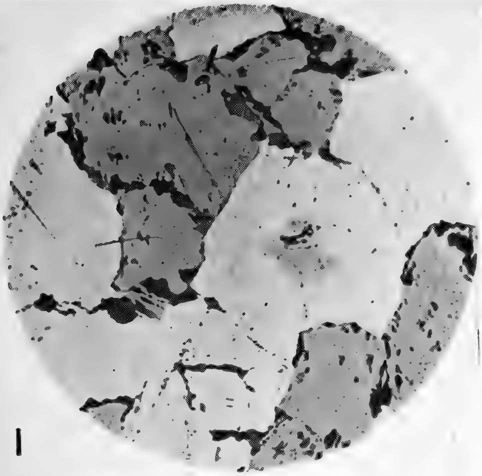

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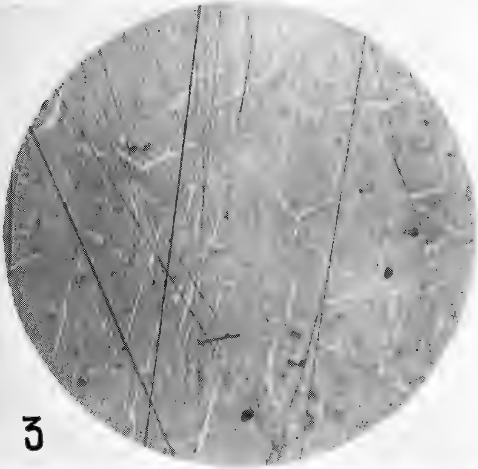

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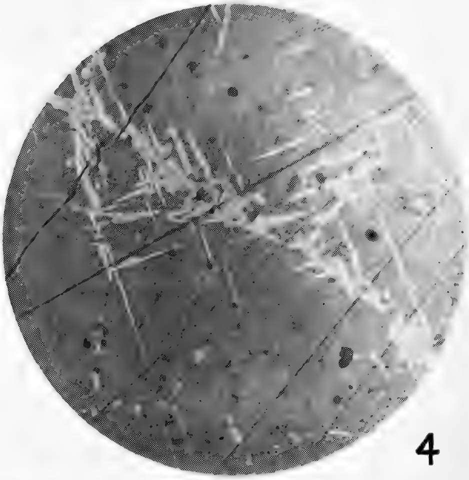

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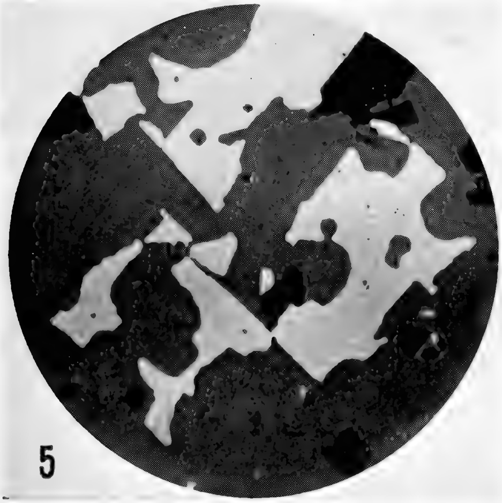

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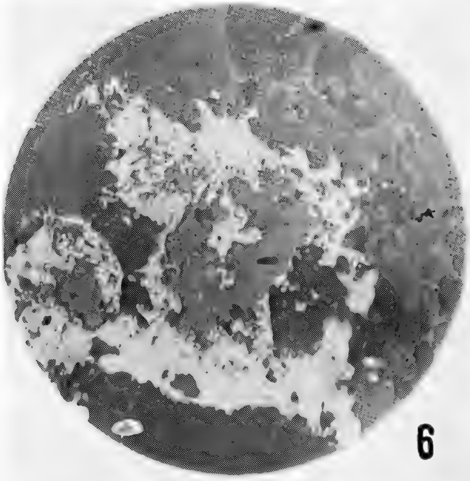

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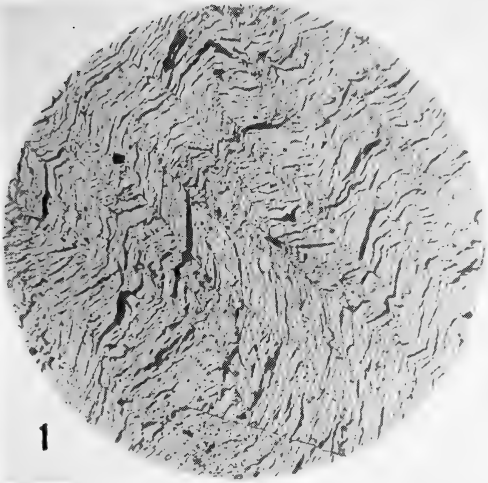

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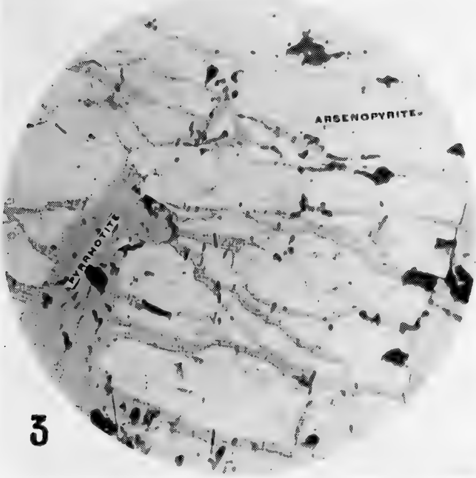

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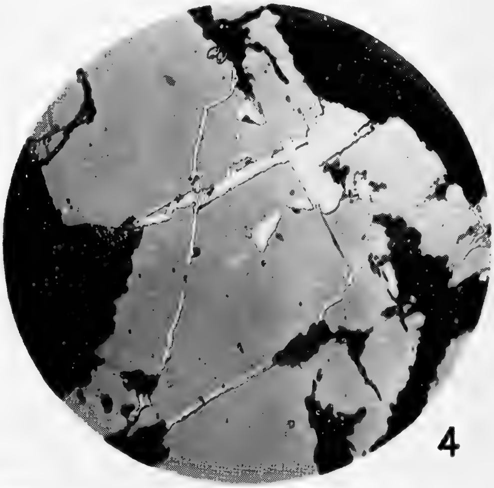

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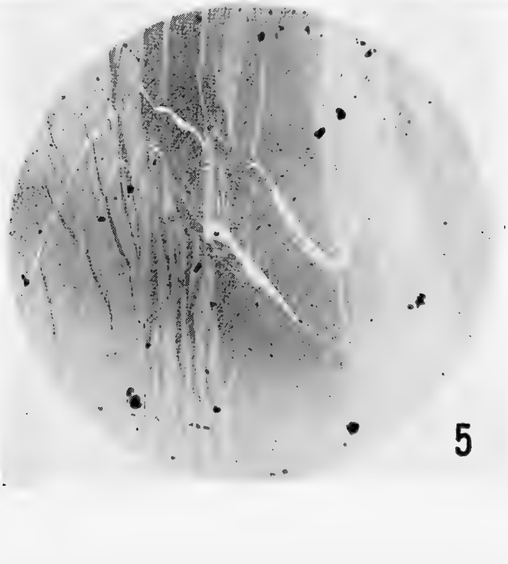

5

SEISMICITY OF AUSTRALIA.

By T. N. BURKE-GAFFNEY, S.J.
(Communicated by D. J. K. O'CONNELL, S.J.)

Manuscript received, June 12, 1951. Read, July 4, 1951.

Since the first settlement of Australia more than 500 earth tremors are known to have been felt in various parts of the Continent, exclusive of a remarkable series of 2,540 felt in Tasmania between 1883 and 1886. It is highly probable that many more have occurred, which either were not at any time reported, or not reported in any of the sources of which use was made in this enquiry.

The sources are: the Seismological Bulletins of Adelaide, 1921–41; of Brisbane, 1937+; of Melbourne, 1929–39; of Perth, 1929+; of Riverview, 1909+; of Sydney, 1930–45; the Reports of the Australasian Association for the Advancement of Science, Vols. IV-XIV, where 338 tremors are reported, 210 of which were collected by G. F. Dodwell from South Australia; it is possible that greater numbers from other States would have been included had there been equally enthusiastic collectors to report them. For the few tremors large enough to have been recorded outside Australia, use has also been made of the Bulletins of Batavia (Djakarta), Christchurch, Wellington (N.Z.) and Manila, and of Gutenberg and Richter's "Seismicity of the Earth". These sources have been supplemented by Press reports and by special papers on particular tremors, acknowledged in the references.

Only those tremors are included here for which an epicentre could be determined with reasonable certainty, and then only when the epicentre is not beyond the Continental Shelf. Earthquakes, therefore, originating in the Banda Sea or in the region off the north-west coast of Australia are excluded, even when great enough to have been felt at Darwin, Broome or other places in that area.

For those tremors reported in the years before which instrumental recording was available, the epicentres have been determined by drawing isoseismal lines, based upon the Modified Mercalli Scale of Intensities. These intensities were deduced from the reports received from observers on the spot, which are included in the notes to the Reports of the A.A.A.S., and which comprise such effects as rumbling noises, rattling windows, displacement of objects, falling plaster and so on. Evidently such reports depend on the subjective impressions of the observers and in some few cases—remarkably few, indeed—the reports were so discordant that isoseismals based upon them could not be drawn. This method gives an indication of the region of the epicentre, but does not serve to locate it to high precision.

For tremors for which data are obtainable from Station Bulletins, epicentres have been determined by stereographic projection. Where three, or more, stations have recorded the tremor, this presents no difficulty; where only two stations have recorded a tremor, use has been made of press reports to confirm the epicentre so determined. In a few cases an epicentre is given based upon the readings of a single station. This has only been attempted when the records

EPICENTRES ACCORDING TO STATES.

(Where magnitudes are not given, the place where the intensity was greatest and its value there on the M.M. Scale, is given in the last column.)

South Australia.

Date.	Time (U.T.)	Epicentre.		Qual.	Mag.	Remarks.
	h m s	°	°			
1883, July 7	13 58	35·1 S.	138·8 E.	c		Mt. Barker. V.
1886, June 1	05 56	35·5	139	c		Mt. Barker. III.
July 11	07 01	33·5	138·5	c		Blyth, Hoyleton. III.
1887, April 16	13 31	33	139	c		Terowie, Farrell's Flat. IV.
April 16	22 16	34	137	c		Pt. Lincoln, Kadina. IV.
1889, Feb. 12	07 16	33·9	139	c		Adelaide and Suburbs. III.
1890, July 24	21 46	33·1	139	c		Terowie. IV.
1891, Aug. 29	09 16	32	138·5	c		Hawker, Wilson. IV.
Sept. 18	09 01	34·5	139	c		Gawler, Roseworthy. III.
1893, Aug. 13	02 06	34·2	139	c		Eudunda, Kapunda. III.
1897, May 10		37	139	c		All over State; VIII at Blackport. Epicentre by *Hogben*. *Dodwell* gives 36°·9 S. 139°·3 E.
1902, May 7	04 10	32·7	138·7	c		Carrieton, Orroroo. V.
Sept. 18	17 05	33·8	138·8	c		Auburn, Redhill. IV.
Sept. 19	10 30	35·3	137·8	c		Warooka. VI. *Dodwell's* epicentre.
Sept. 20	09 00	35·3	137·8	c		Aftershock.
1904, Sept. 21	13 45	31·8	138·5	c		Hawker. IV.
1905, Aug. 21	18 30	34·2	139·1	c		Lyndoch, Nairne. V.
1937, Oct. 28	09 34 53	29·0	132·5	b	6½	Epicentre from data of Adel., Bris., Riv.
1939, Mar. 26	03 56 00	30·5	138·0	b	6½	From data of Adel., Melb., Riv.
May 1	19 07 29	31·4	138	c	4	From data of Adel., Riv.
June 5	12 20 43	31·5	138·5	c	4	From data of Adel., Riv.
1942, Feb. 14	22 50 43	29·5	136	c	4½	From data of Adel., Riv.
1948, Aug. 6	03 29 23	37	137	b	6	From data of Adel., Bris., Riv.

New South Wales.

Date.	Time (U.T.)	Epicentre.		Qual.	Mag.	Remarks.
1886, Nov. 2	16 35	34·8	146·8	c		Yass. VII.
1887, July 28	06 55	31·3	147	c		Cannonbar, Girilambone. VI.
1888, July 5	20 05	34·5	150·5	c		Baw Baw, Berrima. IV.
1912, Jan. 27	20 09 17	36·5	150·5	c	3½	Bega. Epicentre by *E. F. Pigot*.
1919, Aug. 15	10 21 21	33·5	150·7	c	4	From Riv., and press reports.
1921, May 30	14 51 59	35	145	c	4¾	From Riv., and local reports.
1922, Feb. 28	15 03 53	35	150	c	3½	From Riv., and local reports.
1925, Dec. 18	10 47 10	33	152	c	4½	From Riv., and local reports.
1930, Oct. 27	02 03 51	34·5	149·0	b	5½	From Melb. and Riv.
1931, Mar. 13	21 13 56	35	150	c	3½	From Riv., and local reports.
1932, May 22	10 46 28	32·5	143·8	c	4	From Riv., and local reports.
June 7	09 59 36	32·5	143·8	c	3½	Aftershock.
1933, Jan. 11	20 10 51	34·8	139·5	b	4¼	From Melb. and Riv.
1934, Jan. 30	08 02 52	34·8	139·5	c	3¾	From Melb. and Riv.
Jan. 30	20 27 54	34·8	139·5	b	4¼	From Melb. and Riv.
Nov. 10	23 47 40	34·9	150·0	b	4½	From Melb., Perth, Riv.
Nov. 11	10 46 32	34·9	150·0	c	3½	Aftershock.
Nov. 18	12 58 41	34·5	149·5	b	5½	From Adel., Melb., Perth, Riv.
Nov. 19	06 56 18	34·5	149·5	c	3	Aftershock.
Nov. 19	07 10 17	34·5	149·5	c	3¼	Aftershock.
Nov. 21	06 32 06	34·5	149·2	c	4½	From Adel., Melb., Riv.
1935, Dec. 8	03 08 07	34·5	150·5	c	3	From Riv. and local reports.

EPICENTRES ACCORDING TO STATES.

New South Wales.—Continued.

Date.	Time (U.T.)	Epicentre.		Qual.	Mag.	Remarks.
	h m s	°	°			
1938, Mar. 24	20 03 33	35·5 S.	146·0 E.	b	5½	From Adel., Melb., Bris., Riv.
June 27	22 38 47	30·4	151·8	c	4½	From Bris., Riv.
1940, Sept. 21	14 54 46	35·4	149·2	c		From Riv. and local reports.
1947, May 5	04 43 48	35	149·5	c	4	From Riv. and local reports.
May 5	04 46 2	35	149·5	c		Aftershock.
May 5	04 57 4	35	149·5	c		Aftershock.
Sept. 25	10 56 27	34	148·6	c	4	From Riv. and local reports.
1949, Mar. 10	22 30 33	34·8	149·3	b	4½	From Bris. and Riv.
Mar. 11	03 33 02	34·8	149·3	c	3½	Aftershock.
Mar. 16	13 24 06	34·8	149·3	c	3	Aftershock.
Victoria and Tasmania.						
1883, Apr., to 1886, Dec.		41	154	c		2,540 shocks, felt in Tasmania, greatest VI. Epicentre by *Hogben.*
1885, May 12	23 50	41	154	c		One of above; VI at Wilson's Prom.
July 2	16 20	41	154	c		VI at Flinders.
1900, May 27	02 25	38·5	145·8	c		Foster, Sassafras. V.
1902, Dec. 22	12 45	38	144·8	c		Ballarat. V.
1903, Apr. 6	11 52	39	144	c		Warrnambool. VII. Epicentre by *Gregory and Baracchi.*
Apr. 8	09 30	39	144	c		Aftershock.
1922, Apr. 10	10 47 39	40	147·5	b	4¾	From Adel., Christchurch, Riv. Wellington.
1929, Dec. 28	01 22 43	40·5	148·5	b	5	From Adel., Chrisc., Melb., Riv., Well.
1932, Nov. 2	13 22 32	38·3	145	c		Mornington. V. Epicentre by *Holmes.*
1939, Apr. 3	12 59 41	38	144·5	c		From Melb., Riv.
1944, Nov. 2	14 05 43	38·0	145·9	c		Cerberean Range. IV. Epicentre by *Gaskin.*
1946, Sept. 14	19 48 41	40	147	c	5	From Riv. and local reports.
Queensland.						
1913, May 1	16 20 17	27	152·5	c	4	From Riv. and local reports.
Dec. 18	13 54·0	20	147	b	4	Epicentre by *Gutenberg.*
1918, June 16	18 14 15	24	154	c	6	Epicentre by *Pigot.*
1935, Apr. 12	01 32 24	26·0	151·1	c	5	Epicentre by *Bryan and Whitehouse.*
1947, June 11	10 03 13	25·5	152·5	c		Maryborough. V. Epicentre by *Jones.*
Western Australia, Northern Territory, Central Australia.						
1929, Aug. 16	21 28 25	16·2	121·7	b	7	Epicentre from I.S.S.
1941, Apr. 29	01 36 00	27·0	117·0	b	6½	From Bris., Perth, Riv.
May 4	22 07 28	26·0	137·0	b	5½	From Adel., Bris., Riv.
May 4	22 31 50	26·0	137·0	c	5	Aftershock.
May 4	23 24 10	26·0	137·0	c		Aftershock.
June 27	07 55 49	26·0	137·5	a	6¼	Epicentre by *Gutenberg.*
June 27	08 40 36	26·0	137·5	c		Aftershock.
June 27	12 40 30	26·0	137·5	c		Aftershock.
June 27	14 40 31	26·0	137·5	c		Aftershock.

gave clear P and S phases, making possible a reliable calculation of the epicentral distance, and when press reports were confirmatory. For the few epicentres for which overseas reports were available, the graphical method of Gutenberg and Richter (1937) was used as a check.

It has happened occasionally that the origin times obtained from the individual bulletins did not agree very well. This necessitated a reinterpretation of the phases reported and the adoption of an origin time which fitted best with every report. In one particular case, that of the Gayndah (Q.) tremor of April 12, 1935, the individual origin times were quite irreconcilable. This tremor has been the subject of a paper by W. H. Bryan and F. W. Whitehouse (1938), in which the epicentre was determined after an investigation on the spot. In the light of the information there provided, the Riverview seismograms were reexamined and it was found possible so to interpret them that an origin time was obtained not noticeably different from that of the authors. By interpreting the phases reported by other stations with reference to this origin time it was possible to obtain their epicentral distances and thence, by stereographic projection, the epicentre. Not unnaturally, this agreed closely with that of Bryan and Whitehouse.

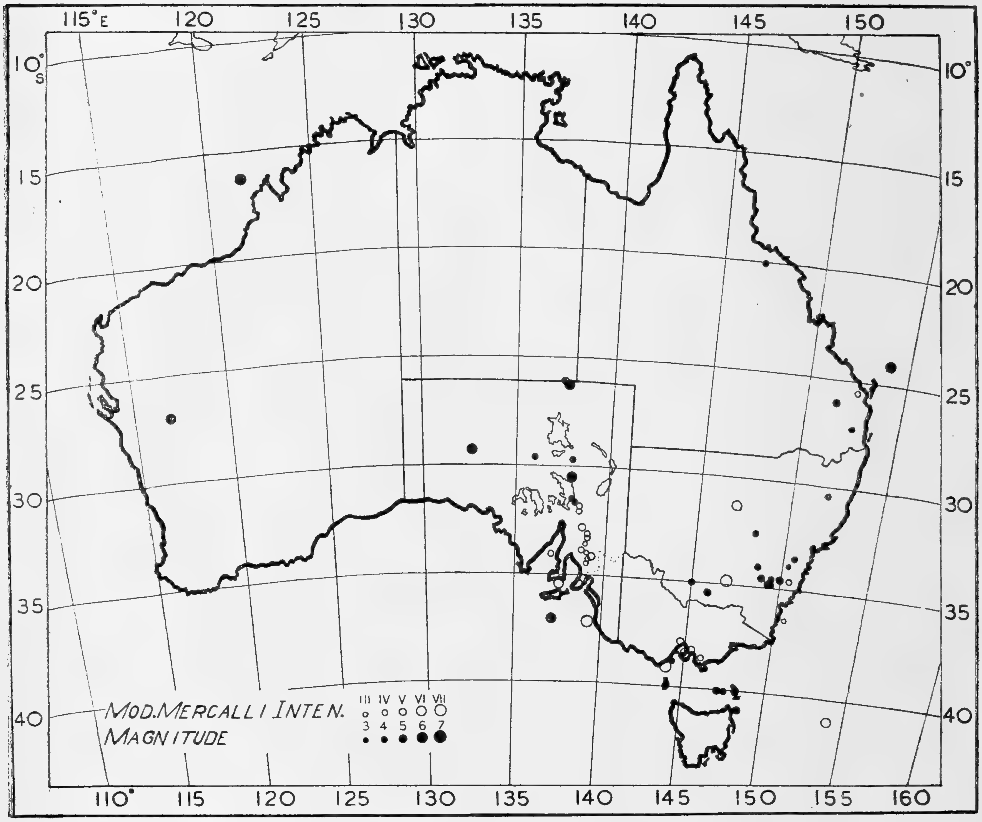

Fig. 1.—Australian Epicentres

Epicentres already determined and published have been included in this list, confirmed, where data made such confirmation possible, by the graphic method of Gutenberg and Richter (1937), or by stereographic projection. These epicentres are: that of the Tasmanian series of 1883–86, by Hogben; of 1897, May 10, by Hogben and Dodwell (independently); of 1902, September 19 (Warooka), by Dodwell; of 1903, April 6 (Warrnambool), by Gregory and Baracchi; of 1912, January 17 (Bega) and of 1918, June 6 (S. Queensland), by Pigot; of 1929, August 16, in the International Seismological Summary; of 1932, September 2 (Mornington), by Holmes; of 1935, April 12 (Gayndah), by Bryan and Whitehouse; of 1941, June 27 (Finke), by Gutenberg; of 1944, November 2, by Gaskin; of 1947, June 11 (Maryborough), by Jones.

The quality of the epicentres is indicated by the letters *a*, *b*, *c*. Those classified as *a* are very good; *b* is good; *c* is only fair.

The intensities of the earlier tremors are given in terms of the Modified Mercalli Scale, that plotted being the greatest reported for each tremor. For later tremors magnitudes are given, determined from Richter's tables (1935), where the epicentral distance is less than 500 Km., otherwise by the method of Gutenberg (1945*a*, 1945*b*), from M or P as was most convenient. As magnitudes depend upon ground motion, only those stations—Riverview and some overseas stations—which give earth amplitudes in the Bulletins could be used for this determination. According to most recent theory (Gutenberg and Richter, 1949), the energy released by an earthquake is related to the magnitude as shown by the equation

$$\log E = 12 + 1{\cdot}8\,M$$

where E is the energy, in ergs, and M is the magnitude.

On the accompanying map, epicentres are represented by circles graded according to intensity, or magnitude, open circles for Modified Mercalli Intensities, closed circles for absolute magnitudes. It is probable that the whole area considered is covered down to magnitude 6; for smaller magnitudes, those areas around the recording stations are best covered—within 10° of them for magnitudes of about 5. New South Wales is probably covered for magnitudes of little more than 4. Smaller tremors at distances greater than 10° from any station are not likely to have been recorded at all.

As an indication of the area covered by any one station, it may be noted that the number of tremors in the Australian region recorded by Riverview, between 1909 and 1950, is: from New South Wales, 85; from Central Australia, 9; from Queensland, 6; from South Australia, 6; from Victoria, 5; from Western Australia, 4; from Tasmania, 2. For purposes of comparison the total number of shocks of all magnitudes reported from Australia generally and from N.S.W. in particular is set against the average annual numbers throughout the world in the following table.

Magnitude.	World, Number per Year.	Australia, 41 Years.	N.S.W., 41 Years.
7–8	13	1	—
6–6·9	108	6	—
5–5·9	800	8	3
4–4·9	6,200	18	12
3–3·9	49,000	11	11

This table includes only those for which epicentres have been determined; a great many lesser tremors occur, as may be seen from those recorded at Riverview alone. Nevertheless, it is evident that Australia is one of the stable regions of the earth ; even the seismic activity of the Great Rift Valley, from Spencer Gulf to Lake Eyre, which is the region most subject to disturbance in Australia, is negligible compared with the activity of the minor seismic zones of the earth.

ACKNOWLEDGEMENT.

The writer is greatly indebted to Father O'Connell, Director of Riverview Observatory, for advice and encouragement in this investigation.

SUMMARY.

Epicentres are given for all Australian earth tremors for which sufficient observations are available. Where possible, magnitudes are given on the Gutenberg-Richter Scale, or intensities on the Modified Mercalli Scale. Australian seismicity is compared with that of the world as a whole.

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CONTOUR TRENCH FORMATIONS IN UPLAND PLAINS OF NEW SOUTH WALES.

By C. T. McElroy, B.Sc.

With Plate V and two text-figures.

Manuscript received, June 29, 1951. Read, August 1, 1951.

I. Introduction.

(*a*) *General.*

The features to be described consist of trench-like depressions in the general land surface, in areas of gentle slope, in saddles or on flat ridges.

The trenches were first observed by the writer in the north-east section of Happy Jack's Plain, 33 miles north of Mt. Kosciusko. Viewed from a distance, they stand out with remarkable clarity on an otherwise uniformly grassed slope, the strong degree of orientation here emphasizing the extraordinary nature of the phenomenon, as shown in Plate V, Fig. 1. In Plate V, Fig. 2, is shown a close-up of the trenches in Fig. 1.

The following account is based on seventeen field trips, and laboratory studies carried out between January, 1949, and May, 1950. The accompanying locality map indicates the known distribution of the trenches, viz. Hernani, Madden's Plains, Little Forest and Kiandra to Mt. Kosciusko.

(*b*) *Previous References.*

Andrews (1901) has briefly referred to an occurrence in the Kiandra district. Davis (1936) records the trenches at Madden's Plains. Costin (1948) has also recorded an occurrence near Mt. Kosciusko below Seaman's Hut, which may be identical with these features.

II. Nature of the Formation.

(*a*) *General Properties of all Occurrences.*

(i) *Topography.* In all cases the formations occur in naturally grassed, treeless plains, which are usually the gathering grounds of swamps or streams, or, as in the Main Range occurrences in the Monaro, on well grassed ridges and saddles. The areas are elevated, considered on a regional basis with respect to the adjoining country, altitudes ranging from 1,200 feet to nearly 7,000 feet above sea level. Where the slope of these lands is less than 4½ degrees, the trenches may occur. The trenches may be considered as being of two main types, which grade into each other, these being (i) long and narrow, disposed along the contour on gentle slopes with typical dimensions 20 feet long, 1 foot wide and 9 inches deep; and (ii) broad and irregular in outline, occurring on more level surfaces, as in saddles, or minor horizontal portions of long slopes, with typical dimensions 6 feet long, 4 feet wide and 6 inches deep. The trenches occur in groups, individual trenches being from a few inches to a few feet apart.

In general, it may be stated that, with increasing slope up to this maximum of 4½ degrees, at which trenches no longer form, the depressions are

(*a*) more strongly oriented along the contour;

(*b*) shallower and narrower.

Further, as a uniform slope is descended and the moisture content of the soil increases, the depressions merge into normal minor surface irregularities and lose their identity. At the top of the slopes in the most thoroughly drained areas, the maximum depth of development is attained.

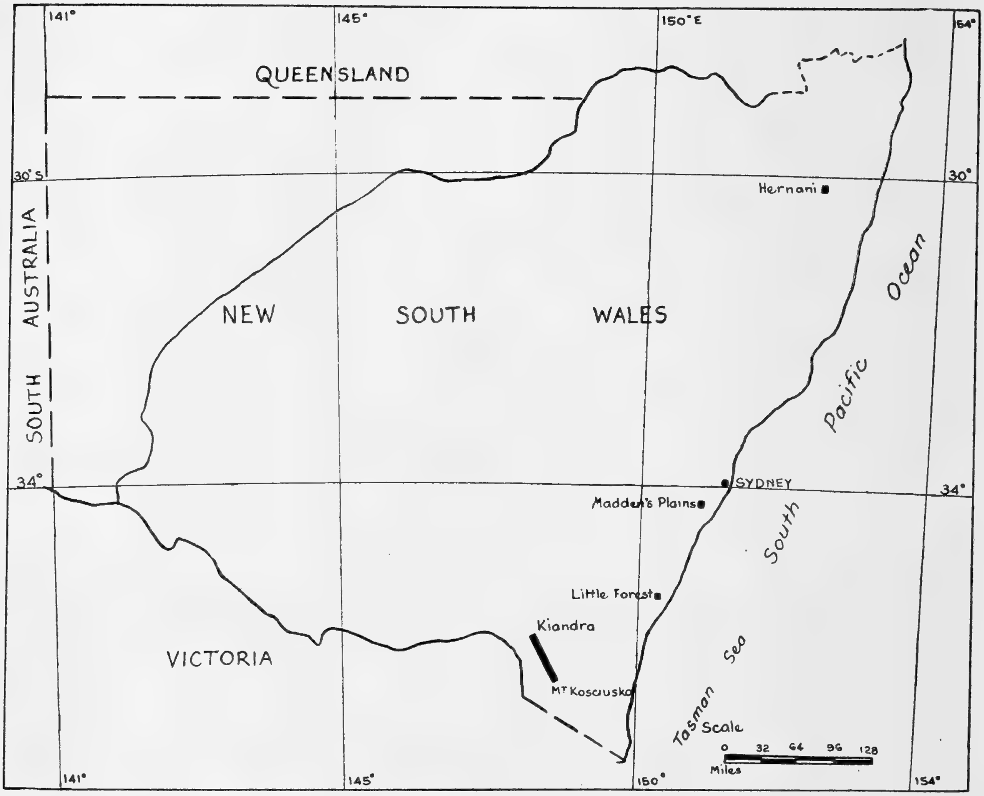

Fig. 1.—Locality map of New South Wales showing distribution of Contour Trench Formations.

The orientation with respect to contour is simply demonstrated by the fact that after moderate falls of rain there is no overflow from the completely filled trenches of uniform depth, these observations having been made on trenches 40 yards long. On level surfaces, where ideally there are no contours, the trenches become broad and irregular in outline, or if elongate, are sinuous. These may be considered to coincide with the closed contours of actual minor surface irregularities. Thus the name " Contour Trench Formation " is valid for the different modes of occurrence of the feature.

(ii) *Ecology.* The very existence of the natural plains is an interesting study, though beyond the scope of the present writing. The relationships of tree line, grasses and bog vegetation is basically due to the balance between soil moisture and aeration. The following is an indication of the relation of botanical types to topography, taking the Little Forest plant assemblage as an example.

The dominant plant species in this area are:

(*a*) On normal surface level:

- (1) Various species of *Banksia*, *Hakea*, *Sprengelia* and other small shrubs over whole area of slope.
- (2) At top of slope and on crests of low ridges. *Eucalyptus gummifera* (Bloodwood) in both mature and stunted forms.
- (3) On higher parts of slope the sedges *Tricostularia paludosa* and *Leptocarpus tœnax.*
- (4) On lower part, *Blandfordia nobilis.*
- (5) In swampy areas, *Charizandra sphœrocephala.*

(*b*) On the floor of the depressions:

- (1) Up slope: *Goodenia paniculata*, *Selaginella uliginosa* and water lily types.
- (2) Down slope: *Charizandra sphœrocephala*, *Lepidosperma concavum*, *Schoenus brevifolius*, with the upslope types above subordinate.

This relationship is as expected, the more lowly forms being in their natural habitat of more poorly aerated soil.

Davis (1936) lists detailed assemblages in the Madden's Plains area.

(iii) *Climate.* The Eastern Highlands come under the Koppen Classification *Cfa* and *Cfb.* Average annual rainfalls of the areas studied vary from 35 inches to 80 inches. In winter all areas are subject to very heavy frosts and strong winds, with moderate temperatures in summer. The Monaro and Northern Tablelands Groups are also subject to winter snows. The effective rainfall is high, the thickly grassed gentle slopes reducing run-off and surface evaporation. The resultant impeded drainage tends to develop a meadow soil profile.

(iv) *The Individual Formation.* It is convenient to divide the type of individual formation into three classes, termed α, β and γ.

α-types may be considered as the elongated trenches following the contours on slopes varying from ½ to 4½ degrees. These range in size from 2 feet long, 6 inches wide and 2 inches deep to as much as 250 feet long, 6 feet wide and 8 inches deep or 150 feet long, 2 feet wide and 18 inches deep.

β-types are trenches showing no orientation, usually fairly short, perhaps up to 30 feet in length. These types may be arcuate, U-shaped or sigmoid and occur on level surfaces or slopes up to ½ degree.

γ-types occur more typically on level areas than β-types. They are relatively broad and may be almost equidimensional in plan, with width of up to 30 feet. Outline may be square, rectangular, subcircular or quite irregular, some being racquet-shaped as in Plate V, Fig. 3, or even cruciform. Both β and γ-types have depths ranging up to 18 inches, generally deeper than associated α-types.

When a small patch of β- or γ-types occurs in an α-area, it is found that it is always associated with a local decrease in gradient to ½ degree or less.

The walls of the trenches are generally vertical, although some have been observed at angles up to 10 degrees from the vertical. The up-slope wall is sometimes less nearly vertical than the down-slope wall, probably due to a certain amount of overwash of silty material in very wet conditions.

(v) *Soil Profile.* All occurrences lie within the Eastern Podsol Belt (Prescott, 1944). Some of the Monaro Group are classified as High Moor Soils. This, however, is a regional classification, from which there are local variations.

Textures of surface soils range from medium clay to coarse sand, being locally somewhat heavier in trench than on immediately adjacent surface.

TABLE 1A.

Details of Individual Occurrences.

Group.	Regional Physiographic Situation.	Climate.	Vegetation.	Location.	Significa Trenc Type.
Monaro.	In a 50 mile long belt from Kiandra, south to near Kosciusko. See Snow Lease Map for general locations. Altitudes from 4,500 feet near Kiandra to 7,000 ft. at Mt. Twynam.	Precipitation 62 in. at Kiandra to 80 in. at Kosciusko. Snow cover 4 to 6 months. Heavy frosts may occur through whole year. Winds extreme.	*Eucalyptus pauciflora* (Snow Gum) on ridges, but suppressed at 6,000 feet. *Poa cæspitosa* (Snow Grass) is dominant grass, with *Celmisia longifolia* (Snow-daisy) abundant. Heaths and *Sphagnum* bogs at lower parts of slope.	(1) 3 to 5 miles north of Kiandra between main road and Eucumbene River.	α
				(2) ¾ mile south of Tabletop Hut.	γ
				(3) Happy Jack's Plain, 9 miles west of Adaminaby, near Grey Mare track.	α
				(4) Farm Ridge, northern end.	γ
				(5) High Peaks, Jagungal to Twynam.	γ
				(6) Johnnie's Plain, ¾ mile north-east of Chalet.	α
Far South Coast (Little Forest).	On Tabletop Plateau, area 6 square miles, 8 miles north-west of Milton. Altitude 1,800 ft.; plateau bounded by cliffs 500 ft. high.	Estimated rainfall 60 in. Prevailing strong westerly winds. Heavy frosts uncommon. No snow recorded.	*Eucalyptus gummifera* (Bloodwood), both normal and mallee growth, on ridges. Sedges, *Tricostularia*, *Leptocarpus*, etc., on higher slopes; *Blandfordia*, *Charizandra*, etc., on lower slopes. See Section II(a) (Ecology) (ii) for details.	(1) ½ mile north-west of Little Forest Trig.	β
				(2) 100 yds. south from (1) above.	α
				(3) ½ mile south of (1) above, on opposite side of swamp.	α
				(4) 1½ miles south from Little Forest Trig.	α
				(5) 1½ miles east-south-east from Little Forest Trig.	α and
Near South Coast (Madden's Plains).	On Illawarra Plateau. Natural plains, extending 2 mls. along west side of Prince's Highway, from 37 mls. south of Sydney to ½ ml. north of Sublime Point. Altitude 1,200 ft. Cliffs and steep slopes drop to sea ½ ml. to east.	Rainfall 59 in. Dense mists drift across from seaward in all seasons.	As at Little Forest.	(1) 400 yds. west of road, 38¾ mls. south from Sydney.	α
Northern Tablelands.	On Dorrigo Tableland, altitude 3,700 ft.	Rainfall 35 in. Five months' heavy frosts. Often snow in winter months.	Trenched areas treeless. Dense natural grass cover.	(1) Hernani, near "The Glen" homestead.	α

TABLE 1B.

Details of Individual Occurrences.

Local Topographic Situation.	Parent Material.	Surface Soil.			Comments.
		Colour.	Texture.	pH.	
Across small flat ridge sloping at 1°, terminated by a gentle rise, as in Text-fig. 2 (*a*).	Basalt, Tertiary and Recent alluvial deposits, and Ordovician slate.	Dark grey.	Peaty loam.	—	Terminal rise of ridge casts doubt on possibility of appreciable solifluction.
Flat open areas.	Very acid granite.	—	—	—	Depths of trenches vary from 4 in. to 8 in.; up to 30 ft. square.
On small " terrace " below 4° slope, as in Text-fig. 2 (*b*).	Granite.	Dark grey.	Peaty loam.	5·50	Considered " type area ". Excellent development. Ten yards up-slope from trenches are granite boulders 3 in. below surface. Soil profile to depth 24 in., is identical 75 yds. along contour from trenched area, in identical topography, but no suggestion of trenches.
On rocky flat area.	Basalt.	—	—	—	Trenches in soil surrounding and covering blocks of detrital basalt, solid rock being exposed in bottoms of some trenches 8 in. deep.
Exposed ridges and saddles.	Amphibolite and granite.	—	—	—	Often dry; sun-cracked and flaked; observed scouring action of high velocity winds.
" Terrace ", 25 yds. wide, as in Text-fig. 2 (*c*).	Granite.	Medium brown.	Gritty loam.	5·55	Not typical of Monaro Group; relief of trenches subdued by thick grass cover.
At top of flat ridge. Trenches among stunted *Eucalyptus gummifera.*	Upper Marine sandstone and grit.	Dark grey.	Sandy loam.	—	Only record of trenches occurring among trees. Trenches probably preceded tree growth.
3° slope.	Do.	Do.	Do.	—	A 4 ft. deep cut was made across a trench; no depression of lower soil horizons observed.
Flat ridge, sloping axially at 2°.	Do.	Do.	Do.	5·9	Complete laboratory analyses carried out of soil profiles (*a*) in and (*b*) adjacent to trenches, and (*c*) among trees 120 yds. distant. Some typical results given in Table 2.
On " terraces " on slope as in Text-fig. 2 (*d*).	Do.	Do.	Do.	—	Exemplifies successive relationships between angle of slope and occurrence of trenches.
On slope as in Text-fig. 2 (*e*).	Do.	Do.	Do.	—	Trenches up to 50 yds. long, 12 ft. wide, 9 in. deep, formed on shallow soil on sandstone.
Uniform slopes up to 3½°.	Hawkesbury sandstone.	Do.	Do.	5·30	Trenches up to 85 yds. long, then a short " cross-tie ", and then a further trench along same contour. Large pit dug, 6 ft. 6 in. deep; soil horizons straight. Specific gravity determinations show no compaction vertically or horizontally.
Semi-saucer shaped area, 100 yards wide, slopes of ½°.	Tertiary basalt and (?) Silurian slate.	Light brown-grey.	Loamy clay.	5·50	Some trenches ploughed under 15 years ago; sown with cocksfoot and paspalum; no recurrence.

TABLE 1A.

Details of Individual Occurrences.

Group.	Regional Physiographic Situation.	Climate.	Vegetation.	Location.	Significa Trench Type
Monaro.	In a 50 mile long belt from Kiandra, south to near Kosciusko. See Snow Lease Map for general locations. Altitudes from 4,500 feet near Kiandra to 7,000 ft. at Mt. Twynam.	Precipitation 62 in. at Kiandra to 80 in. at Kosciusko. Snow cover 4 to 6 months. Heavy frosts may occur through whole year. Winds extreme.	*Eucalyptus pauciflora* (Snow Gum) on ridges, but suppressed at 6,000 feet. *Poa cæspitosa* (Snow Grass) is dominant grass, with *Celmisia longifolia* (Snow-daisy) abundant. Heaths and *Sphagnum* bogs at lower parts of slope.	(1) 3 to 5 miles north of Kiandra between main road and Eucumbene River.	α
				(2) ¾ mile south of Tabletop Hut.	γ
				(3) Happy Jack's Plain, 9 miles west of Adaminaby, near Grey Mare track.	α
				(4) Farm Ridge, northern end.	γ
				(5) High Peaks, Jagungal to Twynam.	γ
				(6) Johnnie's Plain, ¾ mile north-east of Chalet.	α
Far South Coast (Little Forest).	On Tabletop Plateau, area 6 square miles, 8 miles north-west of Milton. Altitude 1,800 ft.; plateau bounded by cliffs 500 ft. high.	Estimated rainfall 60 in. Prevailing strong westerly winds. Heavy frosts uncommon. No snow recorded.	*Eucalyptus gummifera* (Bloodwood), both normal and mallee growth, on ridges. Sedges, *Tricostularia*, *Leptocarpus*, etc., on higher slopes; *Blandfordia*, *Charizandra*, etc., on lower slopes. See Section II(a) (Ecology) (ii) for details.	(1) ½ mile north-west of Little Forest Trig.	β
				(2) 100 yds. south from (1) above.	α
				(3) ½ mile south of (1) above, on opposite side of swamp.	α
				(4) 1½ miles south from Little Forest Trig.	α
				(5) 1½ miles east-south-east from Little Forest Trig.	α and γ
Near South Coast (Madden's Plains).	On Illawarra Plateau. Natural plains, extending 2 mls. along west side of Prince's Highway, from 37 mls. south of Sydney to ½ ml. north of Sublime Point. Altitude 1,200 ft. Cliffs and steep slopes drop to sea ½ ml. to east.	Rainfall 59 in. Dense mists drift across from seaward in all seasons.	As at Little Forest.	(1) 400 yds. west of road, 38¾ mls. south from Sydney.	α
Northern Tablelands.	On Dorrigo Tableland, altitude 3,700 ft.	Rainfall 35 in. Five months' heavy frosts. Often snow in winter months.	Trenched areas treeless. Dense natural grass cover.	(1) Hernani, near "The Glen" homestead.	α

TABLE 1B.

Details of Individual Occurrences.

Local Topographic Situation.	Parent Material.	Surface Soil.			Comments.
		Colour.	Texture.	pH.	
Across small flat ridge sloping at 1°, terminated by a gentle rise, as in Text-fig. 2 (*a*).	Basalt, Tertiary and Recent alluvial deposits, and Ordovician slate.	Dark grey.	Peaty loam.	—	Terminal rise of ridge casts doubt on possibility of appreciable solifluction.
Flat open areas.	Very acid granite.	—	—	—	Depths of trenches vary from 4 in. to 8 in.; up to 30 ft. square.
On small "terrace" below 4° slope, as in Text-fig. 2 (*b*).	Granite.	Dark grey.	Peaty loam.	5·50	Considered "type area". Excellent development. Ten yards up-slope from trenches are granite boulders 3 in. below surface. Soil profile to depth 24 in., is identical 75 yds. along contour from trenched area, in identical topography, but no suggestion of trenches.
On rocky flat area.	Basalt.	—	—	—	Trenches in soil surrounding and covering blocks of detrital basalt, solid rock being exposed in bottoms of some trenches 8 in. deep.
Exposed ridges and saddles.	Amphibolite and granite.	—	—	—	Often dry; sun-cracked and flaked; observed scouring action of high velocity winds.
"Terrace", 25 yds. wide, as in Text-fig. 2 (*c*).	Granite.	Medium brown.	Gritty loam.	5·55	Not typical of Monaro Group; relief of trenches subdued by thick grass cover.
At top of flat ridge. Trenches among stunted *Eucalyptus gummifera*.	Upper Marine sandstone and grit.	Dark grey.	Sandy loam.	—	Only record of trenches occurring among trees. Trenches probably preceded tree growth.
3° slope.	Do.	Do.	Do.	—	A 4 ft. deep cut was made across a trench; no depression of lower soil horizons observed.
Flat ridge, sloping axially at 2°.	Do.	Do.	Do.	5·9	Complete laboratory analyses carried out of soil profiles (*a*) in and (*b*) adjacent to trenches, and (*c*) among trees 120 yds. distant. Some typical results given in Table 2.
On "terraces" on slope as in Text-fig. 2 (*d*).	Do.	Do.	Do.	—	Exemplifies successive relationships between angle of slope and occurrence of trenches.
On slope as in Text-fig. 2 (*e*).	Do.	Do.	Do.	—	Trenches up to 50 yds. long, 12 ft. wide, 9 in. deep, formed on shallow soil on sandstone.
Uniform slopes up to 3½°.	Hawkesbury sandstone.	Do.	Do.	5·30	Trenches up to 85 yds. long, then a short "cross-tie", and then a further trench along same contour. Large pit dug, 6 ft. 6 in. deep; soil horizons straight. Specific gravity determinations show no compaction vertically or horizontally.
Semi-saucer shaped area, 100 yards wide, slopes of ½°.	Tertiary basalt and (?) Silurian slate.	Light brown-grey.	Loamy clay.	5·50	Some trenches ploughed under 15 years ago; sown with cocksfoot and paspalum; no recurrence.

There is an increase in clay content down the profile, with marked textural change and strong mottling or ortstein development at about 20 inches, which is the normal height of the water table. Vegetation between trenches, principally grasses and sedges, is very dense, roots being abundant to a depth of several inches and offering considerable resistance to digging. The trench is relatively poorly grassed with little vegetative binding, the proportion of roots being approximately equal to that in the same horizon of the immediately adjacent profile. Structure of surface soil ranges from very poor to excellent crumb-structure. Organic matter determinations of the Little Forest soils were all less than 7%. Organic matter diminishes down the profile and is slightly higher in the trench.

To depths ranging up to 6 feet 6 inches it has been proved that the glei, ortstein and other identifiable horizons are quite level, reflecting nothing of the surface irregularity. Parent material varies greatly, including sandstone, slate, granite and basalt.

pH of over seventy samples, determined by electronic pH meter, shows the pH range of all horizons in all occurrences as between 5·0 and 6·3. There is usually a slight increase in pH down the profile, with either slightly higher or lower values in trench than adjacent.

Colours of the soils range from dark grey and dark brown to light grey at the surface, and to orange-red and light grey at depths of a few feet. Free carbonate is absent from all profiles.

The catenary development of the profile has not been investigated quantitatively, but it may be stated that texture becomes heavier and colouring deeper in a given horizon as the slope is descended. When the trenches do not occur at the top of gentle slopes, the B horizon up-slope is not clearly defined. However, on entering the trenched areas this horizon becomes markedly developed. The same general rule holds for ortstein layer development when present.

(*b*) *Distribution and Description of Individual Occurrences.*

In Tables 1A and 1B are shown brief details of some of the known occurrences of contour trench formations. (See p.p. 56-57).

Table 2 shows results of analyses carried out on a typical soil profile from Little Forest, Location (3).

TABLE 2.

Analysis of a Typical Soil Profile from Little Forest, Location (3).

Depth.	Col.	Text.	pH.	% O.M.	% N.	% Cl.	% Sol. Salts.	Exch. Cap. M.E. %	Total Exch. Bases M.E. %	Mechanical Analysis.				
										CS.	FS.	Si.	Clay + O.M.	R_2O_3.
0″– 3″ ..	M-Gr	SL	5·9	4·55	0·11	0·006	0·23	6·9	0·15	33·3	35·7	9·2	17·6	0·6
3″– 6″ ..	Gr	SL	6·2	3·60	0·10	0·005	0·05	2·5	0·37	33·5	34·9	10·1	14·8	1·4
6″–12″ ..	l-Gr	SL	6·2	1·74	0·10	0·008	0·04	4·3	0·39	33·9	35·1	10·1	16·8	1·7
20″–24″ ..	Y-Bn	SL	5·1	1·30	0·04	0·004	0·05	5·6	0·56	41·0	38·3	5·2	18·2	1·3

Although in Table 2 mechanical analyses classify all samples as sandy loam, simple qualitative tests indicate an appreciable increase in apparent clay content descending the profile. At a depth of 21 inches is a well-developed ortstein layer 2 inches thick, consisting of limonite nodules ranging in size from ½ inch to 1 inch, forming, with associated quartz grit, 30 per cent. of the sample 21″–24″. However, only the fine earth fractions were analysed. No free carbonate is present.

C : N ratio for all samples in the area ranges from 10·1 to 34·1. Total phosphorus, determined as such, is very low; *e.g.* sample 0–3″ contains only 0·012% P. In addition to those shown organic matter content of several other surface samples were determined, none of which exceeded 7% O.M.

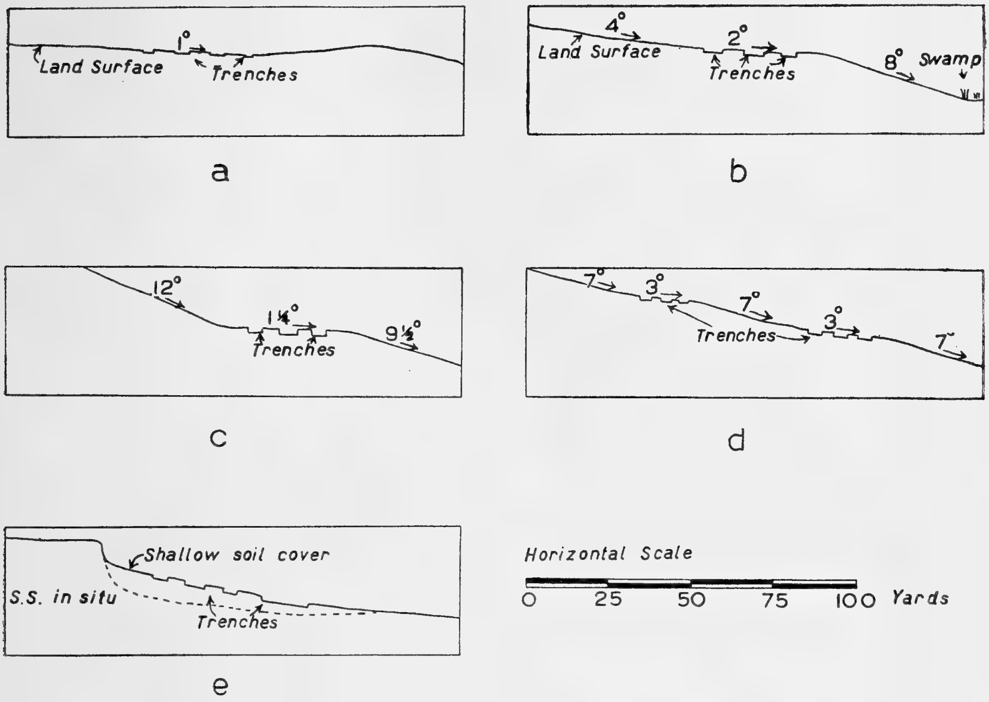

Fig. 2.—Sections across contour trench formations. (See Table 1.)

III. Possible Origins of the Formations.

The origin is considered from the viewpoint of initial development and subsequent enlargement.

(*a*) *Initial Development.*

(i) *Man Made.* This explanation is unacceptable because of the lack of purpose in the digging of trenches over such a wide area, varying from 0 to 18 inches in depth, and the gradation from α- to γ-types.

(ii) *Animal Activity.* Animal tracks could not have been responsible for β- or γ-types, or for the great number of α-types often found adjacent.

Initiation by eating out of grass roots by animals would require an improbable degree of selectivity in grazing.

The tentative suggestion of Davis (1936), that crayfish may have initiated trenches by their burrowings, was later virtually abandoned by that writer (Davis, 1941).

(iii) *Water Erosion.* Orientation along the contour of α-types, and irregular shapes of γ-types is inconsistent with erosion due to water run-off.

(iv) *Fire-formed.* The suggestion that, in grass fires, prevailing winds have caused to be burnt out groups of grass roots, ignores the strict relation to contour and degree of slope.

(v) *Jointing.* Subsidence in pronounced parallel joints is not possible as soil horizons show no downward displacement, and the direction and spacing of joints of rocks in the area are unrelated to direction and spacing of trenches.

(vi) *Gilgai Formation.* Gilgais are normally characterized by free carbonate in the B-horizon, relative vertical displacement of puff and shelf, and the sequence in formation of deep-cracking—infilling—wetting and expansion—wedging-up to leave depression. These factors are contrary to characteristics of Contour Trench Formations.

(vii) *Sun Cracks.* The formation of deep regular cracks due to contraction in drying out implies a very heavy texture, or high organic content as in peat bogs ; neither of these characteristics is typical of the Contour Trench Formation.

(viii) *Salt Pan Formation.* Salt accumulation in trench sites with suppression of vegetation might be an initiating factor. However, analysis of Little Forest soils showed that content of chloride, carbonate, phosphate and exchangeable cations Ca, Mg, K and Na was small or very low.

(ix) *Seed Deposition.* The suggestion has been put forward that, in the Kosciusko area, if a body of snow were " sown " with wind-blown seeds, a rhythmic deposition (analogous to lines of litter left by the ebbing tide) might be set up by the daily recurrence of thawing as the snow line retreats up-slope. The lines of deposited seeds, which would tend to be along the contour, would initiate differential development of the vegetation, which might tend towards the development of depressions between the lines. If acceptable, this theory is nevertheless of limited application, as suitable masses of snow do not occur in other localities.

(x) *Solifluction.* The theory that the Contour Trench Formation is due to some form of solifluction is a fairly obvious line of reasoning which merits serious consideration.

Although, in general, slopes of 10 to 20 degrees and greater are associated with the phenomena of creep and mass wasting, it must be appreciated that, if the medium is in a sufficiently fluid condition, as may be the case when saturated from prolonged precipitation, gravitational movement may be initiated at very low angles. Initiation of movement by seismic activity might also be borne in mind as a possibility.

Gravitational slumping was studied in many South Coast localities, on slopes of the order of 20 degrees. Strong parallelism along the contour is common. In many cases grass roots have been torn away and " terraces " about one foot wide formed. In the Kosciusko area this feature frequently occurs on the steeper slopes. Frost-heave in such areas would doubtless be a very significant factor in this mechanism. The " Parallel Ledge " formation of Van der Merwe (1941) may have thus originated. Referring to slumping of soil on steep hillsides, Flint (1932) states : " This process is responsible for some of the ' sheep paths ' that so commonly contour the slopes in hilly pasture land."

It is possible that a tendency for slumping to develop on the gentle slopes where contour trenches form may result in some downslope movement of a given unit of soil, bound by a grass tussock. This unit, essentially a surface element, may move until the resistance to its progress is too great, *e.g.*, it may strike another, more firmly established mass of grass roots. A lineation of such movements would give the parallelism of the α-type trenches. Against this theory we have that, in many localities, the sum of the areas of individual formations exceeds, by a factor of 2 or 3, the sum of the areas between trenches. This calls for considerable compaction. However, specific gravity determinations of Madden's Plains soils show that all horizons examined of the surface and subsurface soils among the trenches had a lower S.G. than on the untrenched ridge at top of the slope. No compaction could have occurred in this instance. Similarly, no selective vertical compaction could have occurred as the mean S.G. of trench soil is less than adjacent soil, taken to a depth of 18 inches. If it be accepted that there is no compaction, it might be contended that there is large-scale successive migration down the slope of the upper root-bound part of the A horizon, the lower edge of the main migrating sheet being carried away in the central drainage system. Although possible for α-type trenches, this theory must break down when applied to β-types and γ-types, especially when groups of the latter may consist of trenches 30 feet wide separated by only 2 to 3 feet, on a horizontal surface and up to 50 yards away from the slightest slope. Furthermore, although a perceptible steepening of slope often occurs below trenched terraces, which would assist solifluction, sometimes, as in Monaro Locality 1, there occurs at the end of the slope a rise, so that migrating soil could not in this case be transported away by the drainage system.

(*b*) *Subsequent Enlargement.*

All the foregoing theories have dealt only with the initiation of depressions, no matter how slight this may be. Assuming initiation, we now consider later stages.

(i) *Ecological Adjustment.* In any depression formed, water will tend to lie, saturating the soil. Ultimately the depressions will be bordered by tussocks of the normal grasses, which are suppressed in the depressions where more lowly mossy types can flourish in the relatively anaerobic condition of the soil. Thus, for α-type trenches, the explanation of which is the real problem, differential growth of vegetation will be set up along the contour. Consider now the β- and γ-types. On a fairly level surface, water will lie in the minor surface irregularities always present. Ecological adjustments then occur as above. Indeed, γ-type trenches are common to marsh soils in many parts of the world. It is their extreme development, their ability to dry out so as to appear as trenches, and the associated α-types that have made them worthy of note in the present discussion.

(ii) *Raindrop Action.* The effects of impact of raindrops are expressed in vertical walls, the adjacent grass acting as a protective capping, and a general levelling of the relatively bare floor of the trench.

(iii) *Flooding Effects.* In periods of excessive rain when all trenches are completely filled and there is a surface sheet of water moving downslope, any particles of soil stirred up by turbulence from the poorly grassed floor of the trench will be transferred either to the adjacent grassed strip or ultimately to the central drainage system.

(iv) *Eluviation.* The possibility was considered of removal of the clay fraction from the trenches by a downward eluviating process, which would act most effectively in the poorly bound trench floor, and its downslope migration on meeting the plane of the mobile water table just above the heavier textured horizon. The results of mechanical analyses, however, indicate that this has not occurred, as the proportions of all fractions of the trench and adjacent profile are comparable.

(v) *Wind Action.* The study of physics of particle movement in air stresses the importance of the part played by wind as an abrasive and transporting medium. The effect of wind in trench formation was directly observed in the High Peaks area north of Kosciusko. Here gale force winds were observed to remove fine particles from the cracked and flaking bare floors of trenches. Fine quartz grains from decomposing gneissic granite of the area are whipped into the trenches by the winds, where the effects of saltation and turbulent flow remove the loosened particles. The slightly undercut appearance of the sides of some of the Monaro trenches is strongly suggestive of wind scouring. Some loosened particles are driven into the adjacent grass and consolidated, others are transported out of the area. The flaking and curling of clayey soils, and the powdering of sandy soils in dry conditions, greatly assists the scouring action. The existence of deeper trenches on the crests of ridges or in the more exposed positions, in many localities, is consistent with there being greater susceptibility to scouring action in such positions.

(c) *Conclusions as to Origin.*

Of the theories advanced, those depending on human or animal activity, normal water erosion, jointing systems, gilgais, sun cracks, salt pans and eluviation are rejected. The theories of fire formation and seed deposition cannot be wholly discounted. For α-types, it is considered that solifluction is the principle initiating factor. β- and γ-types are considered to have their origin in minor surface irregularities. Secondly, all types are then enlarged by ecological adjustment, this being the most important single factor in the development. Raindrop action, flooding and wind action are considered effective as tertiary factors.

IV. SUMMARY.

An account is given of observations made on naturally-occurring, trench-like depressions in the general land surface, conforming to the contour, in upland plains of New South Wales. Soil profiles and relation to topography are dealt with in some detail. The modes of origin favoured are solifluction and adaptation of the root systems of plants to a specialized soil-moisture environment, with further development by wind and rain action.

V. ACKNOWLEDGEMENTS.

Sincere thanks are due to the Hill family of Little Forest and the Goddard family of Hernani for making available accommodation ; to Dr. E. G. Hallsworth of the University of Sydney for encouragement and helpful discussions ; to many fellow students for assistance in field trips and laboratory work ; and in particular to Mr. F. R. Gibbons, B.Sc., University of Sydney, for sustained advice and assistance in all phases of the work.

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EXPLANATION OF PLATE V.

Fig. 1.—Occurrence of Contour Trench Formation at Monaro, Location (3), Happy Jack's Plains, showing relation to topography, viewed from a distance of ¼ mile.

Fig. 2.—Close-up of α-type trenches shown in Fig. 1. Photograph by courtesy of Mr. C. L. Adamson.

Fig. 3.—α-type trenches at Little Forest, near Location (1).

Fig. 4.—Racquet-shaped γ-type trenches at Monaro, Location (1), Kiandra.


1


2


3

THE GEOLOGY OF THE NANIMA-BEDULLUCK DISTRICT, NEAR YASS, NEW SOUTH WALES.

By Kathleen Sherrard, M.Sc.

With Plate VI and five text-figures.

Manuscript received July 11, 1951. Read, August 1 1951.

I. Introduction.

The geology of the Nanima–Bedulluck district has not been described previously, though it has been referred to in mineral reports (Watt, 1897; Carne and Jones, 1919) and is bounded on three sides by areas whose geology has been studied, namely the Yass–Jerrawa district to the north, the area of the Burrinjuck Dam on the Murrumbidgee River to the west, and the Australian Capital Territory to the south (Fig 1). The district studied includes the parishes of Nanima and Bedulluck as well as adjoining portions of several other parishes.

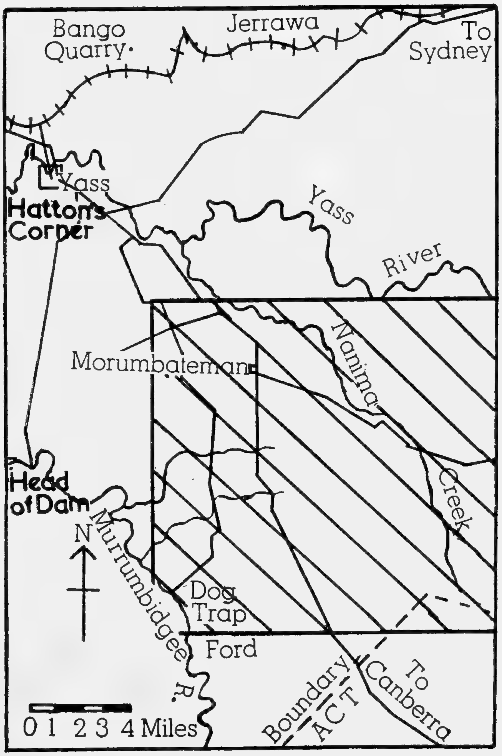

Fig. 1.—Sketch-map to show position of area described in relation to Yass, Australian Capital Territory and Burrinjuck Dam

Its geology has been studied to gain information on the relations between Ordovician and Silurian sedimentary rocks; and between those rocks and the igneous rocks occurring near them; and to correlate the sedimentary rocks with those elsewhere.

The discovery of both Upper Ordovician and Silurian graptolites, including species not previously recorded from Australia, has made possible the assignment of the beds in which they occur to particular zones of those systems. In the case of the Silurian, beds with shelly fossils occurring in conformable relation with graptolite-bearing slates can also be dated.

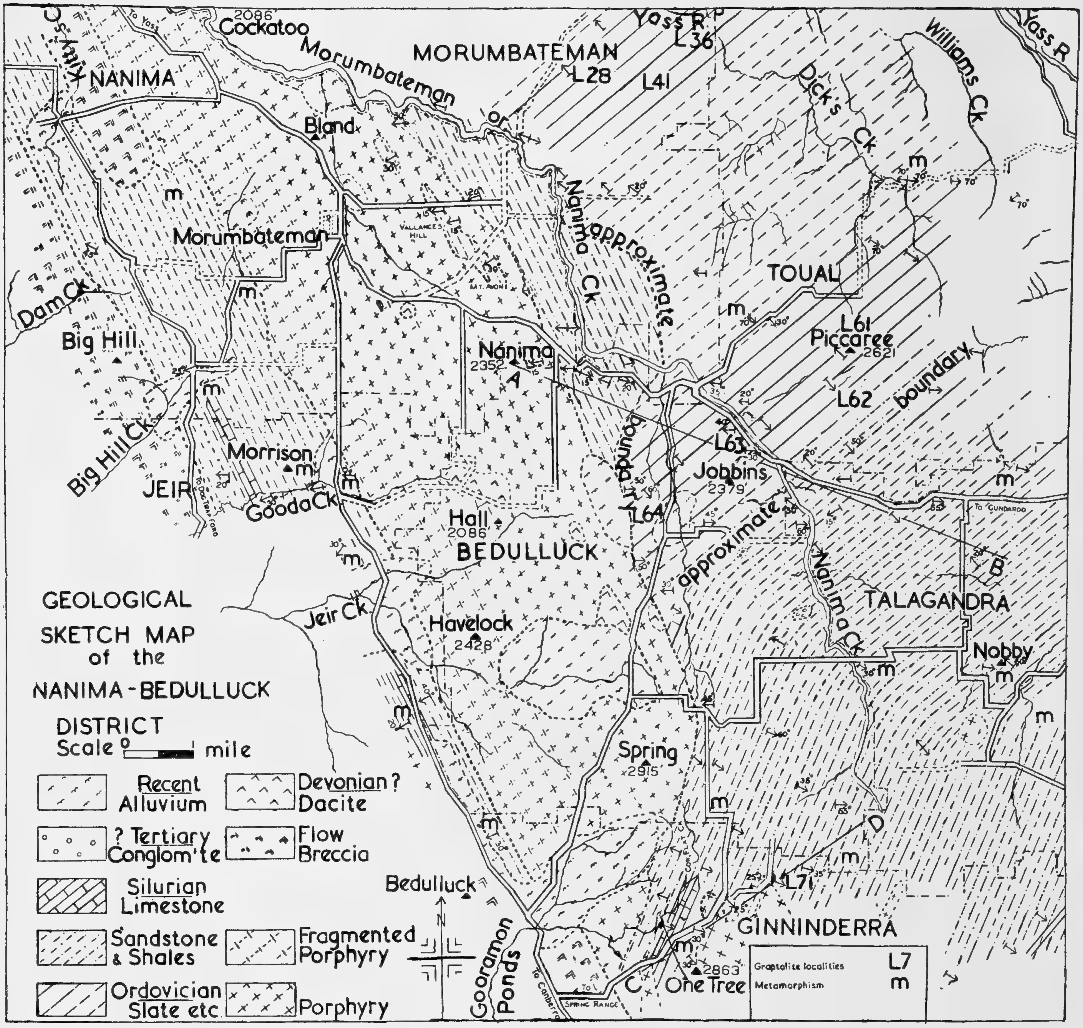

Fig. 2.—Geological Sketch-map of the Nanima-Bedulluck District.

Information regarding the origin of the confusing textural features in the igneous rocks has been gained in the field, in thin section and by chemical analysis, and has helped in the understanding of these rock types and of those similar in adjacent areas.

Gold and bismuth were mined in this district, but now the chief products are fine merino wool and cattle. Earthquake tremors have been recorded near Morumbateman, the only village in the area of 250 square miles examined (Cotton, 1925). Two spellings, " Morumbateman " and " Murrumbateman ", are in use. For uniformity, the first only will be used in this paper.

II. PHYSIOGRAPHY.

The area is divided geologically into two nearly equal portions. There is a western largely igneous and metamorphosed part and an eastern sedimentary part. The main stream, Nanima Creek, flows north, almost entirely within the sedimentary section, which is timbered and rough. The igneous and metamorphosed area is a tableland with isolated hills and is largely cleared. It has a slight slope to the south-west and is drained by Jeir, Gooda and Big Hill Creeks and Gooramon Ponds. These are subject to flooding and must have been held back for some time, because much alluvium has accumulated near their heads. Later rejuvenation enabled them to cut through 10–15 feet of alluvium and make their way south-west to the Murrumbidgee River.

III. UPPER ORDOVICIAN.

Graptolites have been collected from Upper Ordovician slate in four localities on a dissected anticline. Phyllites and schists, also probably of Ordovician age, occur in anticlines outcropping on either side of that in which graptolites were found. Unfossiliferous sandstone conformably overlies the graptolite-bearing slate.

(*A*) *Zone Represented.*

(Locality numbers continue the series from Sherrard, 1943.)

Graptolites have been obtained from:

(*a*) Locality 61. Piccaree Trig., Portion 34, Par. Toual.
Dicellograptus caduceus Lapw.
Climacograptus sp.
Diplograptus (*Orthograptus*) *apiculatus* (E. & W.).
Cryptograptus tricornis (Carr.).

(*b*) Locality 62. One mile south-west of Piccaree Trig., Portions 224 and 134, Par. Toual.
Dicellograptus morrisi Hopk.
Dicranograptus ramosus (Hall).
Climacograptus bicornis (Hall).
C. caudatus Lapw.
C. minimus (Carr.).
Diplograptus (*Orthograptus*) *calcaratus* var. *basilicus* Lapw.
D. (*O.*) *apiculatus* (E. & W.).
Cryptograptus tricornis (Carr.).
Glossograptus hincksii (Hopk.).
Lasiograptus harknessi (Nich.).

(*c*) Locality 63. Portion 283, Par. Bedulluck.
Climacograptus bicornis (Hall).

(*d*) Locality 64. Portion 229, Par. Bedulluck.
Climacograptus bicornis (Hall).
C. caudatus Lapw.

These graptolites indicate Zone 12 (*Dicranograptus clingani*) of the British Upper Ordovician. This is the upper horizon of the two recognized in the slates east of Yass (Sherrard, 1943) and is equivalent to the upper part of the Eastonian as recognized in Victoria.

(*B*) *Ordovician–Silurian Relations.*

The Ordovician–Silurian junction has not been found, although an almost continuous section is exposed on the Morumbateman-Gundaroo Road between fossiliferous Upper Ordovician at graptolite locality 63 and fossiliferous Silurian near Nanima Trig. (Text-fig. 3, Section A–B). There is, however, a big time-gap between these two fossiliferous outcrops. The older contains graptolites from Zone 12 of the Upper Ordovician, that is, from three zones below the top of the Ordovician, while the fossils near Nanima Trig. characterize a Ludlow horizon, unless they occur there on a lower horizon than elsewhere in the world. They, therefore, belong near the top of the Silurian and above the horizons in the Silurian exposed in other parts of the area. It is unlikely that the unfossiliferous rocks exposed in the road section entirely bridge this gap.

In any case a reversed fault must be pictured as bringing the westerly dipping Ludlow shales near to Nanima Trig., because they dip beneath the nearest fossiliferous sedimentary rock to the west, which is a quartzite with *Halysites* cf. *pycnoblastoides* found near Big Hill, about four miles west. This will be shown to belong to a lower horizon than the shale near Nanima Trig. The shale lies not more than 200 feet higher above sea-level than the quartzite. The reversed fault is not taken as the Ordovician–Silurian junction, because the shales and sandstones of the Gundaroo road east of it are lithologically similar to fossiliferous Silurian elsewhere.

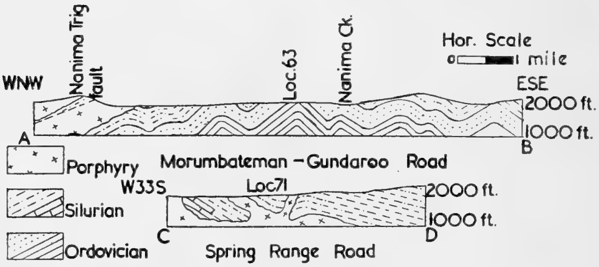

Fig. 3.—Geological sketch sections along lines AB and CD, which are indicated on map, Fig. 2.

The boundary between Ordovician and Silurian has been tentatively shown on the map as coinciding with a wide quartz vein traceable across country for some distance. To its east, a coarse sandstone, dipping west, is the sole outcrop for nearly a mile, though its outcrop is not continuous. A syncline of sandy shale a mile east of the quartz may be a reappearance of Silurian. Half a mile further east, westerly-dipping sandstone conformably overlying graptolite-bearing slate is fractured and crumpled against the slate, because of folding against a more competent bed, not because of faulting. East of the anticline in the graptolite-bearing slate and west of Nanima Creek, the slate is conformably overlain by a silicified sandstone dipping east. Sedimentary rocks, almost certainly of Silurian age, outcrop to the east of Nanima Creek, but no fossils have been found in them.

To the west of the tentative Ordovician–Silurian boundary the shales and sandstones are regularly folded. It cannot be said there is any evidence of angular unconformity.

IV. SILURIAN.

Sandstones, quartzites, limestones and mudstones containing fossils from the Ludlow and Wenlock horizons of the Silurian occur. Some of these fossils have been found previously in the Yass, Hume and Bango Series of the Silurian as recognized at Yass (Brown, 1941), as well as at Canberra (Woolnough, 1939) and at Boambolo, near Burrinjuck Dam (Harper, 1909).

Outcrops in the Nanima-Bedulluck district are discontinuous because the sedimentary rocks have been intruded and metamorphosed by igneous rocks, while wide areas are covered by alluvium.

The Silurian rocks dip to the south-west in the west of the area and generally to the east-south-east and south-east in the east of the area making a plunging anticline whose eastern limb shows minor folding also. The north and south prolongation of the igneous mass practically coincides with the main axis of the plunging anticline and it may be that the intrusion of the igneous mass was connected with the folding.

(*A*) *Silurian Sections.*

Silurian sedimentary rocks are exposed in the following sections. They have been intruded by igneous sills and dykes which may be younger than Silurian.

(The arabic numbers refer to the relative positions of the beds as shown in Table 1.)

(i) Spring Range road Section from Portion 176 to Portion 47, Par. Ginninderra. (Text-fig. 3, Section C–D.)

Porphyry dyke, highly devitrified.
12. Slate with *Monograptus flemingii* vars. *elegans* and *compactus*, *M. vomerinus*, *M. testis* var. *inornatus* (Loc. 71). (See Plate VI.)
11. Shale with *Plumulites mitchelli*, *Hyolithes* sp., *Encrinurus* sp., Gastropod.
10. Slate with ?? *Climacograptus*, trilobite fragments.
9. Cherty quartzite and ferruginous sandstone.
8. Felspar porphyrite sill.
7. Mudstone with *Lingula* cf. *lewisii*, *Eoplectodonta* sp., *Pterinea* sp., *Plumulites mitchelli*, gastropod and trilobite fragments. (See Plate VI.)
6. Psammo-pelite.
5. Limestone with *Halysites* sp., other corals and brachiopods.
Porphyry.

The sedimentary rocks dip W.N.W. and E.S.E. at angles between 20 and 35 degrees. The section extends for four miles from the side of One Tree Hill along the Spring Range road, where the rocks are poorly exposed in low cuttings.

(ii) Gooda Creek Section from Portion 40 to Portion 185, Par. Jeir.

Fragmented porphyry.
5. Limestone with *Heliolites daintreei*, *Hercophyllum shearsbyi*, *Favosites* sp., *Howellella* cf. *elegans*, cf. *Homœospira evax.* (See Plate VI.)
4. Shale, sandstone and quartzite.
3. Pelite.
2. Psammite.
Fragmented porphyry.

The sedimentary rocks dip W.S.W. and W.N.W. at 30 to 50 degrees and are exposed along the banks of Gooda Creek and in a borrow-pit on the eastern side of the Yass-Canberra road. The pelite and psammite in this pit have been metamorphosed by the fragmented porphyry on which they rest.

(iii) Big Hill Section, Portion 235, Par. Nanima to Portion 255, Par. Jeir.

Flow breccia.

11. Ferruginous sandstone with *Parmorthis* cf. *elegantula*, *Howellella* cf. *elegans*, "*Orthotetes*" *shearsbyi*, *Leptena rhomboidalis*, trilobite fragments.
5. Quartzite with *Halysites* cf. *pycnoblastoides*.
3. Pelite.
2. Psammite.

Fragmented porphyry.

Bed 11, which is not metamorphosed, occurs in poor outcrops in Portion 246, Par. Nanima, a short distance east of Big Hill. Quartzite with *Halysites* cf. *pycnoblastoides* is found in Portion 86, Par. Nanima, and *Halysites* sp. also occurs in quartzite in Portion 31, Par. Nanima. Fragmented porphyry in Portion 255, Par. Jeir, has metamorphosed beds 5, 3 and 2.

(iv) Nanima Trig. Section from Portion 144, Par. Nanima, to Portion 142, Par. Bedulluck.

Porphyry.

17. Sandstone.
16. Shale with *Cosmogoniophora* n.sp., *Hormotoma* cf. *articulata*, *Temnospira* cf. *monilis*, Ostracod. (See Plate VI.)
14. Psammite.

Porphyry.

Quartzite.

(v) Vallance's Hill Section, Portion 177, Par. Nanima.

Porphyry.

17. Quartzite, pelite.
16. Sandstone with *Euomphalopterus* cf. *alatus* var. *subundulatus*, *Hormotoma* cf. *articulata*, *Cosmogoniophora* n.sp., *Pterinea* cf. *retroflexa*, *Howellella* cf. *elegans*, Echinoid. (See Plate VI.)
15. Shale.
14. Psammite.

Fragmented porphyry.

(*B*) *Zones Represented.*

The graptolites at the top of the Spring Range section indicate Zone 31 of the British Silurian, that is the top of the Wenlock. The beds, conformably underlying the graptolite-bearing slates, must therefore be Wenlock or older in age. These include limestone with *Halysites* sp. near the centre of the Silurian anticline. Limestone (now replaced by quartzite) containing *Halysites* cf. *pycnoblastoides* in Portion 86, Par. Nanima, in the Big Hill section is almost certainly an outcrop, on the western limb of the anticline, of the same bed and can be dated as Wenlock or older, also. The same limestone outcrops in the Gooda Creek section, but *Halysites* has not been found in it.

The sedimentary rocks in the Spring Range, Big Hill and Gooda Creek sections contain fossils also recorded from all three horizons of the Silurian recognized at Yass, that is the Bango, Yass and Hume beds, but cannot be said to correspond precisely with any one of them.

Apart from the graptolite-bearing slate, the best correlation of these sections with other parts of the world can be made by means of the fossils occurring near Nanima Trig., particularly *Cosmogoniophora* n.sp., which shows radial striæ both above and below its carinated ridge. This is characteristic of this sub-genus when found in beds of Ludlow age in Canada (McLearn, 1924) and England (Reed, 1927). *Goniophora* in beds of Devonian age has radial striæ only below the ridge. *Cosmogoniophora* n.sp. resembles closely *Goniophora* aff. *cymbæformis* from the Upper Ludlow of Malvern, England. (Geol. Surv. Gt. Britain, No. 21987.) *Hormotoma* cf. *articulata* from the same bed compares closely with *H. articulata* from Ledbury, England (Geol. Surv. Gt. Britain, No. 6707) from the Upper Ludlow.

The high Ludlow age of this bed is confirmed when it is traced to Vallance's Hill, where *Euomphalopterus* cf. *alatus* var. *subundulatus* occurs. It is close to *E. alatus* var. *subundulatus* from the Aymestry near Caradoc (No. 36779, Geol. Surv. Gt. Britain). The assemblage of fossils therefore supports a Ludlow age for the beds in this part of the area.

TABLE 1.

CORRELATION OF SILURIAN BEDS IN NANIMA-BEDULLUCK DISTRICT.
(Igneous sills and dykes may be younger than Silurian.)

	Spring Range. (i)	Gooda Creek. (ii)	Big Hill. (iii)	Nanima Trig. (iv)	Vallance's Hill. (v)
LUDLOW.	Porphyry.	Fragmented porphyry.	Flow breccia.	Porphyry. 17. Sandstone. 16. Shale with *Cosmogoniophora*, *Hormotoma*, etc. 14. Psammite. FAU Porphyry.	Porphyry. 17. Quartzite. 16. Sandstone with *Euomphalopterus*, *Cosmogoniophora*, *Howellella*, echinoid. 15. Shale 14. Psammite. LT. Porphyry.
WENLOCK.	12. Slate with *Monograptus*. 11. Shale with *Hyolithes*, *Encrinurus*, *Plumulites*. 10. Slate with ??*Climacograptus*, trilobite. 9. Quartzite. 8. Porphyrite. 7. Mudstone with *Eoplectodonta*, *Lingula*. 6. Psammopelite. 5. Limestone with *Halysites*. Porphyry.	5. Limestone with *Heliolites*, *Hercophyllum*. 4. Shale, sandstone. 3. Pelite. 2. Psammite. Porphyry.	11. Sandstone with *Howellella*, "*Orthotetes*", *Parmorthis*, *Leptena*. 5. Limestone with *Halysites*. 3. Psammite. 2. Pelite. Porphyry.		

V. (?) TERTIARY.

Isolated patches of a coarse, iron-stained cemented conglomerate are found some feet (10–50) above Nanima Creek in a few places. This conglomerate was also found along the Yass River (Sherrard, 1939) and was tentatively correlated with Tertiary leaf-bearing conglomerate at Dalton. In Portion 189, Par. Bedulluck, a tributary to Nanima Creek has cut a cliff showing 10 feet of alluvium overlying two feet thickness of conglomerate, which in turn rests on kaolinized white porphyry. The conglomerate was apparently the load of an earlier swiftly flowing stream, which later slowed down until it could only carry finer alluvium.

VI. IGNEOUS AND METAMORPHIC ROCKS.

(*A*) *Mode of Occurrence of Igneous and Metamorphic Rocks.*

Much of the west of the area is covered by igneous rocks which surround *enclaves* of sedimentary rocks including most of the Silurian sections which have been described. No contact has been found between igneous rocks and rocks with Ordovician fossils, though the psammo-pelite of Portion 18, Par. Bedulluck, has formed from slate which is probably Ordovician in age.

The sedimentary rocks have been altered along their contact with igneous rocks, but it can be shown that the sedimentary rocks have also affected some of the igneous rocks. They have been partly the cause of the fragmentation of some igneous rocks and they have contaminated others.

In hand-specimens, the igneous rocks are indistinguishable. All are coarse-grained and greenish in colour, but thin sections show textural differences and four types can be recognized, which outcrop in positions which can be defined within broad limits.

(*a*) The fundamental type of igneous rock is a *quartz porphyry* which outcrops along the eastern margin of the igneous mass and extends for about two miles west of that margin. It contains porphyritic crystals of corroded quartz, sericitized plagioclase (mainly Ab_{70}, but some Ab_{55}) and chlorite set in a devitrified ground-mass and is typically developed at Nanima Trig. To the south, the ground-mass of the porphyry is more highly devitrified as seen in the rock of Spring and One Tree Hills. In Portion 313, Par. Jeir, chemical analysis shows the porphyritic rock is more siliceous and has graded into a *rhyolite.* Minor intrusions belong to this type.

This rock on the eastern margin of the Nanima-Bedulluck igneous mass is the southern continuation of the Hawkins porphyry (Brown, 1941), or most easterly of the igneous rocks of the Yass district.

(*b*) The western section of the area, to the west of the *enclave* of sedimentary rocks, is occupied by *dacitic flow breccia* typically developed at Big Hill. In thin section, this rock shows, as well as hypidiomorphic crystals of quartz and plagioclase (Ab_{73} and Ab_{55}) and chlorite, numerous small chips of quartz and felspar and frequent flow banding in the ground-mass. These two latter characteristics differentiate this rock from porphyry and rhyolite. The outcrop of dacitic flow breccia in the west of the area is a southern continuation of part of the Laidlaw porphyry of Yass (Brown, 1941).

(*c*) Between porphyry in the east and Silurian sedimentary rock on the west lies a third type of igneous rock which shows a much greater concentration of broken chips of minerals than is seen in the dacitic flow breccia. It is almost entirely made up of angular fragments of quartz, felspar and chlorite almost in contact, only being separated by thin partitions of devitrified material which forms the binding. Fossils are very occasionally present among the fragmented minerals. Field work in the Nanima-Bedulluck area, chemical analysis and examination of thin sections of rocks from the area indicate that the name *fragmented porphyry* best describes this rock. It was formerly called " coarse crystal tuff " (Sherrard, 1936, 1939) because it conformed to the definition of that rock type, that is, it was made up of more than 75% by volume of closely interlocking fractured crystals originating from a magma (Pirsson, 1915; Williams, 1926).

Fragmented porphyry occurs :

(i) in a north and south band 14 miles long and one mile wide in this area, extending from Cockatoo Trig. to Portion 122, Par. Ginninderra, with sedimentary rock on one side and quartz porphyry on the other ;

(ii) between flow breccia and sedimentary rock in Portions 12 and 40, Par. Jeir, epidote sometimes forming the cement between the fragments of minerals (Text-fig. 4B);

(iii) with limestone inclusions in Portion 182, Par. Nanima;

(iv) in the Yass area, between Laidlaw porphyry and Silurian sedimentary rocks near Laidlaw Trig.; and between Laidlaw porphyry and the sedimentary rocks underlying the elliptical outcrop of the Hume Series (Sherrard, 1936).

These examples show that fragmented porphyry occurs between sedimentary rock and unfragmented igneous rock. Evidence will be offered to show that its fragmental texture is due, in part at least, to interaction between porphyry and sedimentary rock at the time of intrusion.

(*d*) The fourth type of igneous rock in this area is *dacite.* It is found in isolated patches and does not form conspicuous hills as do the other igneous rocks. It may have been intruded later than they, because its felspars (Ab_{70} and Ab_{50}) are freer from sericitization and its brown biotite from chlorite. Granulitized foreign inclusions can be seen in the field, in dacite in Portion 91, Par. Bedulluck, and in a thin section from Portion 182, Par. Nanima.

Psammites and pelites have formed near the contact of igneous and sedimentary rocks. Metamorphism has occurred to the same degree where sedimentary rocks rest upon igneous (*e.g.* Portion 185, Par. Jeir), as where they appear to dip beneath igneous rocks as in Portion 18, Par. Bedulluck. This proves the igneous rocks must have been intruded and not extruded as a lava or tuff.

(*e*) *Psammites* are dark coloured, gritty to the touch and medium in grain size as at Portion 185, Par. Jeir. Under the microscope well separated chips of quartz and felspar (0·25–1 mm. across) and chlorite and ilmenite are seen. They are set, with some parallelism of their long axes, in an isotropic base. Rocks previously called " medium crystal tuffs " (Sherrard, 1936, pl. vi, fig. 7) are probably psammites. Coarser grained psammites (Tyrrell, 1921) or quartzites also occur.

(*f*) *Pelites* are dense, resinous rocks generally spotted by concretions and have a conchoidal fracture. In thin section, the pelite of Portion 185, Par. Jeir, shows concretions nearly 4 mm. across, which almost coalesce. They are formed by a denser packing of limonite and sericite flakes around angular quartz grains than is seen in the remainder of the rock. Threads of sericite mark the bedding. This rock is practically identical with those from Yass, doubtfully named " fine tuffs " (Sherrard, 1936, pl. vi, fig. 10). The pelite occurring within porphyry in Portion 97, Par. Yass, has been chemically analysed. In it the concretions are smaller and further apart than in the pelite of Portion 185, Par. Jeir, but in other respects the rocks are similar. Their excessively fine-grained bases are made up of mineral grains less than one-fiftieth millimetre across.

The chemical analysis (Table 2, IX) proves the rock from Por. 97 must be a silicified shale or pelite (Tyrrell, 1921). It seems certain that the other extremely fine-grained sedimentary rocks in the Yass and Nanima-Bedulluck districts are pelites. Before they were baked and silicified they may or may not have originated as fine tuff, but they contain none of the cusps and shards characteristic of tuffs, such as are seen in thin sections of tuffs from the Devonian rocks near Taemas Bridge. In any case, Williams (1926) has pointed out that a rock with such a high percentage of silica *if ejected as tuff* would solidify as a completely glassy rock (italics mine).

(*B*) *Previous Views of Origin of Igneous Rocks.*

Igneous rocks with textures similar to those described as occurring in the Nanima–Bedulluck area are also found in the Yass, Canberra and Burrinjuck districts. Published opinions of their origin have varied between the views that they were intruded, and that they were extruded as lavas and tuffs. Professor Cotton (1923) wrote regarding the eastern igneous rock at Yass (Hawkins porphyry): " Its fragmentary structure may be due to shattering and engulfing of the marginal sediments during intrusion of the porphyry ", while Dr. Woolnough (1939) was not satisfied to regard as tuffs all the igneous rocks of the Australian Capital Territory which show fragmentation.

(*C*) *Necessary Scope of Explanation.*

A satisfactory explanation of the causes of the development of the different rock types must account for:

(*a*) the undoubted intrusive relations seen in railway cuttings near Coolalie and Jerrawa, and at places described below;
(*b*) the texture of fragmented porphyry and the flow banding in dacitic flow breccia;
(*c*) contact metamorphism caused in sedimentary rocks lying on top of fragmented porphyry;
(*d*) the presence of fossils in some fragmented porphyry.

(*D*) *Explanation of Origin of Different Rock Types.*

Evidence from field relations, chemical analyses and thin sections of igneous rocks of the district points to the following conclusion:

> All igneous rocks in the Yass–Nanima–Bedulluck district are considered to have been intruded more or less simultaneously in the form of a rhyolite-quartz porphyry magma into fissures which developed in overlying sedimentary rocks. Some sedimentary rocks, with any fossils they contained, were engulfed, contaminating some of the intruding material. Other sedimentary rocks were thrust to new positions. Pelites and psammites were formed. Interaction between sedimentary and igneous rocks caused fragmentation of some of the porphyry, while further fragmentation and flow banding occurred through the action of volatile bodies from the underlying unconsolidated magma acting on the crust which had formed above it. Dacite may represent the last phase of the intrusion.

(*E*) *Evidence Supporting Explanation.*

Evidence obtained from:

(*a*) *Field* of (1) intrusive relations; (2) fracturing and thrusting of sedimentary rocks; (3) contact metamorphism of lower surfaces of sedimentary rocks; (4) presence of volatile bodies.

(1) Intrusive relations seen:

(i) porphyry invading shale in creeks, Portions 24 and 101, Par. Nanima;
(ii) porphyry surrounding quartzite in quarry, Portion 8, Par. Nanima;
(iii) porphyry surrounding pelite, Portion 97, Par. Yass;
(iv) porphyry invading sedimentary rocks, Portion 106, Par. Bango; Portion 233, Par. Jerrawa (pl. xii, Sherrard, 1939)

(2) Fracturing and thrust faulting of sedimentary rocks seen :
   (i) Vallance's Hill ;
   (ii) near Nanima Trig. ;
   (iii) Portion 182, Par. Nanima ;
   which has caused them to be surrounded by porphyry after having been thrust from previous positions.

(3) Contact metamorphism of lower surfaces of sedimentary rocks by igneous rocks beneath them, forming :
   (i) quartzite, Portion 55, Par. Ginninderra ;
   (ii) quartzite, Portions 17, 34 and 68, Par. Jeir ;
   (iii) psammite and pelite, Portion 185, Par. Jeir ;
   (iv) psammite, Portion 84, Par. Nanima.
   Such metamorphism can only be explained as due to the intrusion of igneous rock *after* the deposition of sedimentary rock.

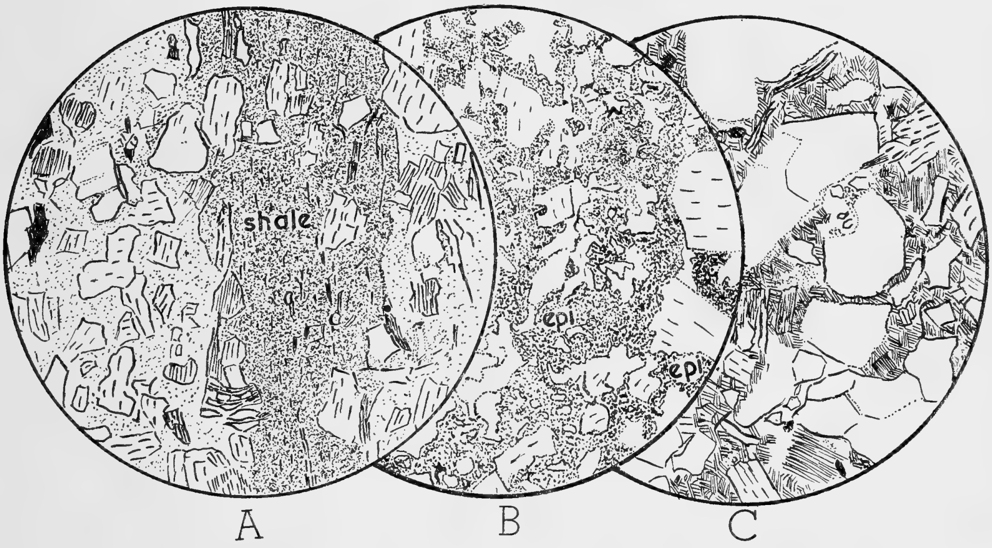

Fig. 4.—A. Porphyry partly fragmented, Portion 258, Par. Nanima. ×13.
B. Fragmented porphyry cemented by epidote, Portion 12, Par. Jeir. ×13.
C. Porphyry partly fragmented, Portion 118, Par. Bedulluck. ×20.

(4) Volatile bodies present, because of :
   (i) pyrite and chalcopyrite veins in porphyry, Portion 21, Par. Nanima, and Portion 313, Par. Jeir ;
   (ii) iron-bearing solutions which have reddened and decomposed porphyry, in road cuttings, Portion 21, Par. Nanima ; Portion 45, Par. Jeir ; surrounding quartzite, Portion 8, Par. Nanima. Similar action in Alderney (Nockolds, 1932) ;
   (iii) gold in Portion 281, Par. Nanima ; Portion 180, Par. Jeir ; Portion 13, Par. Bedulluck ;
   (iv) bismuth in Portion 32, Par. Bedulluck ;

(v) silica replacing limestone by quartz, Portion 31, Par. Nanima ;

(vi) boron forming tourmaline, Portion 70, Par. Bedulluck.

Such bodies, liquid while under magmatic pressure, would be vapourized with lowering of pressure on nearing the surface, and could then powerfully aid in fragmentation of the already solidified crust of the magma.

TABLE 2.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2 ..	73·52	72·11	71·68	69·24	69·23	66·54	64·29	63·94	83·25
Al_2O_3 ..	11·94	13·89	13·57	12·88	15·35	16·05	17·83	16·77	7·63
Fe_2O_3	3·39	1·28	1·28	0·20	1·77	0·64	1·55	1·80	1·48
FeO ..	1·46	2·00	1·94	4·05	2·11	5·29	3·33	1·98	
MgO ..	0·61	1·30	1·37	2·21	1·59	1·04	2·25	1·61	0·23
CaO ..	2·07	4·47	1·88	3·10	2·98	0·74	1·09	0·92	2·24
Na_2O ..	3·49	2·66	2·22	2·94	2·01	3·75	4·20	5·34	1·21
K_2O ..	2·24	0·16	3·87	3·66	3·10	4·13	3·74	4·97	1·58
H_2O+	0·95	1·12	1·24	0·80	1·64	1·26	2·06	1·79	2·48
H_2O-	0·14	0·12	0·29	0·06	0·06	0·08	0·04	0·41	0·49
P_2O_5 ..	0·12	0·05	0·03	0·23	0·11	0·14	0·13	0·27	—
TiO_2 ..	0·66	0·43	0·33	0·55	0·12	0·19	0·15	0·15	—
CO_2 ..	tr.	tr.	0·08	0·04	abs.	abs.	abs.	0·02	—
etc.	—	—	0·13	0·10	—	—	—	0·16	—
	100·59	99·59	99·91	100·06	100·07	99·85	100·66	100·13	100·59

I. Rhyolite, Portion 313, Par. Jeir.—Anal. K. Sherrard.
II. Granite, Tharwa, A.C.T.—Anal. A. G. Hall (Taylor and Mahony, 1913).
III. Quartz porphyry tuff, Mt. Stromlo, A.C.T.—Anal. A. G. Hall (*ibid.*).
IV. Hypersthene dacite, Good Hope Public School site.—Anal. J. C. H. Mingaye (A.R. Dept. Mines, N.S.W., 1907).
V. Dacitic flow breccia, Portion 38, Par. Nanima.—Anal. K. Sherrard.
VI. Fragmented porphyry, Portion 21, Par. Nanima.—Anal. K. Sherrard.
VII. Quartz porphyry, Nanima Trig.—Anal. K. Sherrard.
VIII. Felspar porphyry, Portion 60, Par. Boambolo.—Anal. H. P. White (Harper, 1909).
IX. Pelite, Portion 97, Par. Yass.—Anal. K. Sherrard.

(*b*) *Thin sections* showing (1) fragmentation of porphyry caused by its intrusion into sedimentary rocks ; (2) fragmentation of minerals and development of flow banding in porphyry.

(1) Fragmented porphyry can be seen :

(i) At Mt. Avon, Portion 258, Par. Nanima, at the junction of shale and porphyry. A thin section (Fig. 4A) shows quartz grains and felspar prisms from porphyry, nearly in contact in an argillaceous matrix. A band of unaltered shale passes across the thin section. Threads of chlorite wind around the minerals. If quartz grains and felspar relics, which form about 60 per cent. of the rock, were packed more closely, it would be indistinguishable from fragmented porphyry, which has about 80 per cent. crystal fragments ;

(ii) on Nanima Creek road, one and a half miles east of Morumbateman, at the junction of psammite and porphyry. A thin section shows large grains of quartz and felspar from the porphyry forced into contact with each other and against pieces of psammite ;

(iii) in Portion 118, Par. Bedulluck, at the junction of shale with quartz porphyry of Spring Hill. In thin section (Fig. 4C) can be seen cracked fragments of quartz, " moth-eaten " felspar and chlorite set in an argillaceous matrix.

(2) Fragmentation of minerals and development of flow banding, through the disruptive effect of a volatile body, such as water, on the porphyry causing:

(i) devitrification of ground-mass ;
(ii) sericitization of felspar ;
(iii) chloritization and epidotization of biotite ;

which are seen in different degree in nearly every thin section of an igneous rock from the district, particularly from Portions 16 and 38, Par. Nanima. Sericite forms along felspar cleavages, causing them to broaden. Chlorite and epidote, or part of the devitrified ground-mass, flow with a swirling motion from the ground-mass into the widened cleavage, forcing pieces of the felspar to flow away with the same swirling motion making the flow banding seen in dacitic flow breccia.

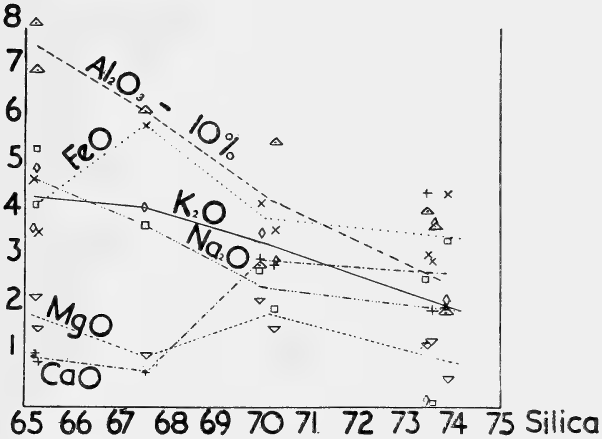

Fig. 5.—Variation diagram.

(c) *Chemical analyses* of rocks from the Nanima-Bedulluck and surrounding districts are given in Table 2. A variation diagram (Text-fig. 5) has been prepared from the analyses, recalculated to 100 per cent., without water. Apart from CaO and total iron calculated as FeO, the variation of the oxides is regular and such as to be expected in rocks from the same igneous reservoir. With rise in SiO_2, there is a fall in Al_2O_3, MgO, K_2O and Na_2O. The alumina curve is perhaps high, while the curve for CaO is distinctly anomalous, showing more discrepancies than can be attributed to errors in analysis. Its rise with rise in SiO_2, can only be accounted for by contamination with limestone, which in any case has been proved in the field to have taken place in Portion 31, Par. Nanima, and elsewhere. The irregularity in the curve for total iron can be accounted for by enrichment with iron-bearing solutions such as are known to have affected the rhyolite of Portion 313, Par. Jeir.

Analysis VI of fragmented porphyry supports field evidence of this rock's intrusive origin. Had it been extruded as a tuff, as previously suggested, its high silica content would have given it a vitric texture instead of the coarse-grained porphyritic texture everywhere seen in this rock in the Yass–Nanima–Bedulluck area.

(*F*) *Summing Up of Evidence.*

Evidence has been presented to prove the intrusion in the Yass–Nanima–Bedulluck district of quartz-porphyry-rhyolite which has fractured and metamorphosed sedimentary rocks. The combined effect of the mingling of sedimentary rocks with porphyry and the attack on both of volatile bodies has fragmented some of the porphyry and produced flow banding and fluxional arrangement of shattered crystals in other parts of it, forming dacitic flow breccia. Dacite may represent the last phase of intrusion.

(*G*) *Presence of Fossils.*

Fossils in fragmented porphyry were derived from sedimentary rocks which were engulfed by porphyry. They are usually unidentifiable, unless they have been silicified or a large section of sedimentary rock remains as a screen, as near Nanima Trig. In other places, as Portion 12, Par. Jeir, Portion 182, Par. Nanima, and Portion 28, Par. Bango (Sherrard, 1939, p. 592), calcareous patches in fragmented porphyry cannot be identified.

(*H*) *Analogies from Other Areas.*

(*a*) The explanation given by Professor Benson (1915) of the formation of rocks near *Tamworth* which he called " intrusive tuffs " is close to that given here for the development of fragmented porphyry and dacitic flow breccia. He pictured the intrusion of a magma with a large quantity of water which acts as a mineralizer ; the crust formed on it is constantly shattered and intrusion proceeds of shattered material into damp sediments.

(*b*) *Great Britain.* Through the courtesy of Mr. P. A. Sabine of the Geological Survey of Great Britain, thin sections of rocks from Ardnamurchan, Scotland, have been examined. These are described as having undergone " intense shattering " due to explosive gases (Richey and Thomas, 1930). Epidote and chlorite have penetrated between cleavages of plagioclase (Geol. Surv. Gt. Brit., Section 22322). Minerals in the eucrite and gabbro are shattered into fragments without losing their individual crystalline form and lie in a thoroughly cataclastic matrix consisting of a granulated mass of broken felspars and recrystallized augite. Flow banding and fluxional arrangement of crystals have developed. The disruption of the Ardnamurchan gabbro (Geol. Surv. Gt. Brit., Section 24447) closely resembles shattered Nanima–Bedulluck rocks, though these show more shattering than those from Ardnamurchan.

Tyrrell (1928) states breccia in Arran has been formed by shattering of the cover of the magma and epidotization has followed. In Ireland (Richey and Thomas, 1930) gases evolved from an acid magma are held responsible for the brecciation of the Newry granite. Nockolds (1933) records mechanical disintegration of invaded rock by intruding magma.

(*I*) *Age of Intrusion.*

Rhyolite-quartz porphyry must have been intruded in late or post-Silurian time, since by its intrusion shale with fossils of Ludlow age has been fractured and thrust-faulted to the east near Nanima Trig. Dacite may have been intruded later.

VII. Descriptions of Fossils.

GRAPTOLITHINA.

Family **Dicranograptidæ** Lapworth.

Genus **Dicranograptus** Hall.

Dicranograptus ramosus (Hall) Elles and Wood, 1904, 175 ; pl. xxiv, figs. *6a, b.*

Biserial stipes 1 mm. wide, 4 mm. long, but full length not preserved, septum present, 10 thecæ in 10 mm., apertures introverted, no spines visible. Uniserial stipes 4 cm. long, 1 mm. wide. Thecæ 10 in 10 mm., each 2 mm. long, overlap a half. Ventral wall curved, apertures introverted. Axial angle up to 110 degrees.

Associate : *Diplograptus apiculatus.* Locality : Portions 224/134, Par. Toual.

Family **Monograptidæ** Lapworth.

Genus **Monograptus** Geinitz restricted.

Monograptus flemingii var. *compactus* E. & W., Elles and Wood, 1913, 426, pl. xlii, figs. *7a-d.*

See Plate VI, photograph 3.

Rhabdosome 6 mm. to 1 cm. long, straight, sicula including virgella 2·5 mm. long, width of sicula 0·4 mm. Proximal end of rhabdosome across hook of first theca 0·8 mm. wide. At 10th theca, rhabdosome is 2 mm. wide, of which hooks occupy two-fifths. Seventeen thecæ in 10 mm., all with pronounced hooks. Thecæ 1·7 mm. long, overlap two-thirds, 0·7 mm. wide. Two-fifths length of theca is involved in hook.

Locality : Portion 55, Par. Ginninderra.

Monograptus flemingii var. *elegans* Elles, Boswell and Double, 1940, 159.

See Plate VI, photograph 2.

Rhabdosome 2 cm. long, slight dorsal curvature, rather limp. Width 1·8 mm. distally, 1·0 mm. proximally, across hook of first theca. Twelve or 13 hooked thecæ in 10 mm., 1·7 mm. long, half of which involved in hook. Overlap three-fifths. Width of theca 0·4 mm. Sicula conspicuous, virgella 0·5 mm. long.

Associate : *M. vomerinus.* Locality : As for *M. flemingii* var. *compactus.*

Monograptus testis var. *inornatus* Elles, Elles and Wood, 1913, 446, pl. xliv, figs. *7a, b.*

See Plate VI, photograph 1.

Rhabdosome small, fish-hook shaped through strong ventral curvature, thecæ on concave side. About 1·5 cm. long, width 0·5 mm. proximally, 1·0 mm. distally, inclusive of hooks, which occupy one-third width. Thecæ 1·5 mm. long and 0·5 mm. wide with slight ventral curvature, all hooked. Thecæ 12 in 10 mm., inclined 30 degrees.

Locality : Portion 47, Par. Ginninderra.

ECHINOIDEA.

Fragments (Plate VI, photograph 4) of a crushed echinoid consist of :

(1) Cylindrical spines, slightly tapering, some 7·5 mm., most 2 mm. long, longitudinal ridges down full length of spine, expanded bases, about three horizontal bars across spine at intervals.

(2) Hexagonal plates, apparently interambulacral, 7 mm. across, recessed with moulds for tubercles spaced round periphery and one larger shallower recess in centre. Some plates sutured.

(3) Smaller, petaloid plates, 2 mm. long.

(4) Raised circular boss, which may be a separate blastoid, one in contact with a large hexagonal plate, one separate.

(5) Portions of jaw, including areas 6 mm. long and 2 mm. wide, formed of long narrow rectangular plates meeting at sharp angle, sometimes with tubercles. These areas raised and long edges adjoining tubercle-bearing plates.

Echinoids are rare in the Silurian.

Associate: *Howellella* cf. *elegans*. Plate VI, photograph 10. Locality: Portion 177, Par. Nanima.

MACHÆRIDIA.

Genus **Plumulites** Barrande.

Plumulites mitchelli (Etheridge fils.) (Plate VI, photograph 8).

Turrilepas mitchelli Etheridge fils., 1890, Geol. Mag. (dec. iii), VII, 337, pl. xi, figs. 1, 2, 4, 5.

Plumulites mitchelli (Etheridge fils.), Withers, 1926, Brit. Mus. Cat., 73.

Compressed, keel or heart-shaped plates with strong, eccentric median fold. Short pointed apex. Lower margin with double sigmoidal curve with central " stalk ". Transverse growth lines, about 3 per mm. Length 7 mm., greatest width 7 mm. A muscle scar should be visible, but ornament impressed through thin plate obscures it.

Several detached plates in mudstone (bed 7) on Spring Range road. One kite or " gum-leaf " shaped plate in bed 11, 7 mm. long, 2·5 mm. wide, with strongly marked median fold and faint growth lines crossing at right angles and then curving away to run parallel with edge of plate. Withers considers kite-shaped plates form an outer column and keel-shaped plates form two inner columns. He has removed *Plumulites* from the phylum, Arthropoda, and suggests it might be placed in the Echinodermata.

LAMELLIBRANCHIATA.

Genus **Goniophora** Phillips.

Sub-genus **Cosmogoniophora** McLearn.

Cosmogoniophora sinuosa sp. nov. (Plate VI, photograph 7).

Holotype. Australian Museum Collection, No. F44214.

Shell sub-trapezoidal, equivalve, inequilateral, anterior margin bluntly rounded to junction with ventral margin at point where umbonal ridge projects as canal when observed in cast of shell. Umbonal ridge strongly carinated, making angle of 30 degrees with ventral margin. Ventral margin from outlet of umbonal ridge makes concave curve downward in posterior half and convex downward in anterior half. Convex curve continuous round anterior margin to sharp-angled junction with cardinal margin. Cardinal margin from one-half to two-thirds greatest length of shell, straight, with umbo projecting slightly above it, directed anteriorly. Broad, very shallow sinus anterior to umbonal ridge. Muscle scars not always seen, but posterior, when present is near ventral margin, just posterior of umbonal ridge. Pallial line often strongly marked, almost making angulation.

Maximum length, 21 mm.; maximum height, 10·5 mm.; depth of each valve, 0·4 mm. Greatest length, about mid-width. Ornament, strongly marked concentric growth lines about 4 per mm., less strongly marked posterior of umbonal ridge. Radial striæ on either side of umbonal ridge, but not near anterior margin, not bifurcated. Striæ most strongly marked near ventral margin, where pit sometimes seen at crossing with growth lines.

Locality: Near Nanima Trig. (common), Vallance's Hill (rare).

Associates: *Hormotoma* cf. *articulata*, *Temnospira monilis*, ostracod.

Goniophoras seen in collections in England from the Silurian are more strongly bent on the umbonal ridge than the Nanima specimens, but it is noticeable that the two valves of the same English specimen, even though still attached, vary in shape on account of unequal crushing and deformation. Similar deformations are frequent in *Goniophora.* (Gosselet *et al.*, 1912, p. 51.)

GASTROPODA.

Genus **Euomphalopterus** Roemer.

Euomphalopterus cf. **alatus** var. **subundulatus** (Salter).

(Plate VI, photographs 12, 14.)

Low, conical gastropod, 5 whorls, which are quadrate and strongly carinated on upper surface. Each whorl slightly concave on upper surface until it rises to keel, which is crossed by growth lines, leaving crescentic markings. Below keel, whorl face slopes outward until it reaches well-marked suture. Strongly marked keel on periphery forming wing. Lower surface rounded. Wide umbilicus. Lines of growth turn back sharply just below suture, then curve forward to keel, then curve sharply back. Partitioning of whorls by transverse septa. Preserved as casts or moulds. Width between 15 and 25 mm., height up to 12 mm., pleural angle about 130 degrees. Salter (1848) comments on variability in size of wing, rarity of undulations in it and variations in closeness of striæ.

Associates: *Howellella* cf. *elegans*, *Pterinea* cf. *retroflexa*, *Hormotoma* cf. *articulata.* Locality: Vallance's Hill.

Genus **Temnospira** Perner.

Temnospira monilis Perner, Knight, 1941, 346, pl. 85, figs. 2*a*, *b*.

(Plate VI, photograph 13.)

Small, low-spired gastropod, whorl profile strongly rounded, four whorls, deep sutures, base phaneromphalous, aperture without slit, but with shallow notch. Whorl expanded to form varices at irregular intervals, 1 mm. to 5 mm. apart, most strongly developed on periphery. Faint growth lines between, transverse without obliquity. Diameter 10 mm., height 5 mm.

Associates: As for *Cosmogoniophora.* Locality: Near Nanima Trig.

VIII. SUMMARY.

Graptolites from Zone 12 of the Upper Ordovician have been discovered in slates in the Nanima-Bedulluck area. Graptolites and shelly fossils of the Wenlock and Ludlow divisions of the Silurian have also been found. Ordovician and Silurian sedimentary rocks apparently show no angular unconformity.

Porphyritic igneous rocks of acid chemical composition have intruded and metamorphosed some sedimentary rocks in post-Ludlow time. A large proportion, possibly one-half, of the igneous rocks have a fragmentary texture or show flow banding. It is demonstrated that these effects are due in part to the mechanical disruption of igneous rocks during their intrusion of sedimentary rocks and in part to the action of volatile bodies. Fossils in the fragmented rocks were derived from the invaded sedimentary rocks.

Chemical analyses prove contamination of some of the igneous rocks and the original sedimentary nature of extremely fine-grained rocks common in this district and near Yass.

IX. ACKNOWLEDGEMENTS.

Professor L. A. Cotton, M.A., D.Sc., and Professor C. E. Marshall, Ph.D., D.Sc., have kindly allowed me to use the library and chemical laboratory of the Geological Department of the University of Sydney while doing this work.

I should also like to record the unfailing generosity of Dr. Ida Browne, D.Sc., in giving me much help and advice.

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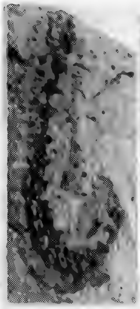
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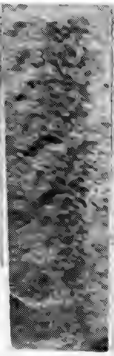
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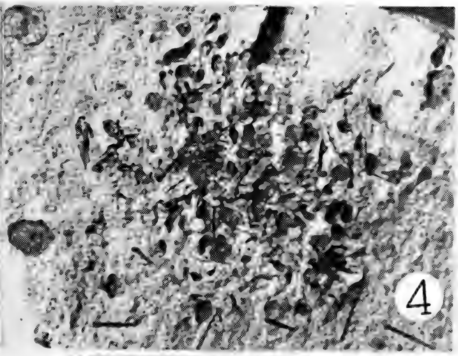
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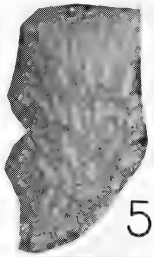
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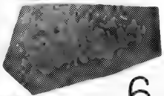
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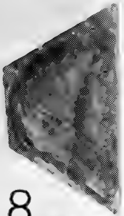
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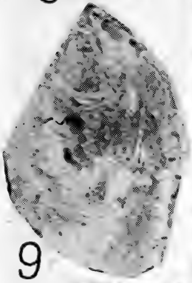
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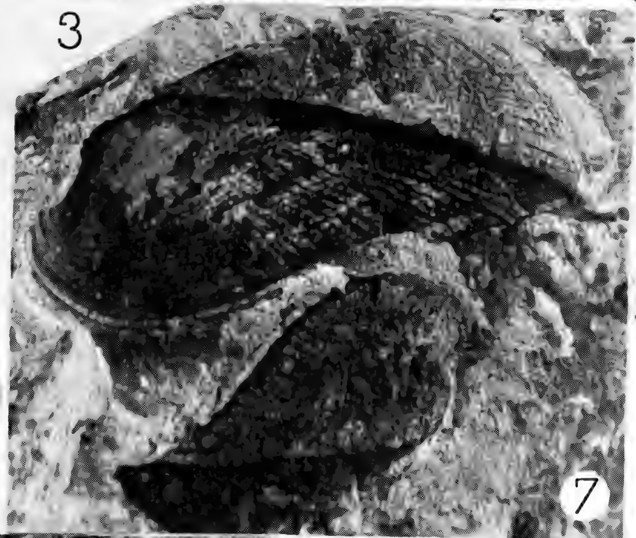
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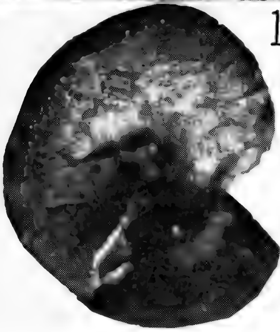
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Explanation of Plate VI.

1. *Monograptus testis* var. *inornatus* Elles. Portion 47, Par. Ginninderra. Horizon : Wenlock. (×3½.)
2. *Monograptus flemingii* var. *elegans* Elles. Portion 55, Par. Ginninderra. Horizon : Wenlock. (×2½.)
3. *Monograptus flemingii* var. *compactus* E. & W. Portion 55, Par. Ginninderra. Horizon : Wenlock. (×6.)
4. Echinoid fragments. Portion 177, Par. Nanima. Horizon : Ludlow. (Natural size.)
5. *Heliolites daintreei* Nich. and Eth. Vertical section. Portion 70, Par. Jeir. Horizon : Wenlock. (About natural size.)
6. *Heliolites daintreei* Nich. and Eth. Transverse section. Loc. and Hor. as for 5.
7. *Cosmogoniophora sinuosa* n.sp. External moulds of right valves. Aust. Mus. Spec. No. F 44214. Portion 84, Par. Nanima. Horizon : Ludlow. (×2½.)
8. *Plumulites mitchelli* (Etheridge fils.). Portion 20, Par. Ginninderra. Horizon : Wenlock. (×3½.)
9. *Lingula* cf. *lewisii* (Sow.). Loc. and Hor. as for 8. (×2½.)
10. *Howellella* cf. *elegans* (Muir Wood). Portion 177, Par. Nanima. Horizon : Ludlow. (×2½.)
11. Cf. *Homœospira evax* H. & C. Loc. and Hor. as for 5. (Natural size.)

12, 14. *Euomphalopterus* cf. *alatus* var. *subundulatus* (Salter). Loc. and Hor. as for 10.

13. *Temnospira monilis* Perner. Portion 84, Par. Nanima. Horizon : Ludlow. (×6.)

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THE POISSON-KELVIN HYPOTHESIS AND THE THEORY OF DIELECTRICS.

By W. B. Smith-White.
University of Sydney.

Manuscript received, August 10, 1951. Read, September 5, 1951.

Contents.

Introduction and Summary.

Anyone acquainted with the Classical Theory of Electricity as presented in the literature will be aware of certain theoretical difficulties which recur throughout the subject, and which are connected with the mechanical forces acting on the material bodies of an electrical system. These difficulties are of long standing but are of a fundamental kind. In the usual texts they are neglected or passed over lightly. The said difficulties arise in electrostatics as well as in the general electrodynamic theory. Consider the following points:

(i) Various views concerning the "body-force" acting in dielectrics *cf.* Larmor (1897), Abraham-Becker (1932), Smith-White (1949).

(ii) Various expressions for the energy in electrostatic systems *cf.* de Donder (1925), Guggenheim (1936), Smith-White (1950).

(iii) The difficulties that have presented themselves in formulating the first law of thermodynamics for systems which involve dielectric bodies in an electric field, or which involve magnetizable bodies in a magnetic field *cf.* Debye (1925), Abraham-Becker (1932), Stoner (1937), Guggenheim (1936), Livens (1948), Smith-White (1951a).

(iv) Various expressions for and interpretations of the "electrostatic stress" by which Maxwell has represented the mechanical actions between electrified bodies *cf.* Livens (1926).

In this paper I consider electrostatics only; but what is written here indicates that a complete reconstruction of electrodynamic theory is essential. In particular it seems obvious that the general electrodynamics of moving media must be reconsidered. The starting point is the hypothesis by which Poisson has explained the behaviour of magnetizable bodies, as transferred, by Lord Kelvin, to explain the behaviour of dielectrics. In the literature the whole content of this hypothesis is supposed to be contained in the potential formula

$$\varphi=\int_v \mathbf{P}\cdot\nabla\left(\frac{1}{r}\right)dv$$

where $\mathbf{P}$ is the polarisation of the dielectric which occupies the volume v. This is transformed by Green's theorem to give

$$\varphi=\int_f \frac{P_n}{r}df-\int_v \frac{\operatorname{div}\mathbf{P}}{r}dv$$

where f is the boundary of v, and P_n is the outward normal component of $\mathbf{P}$ on f. Then it is said, quoting, for example, the text book of Abraham-Becker, " this equation, however, simply states that the insulator carries a surface charge density

$$\sigma=P_n,$$

and a space charge of volume density

$$\rho=-\operatorname{div}\mathbf{P}."$$

These distributions are called Poisson's *equivalent* distributions ; and by means of them the theory of a distribution of polarisation is supposed to be reduced to that of surface and volume charge distributions. *This is a fundamental mistake.* It is a misinterpretation of the physical significance of the hypothesis of Poisson and Kelvin.

The physically significant statements of electrodynamics are those about the mechanical forces which act on the material substances in the system considered ; all observed phenomena are concerned ultimately with these mechanical forces. A theory which does not account for these forces satisfactorily must be regarded as inadequate from a physical point of view. In electrostatics the primary observations concern the *mechanical* action of attraction or repulsion between bodies that have been electrified. So the initial object of electrostatic theory is the quantitative study of the mechanical action on a body under electrical influence. The present formulation of the mathematical theory is distinguished by its insistence on the fundamental nature of the formulae which express this mechanical action.

Consider a dielectric body occupying a volume v_2, bounded by surface f_2, under the influence of a charge distribution, with density ρ, in a volume v_1, bounded by surface f_1. The effect observed is a force and couple acting on the dielectric. We must suppose this force and couple to be distributed ; and it suffices to suppose that on a volume element dv of the dielectric there acts the force $\mathbf{F}dv$, and the couple $\mathbf{G}dv$, and that on a surface element df of the dielectric there acts the force $\mathbf{T}df$. Here $\mathbf{F}$ and $\mathbf{G}$, the body-force and body-couple, are vector functions of position in v_2, and $\mathbf{T}$, the surface traction, is a vector function of position on f_2. The fundamental problem is to *state* $\mathbf{F}$, $\mathbf{G}$ and $\mathbf{T}$ in terms which involve the charge distribution in v_1 and the polarisation of the dielectric in v_2. Suitably interpreted, the Poisson-Kelvin hypothesis enables us to do this ; *and these analytical statements of force and couple, extensions of Coulomb's law for point charges, constitute the proper foundation of the theory of dielectrics.*

Thus, I say that the potential defined by

$$\varphi=\int_{v_1}\frac{\rho dv}{r}+\int_{v_2}\mathbf{P}\cdot\nabla\left(\frac{1}{r}\right)dv$$

is a mere auxiliary to the fundamental statements required. Then, defining the electric field by $\mathbf{E}=-\nabla\varphi$, these statements are

$$\mathbf{F}=(\mathbf{P}\,.\,\nabla)\mathbf{E},$$

$$\mathbf{G}=\mathbf{P}\times\mathbf{E},$$

and

$$\mathbf{T}=\tfrac{1}{2}\mathbf{P}\,.\,(\mathbf{E}_{+}-\mathbf{E}_{-})\mathbf{n}.$$

Here $\mathbf{n}$ is a unit normal drawn outward from f_2, and $\mathbf{E}_{+}$, $\mathbf{E}_{-}$ are electric fields just outside and just inside the dielectric.

On the basis of the above formulae for the mechanical action we may *calculate* the work done in any displacement of the parts of the system. We may examine a given system to see whether or not it is mechanically conservative. We find that electrostatic systems are *not mechanically conservative* in the sense that they are assumed to be by all the writers on electrical theory.

The general acceptance of the fundamental misinterpretation of the Poisson-Kelvin hypothesis, by means of the potential formula above, makes it necessary for me to establish a case for my interpretation in terms of the formulae for the mechanical action. It is also desirable to draw attention to current and wide-spread misconceptions concerning the vital notion of energy in electrical systems. These considerations account for the length of this paper.

The main results may be summarized in two formulae :

1. Let V denote the function

$$\tfrac{1}{2}\int_{v_1}\rho\varphi dv-\tfrac{1}{2}\int_{v_2}\mathbf{P}\,.\,\mathbf{E}dv$$

Then, in any infinitesimal deformation of the charge in v_1 and the dielectric in v_2, the work done by the mechanical forces acting on the parts of the system is

$$\triangle W=-\triangle V-\int_{v_2}\mathbf{E}\,.\,\triangle\mathbf{p}dv,$$

where $\triangle\mathbf{p}dv$ is the increment of the electric moment belonging to the element dv as it moves in the deformation.

2. Suppose a dielectric body, held in equilibrium in an electric field, suffers an infinitesimal deformation. Near a point A in the dielectric let

$\triangle q=$heat absorbed by the dielectric per unit volume,

$\triangle i=$increment of the internal energy of the dielectric per unit volume,

$\tilde{\omega}_{\alpha\beta}=$the symmetric part of the mechanical stress in the dielectric,

$\triangle\nu_{\alpha\beta}=$the infinitesimal strain involved in the deformation.

Then

$$\triangle q=\triangle i-\tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}-\mathbf{E}\,.\,\triangle\mathbf{p}.$$

At first sight these formulae may appear to contain little that is new. They differ slightly from formulae which may be supposed to be well known. The second formula expresses the first law of thermodynamics for systems which contain dielectrics in an electric field. The proper formulation of this law, presented here for the first time, has been a subject of controversy in recent years.

1. POISSON-KELVIN HYPOTHESIS.

In 1845 Lord Kelvin wrote : " As far as can be gathered from experiments which have yet been made, it seems probable that a dielectric, subjected to electrical influence, becomes excited in such a manner that every portion of it, however small, possesses *polarity* exactly analogous to the magnetic polarity induced in the substance of a piece of soft iron under the influence of a magnet. By means of a certain hypothesis regarding the nature of magnetic action, Poisson has investigated the mathematical laws of the distribution of magnetism and of magnetic attractions and repulsions. These laws seem to represent in the most general manner the state of a body polarised by influence, and therefore, without adopting any particular mechanical hypothesis, we may make use of them to form a mathematical theory of electrical influence in dielectrics, the truth of which can only be established by a rigorous comparison of its results with experiment" (Kelvin, 1884).

According to this statement we suppose that a dielectric under electrical influence becomes polarised so that a volume element dv acquires an electric moment $\mathbf{P}dv$. The density $\mathbf{P}$ of this moment is called the polarisation. The paragraph quoted means that the problem of dielectrics is reduced to, or replaced by, the problem of distributions of electric moment, but it *does not say* what we should suppose to be the behaviour of such distributions.

The following remarks by Swann (1922) indicate very clearly the interpretation which is placed on the Poisson-Kelvin hypothesis in the literature of electrical theory. "As regards the role played by dielectric phenomena in electrostatics little is to be said. The fundamental assumption is that the dielectric may be represented as regards its external action by replacing it by a distribution of polarisation $\mathbf{P}$. This turns out to be the mathematical equivalent of a fictitious volume distribution, $-\operatorname{div} \mathbf{P}$, and a fictitious surface distribution which at each point of the surface has a density equal to P_{n}, where the subscript n is taken as denoting the component in the direction of the outward normal. Thus in order to include dielectrics, no further extension is needed in the experimental law as formulated above." The law referred to is Coulomb's law of inverse squares.

This statement reduces the problem of moment distributions to the problem of distributions of electric charge, viz. the equivalent distributions of Poisson.

In the next sections we shall have to consider some quite elementary matters which are usually regarded as completely known. There are, however, some important points to emphasize.

2. Point Charges.

The mathematical theory of electricity begins with the assumption of a law of mechanical action between two point charges, viz. Coulomb's law of inverse squares. In addition, a law of superposition is assumed, so that in the case of a number of point charges the mechanical force which acts on any one charge is the resultant of the several Coulomb forces which would act on it due to each of the other charges. It is then shown that the force which acts on any charge in the system may be expressed in an *alternative* way, by the construction of auxiliary space functions, the potential φ and the electric field $\mathbf{E}$. Thus, suppose we have a system of charges $e_1, \ldots, e_{\mathrm{n}}$ at points $P_1, \ldots, P_{\mathrm{n}}$. If P be any point in space, $PP_{\mathrm{i}} = r_{\mathrm{i}}$, the potential φ is defined by

$$\varphi = \varphi(P) = \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{e_{\mathrm{i}}}{r_{\mathrm{i}}}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and the electric field is then $\mathbf{E} = -\nabla\varphi$.

If now a charge e be placed at P, the mechanical force which acts on e is

$$\mathbf{F} = e\mathbf{E}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The existence of this second specification of the force is of *theoretical* importance because it is capable of a *wider generalization* than is the original specification by means of the elementary law and superposition.

For the charges $e_1, \ldots, e_n$ at $P_1, \ldots, P_n$ let φ_i be the potential at P_i due to the charges other than e_i. Then the *energy* of the system is found to be

$$U = \tfrac{1}{2} \sum_{i=1}^{n} e_i \varphi_i. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

This result is usually obtained by one or other of two arguments. In one of these the charges are brought from infinity to their positions $P_1, \ldots, P_n$, *one after another*, and the total work done in this process, by the forces acting on the charges, is calculated. In the other argument, the charge at each place is accumulated gradually and proportionally, so that when the charge at P_i is λe_i the potential at P_i is $\lambda \varphi_i$, and the work corresponding to an increment $d\lambda$ is

$$\sum_{i=1}^{n} \lambda \varphi_i e_i d\lambda = \lambda d\lambda \sum_{i=1}^{n} e_i \varphi_i.$$

Integrating from $\lambda = 0$ to $\lambda = 1$ the expression (3) is obtained.

Now it appears that neither of the arguments outlined above establishes the real significance of the function U in relation to the system. This is that U, considered as a function of the spatial co-ordinates of $P_1, \ldots, P_n$, is a *mechanical potential energy function* for the system ; for this it would have to be shown that in a differential displacement of the points $P_1, \ldots, P_n$ the work done by the forces acting on $e_1, \ldots, e_n$ is equal to the differential of the function $-U$. The usual arguments suggest rather that we should contemplate the physical entity called energy, and that in order to find the amount of this energy in the present case it is sufficient to calculate the work done when the charges are brought into their positions in any particular manner. This appeal to the notion of physical energy and to the physical principle of its conservation is wholly foreign to the mathematical theory of electrostatics as developed from Coulomb's law. It is more important to note that, when applied to other electrical systems in which we are interested, these notions lead to results which are false.

3. Point Dipoles.

Alongside the primary notion of point charge, a second fundamental element, in the construction of the mathematical theory, is the derived notion of point dipole. This is a point element specified by a vector **p**, its electric moment, and is conceived as a limiting case of two equal and opposite charges $-e$, $+e$ separated by a small vector **s** ; and $\mathbf{p} = e\mathbf{s}$. The mechanical action of this hypothetical dipole, on a charge or on another dipole, is assigned by referring to its conceptual origin ; and we might specify this mechanical action by suitable formulae. But the alternative specification by means of suitable functions φ, **E** is much more convenient. We therefore say that the electrical properties of a point dipole are assigned by the following statements, the derivation of which need not be given here.

The electrical potential at P, associated with a dipole **p** at Q, is

$$\varphi = \varphi(P) = \mathbf{p} \cdot \nabla \left(\frac{1}{r}\right), \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where $r = QP$, and ∇ operates on the co-ordinates of Q. The corresponding electric field is $\mathbf{E} = -\nabla \varphi$.

If the dipole **p** lies near to electric charges or other dipoles, and if **E** be the electric field produced by the charges and other dipoles, then a mechanical force **F** acts on **p** given by

$$\mathbf{F} = (\mathbf{p} \cdot \nabla)\mathbf{E}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

and a mechanical couple **G** acts on **p** given by

$$\mathbf{G}=\mathbf{p}\times\mathbf{E}. \ldots\ldots\ldots\ldots\ldots$$

As before the functions φ, **E** are mere mathematical auxiliaries convenient for the expression of the essential force **F** and couple **G**.

In the next section we contemplate electrical systems consisting of several point charges and several point dipoles. It is important to recognize an essential difference in the conception of point charge on the one hand and point dipole on the other. Electric charge, like mass in ordinary mechanics, cannot be created or destroyed. The only way to increase the charge at a point is to *bring up* additional charge to the point. But dipole moment **p** is creatable and destructible. This arises from its origin as two point charges $\pm e$ separated by the vector **s**. By altering **s** we create or destroy $\mathbf{p}=e\mathbf{s}$. The recognition of the significance of this *non-conservation of electric moment* is fundamental for the present reconstruction of electrostatic theory. Thus in the consideration of systems of charges and dipoles we shall admit the possibility of varying the dipoles *in situ,* so to speak, without any necessity of bringing up to the point considered or of removing from it some amount of electric moment.

4. Discrete Systems of Charge and Dipole.

It is usual to develop the mathematical theory of electrostatics on the ideal notions of continuous distributions of electric charge and of continuous distributions of electric moment. Of course, in view of modern knowledge of the structure of matter and electricity, of the existence of molecules and electrons, we claim no physical reality for such continuous distributions. The object rather is to set up a mathematical model system in which we can recognize a more or less close correspondence with actual electrical phenomena; and the adequacy of the theory in this respect is to be judged as a whole.

An alternative model which, at least in some respects, is not less close to physical reality than the system of continuous distributions, would be a model consisting of discrete point charges and point dipoles. If we consider a number of point charges aggregated together in one region, and a number of point dipoles aggregated together in another region, we have a model representing a dielectric body under the influence of electric charge, which we may expect to exhibit some of the features of the real physical situation.

There are, besides, certain purely theoretical advantages in considering these discrete systems. The theory is clear cut; it is free from certain subtleties of definition, and from certain difficulties of a purely analytical kind which are involved in the theory of continuous distributions. The fundamental error of replacing continuous distributions of electric moment by the equivalent charge distributions of Poisson has no analogue in the theory of discrete systems, for the obvious reason that there are no analogues to Poisson's distributions.

Consider then a system of charges $e_1,\ldots,e_n$ at points $P_1,\ldots,P_n$ and of dipoles $\mathbf{p}_1,\ldots,\mathbf{p}_m$ at points $Q_1,\ldots,Q_m$, and introduce the following notation. Vector $P_iP_j=\mathbf{q}_{ij}$, vector $P_iQ_j=\mathbf{r}_{ij}$, vector $Q_iQ_j=\mathbf{s}_{ij}$. Also, φ_i is the elcetric potential at P_i due to all the elements other than e_i; and $\mathbf{E}_i$ is the electric field at Q_i due to all the elements other than $\mathbf{p}_i$. We use the following formulae, which come from (1), (2) and (4).

The potential due to e at position **q** is

$$\varphi=\frac{e}{q};$$

the electric field due to e at position **r** is

$$\mathbf{E}=\frac{e\mathbf{r}}{r^3};$$

the potential due to $\mathbf{p}$ at position $-\mathbf{r}$ is

$$\varphi=-\frac{\mathbf{p}\,.\,\mathbf{r}}{r^3};$$

the electric field due to $\mathbf{p}$ at position $\mathbf{s}$ is

$$\mathbf{E}=-\frac{\mathbf{p}}{s^3}+\frac{3(\mathbf{p}\,.\,\mathbf{s})\mathbf{s}}{s^5}.$$

For the system of n charges and m dipoles

$$\varphi_i=\sum_j{}'\frac{e_j}{q_{ij}}-\sum_j\frac{\mathbf{p}_j\,.\,\mathbf{r}_{ij}}{r_{ij}^3}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\mathbf{E}_i=\sum_j\frac{e_j\mathbf{r}_{ji}}{r_{ji}^3}-\sum_j{}'\frac{\mathbf{p}_j}{\mathbf{s}_{ji}^3}+3\sum_j{}'\frac{(\mathbf{p}_j\,.\,\mathbf{s}_{ji})\mathbf{s}_{ji}}{s_{ji}^5}. \quad \ldots\ldots\ldots\ldots \quad (8)$$

In the summations j runs through $1, \ldots, n$ or $1, \ldots, m$ according as the sum is over the charges or the dipoles ; and Σ' indicates a summation in which one value, $j=i$, is omitted.

For a second electrical system of charges and dipoles $e'_1, \ldots, e'_n$; $\mathbf{p}'_1, \ldots, \mathbf{p}'_m$ set at the same points $P_1, \ldots, P_n$; $Q_1, \ldots, Q_m$, let φ'_i and $\mathbf{E}'_i$ be the potentials and electric fields which correspond to φ_i and $\mathbf{E}_i$ in the first system. Then

$$\sum_i e'_i\varphi_i-\sum_i \mathbf{p}'_i\,.\,\mathbf{E}_i=\sum_i e_i\varphi'_i-\sum_i \mathbf{p}_i\,.\,\mathbf{E}'_i. \quad \ldots\ldots\ldots\ldots \quad (9)$$

This is Green's reciprocal theorem extended to systems of charges and dipoles. To prove it we have from (7) and (8)

$$\sum_i e'_i\varphi_i-\sum_i \mathbf{p}'_i\,.\,\mathbf{E}_i=\sum_P\frac{e'_ie_j}{q_{ij}}-\sum_{i,j}\frac{e'_i\mathbf{p}_j+e_i\mathbf{p}'_j}{r_{ij}^3}\,.\,\mathbf{r}_{ij}$$

$$+\sum_P\frac{\mathbf{p}'_i\,.\,\mathbf{p}_j}{s_{ji}^3}-3\sum_P\frac{(\mathbf{p}_j\,.\,\mathbf{s}_{ji})(\mathbf{p}'_i\,.\,\mathbf{s}_{ji})}{s_{ji}^5}, \quad \ldots\ldots \quad (10)$$

where $\sum\limits_{i,j}$ is a summation in which i runs through $1, \ldots, n$ and j runs through $1, \ldots, m$; and $\sum\limits_P$ is a summation in which the pair i, j runs through all permutations, two at a time, of $1, \ldots, n$ or $1, \ldots, m$ as the case may be. Examining this expression it will be seen that an interchange of the dashed and undashed letters does not alter any one of its four terms. The relation (9) follows. Simplifying the notation and supposing that the charges in the two systems are the same, $e'_i=e_i$, we have

$$\Sigma e(\varphi'-\varphi)=\Sigma(\mathbf{p}\,.\,\mathbf{E}'-\mathbf{p}'\,.\,\mathbf{E}). \quad \ldots\ldots\ldots\ldots \quad (11)$$

We need also the elementary work formulae as follow.

If a charge e in an electric field $\mathbf{E}$ be given a differential displacement $\triangle\mathbf{u}$, the work done by the mechanical force (2), which acts on it, is

$$\mathbf{F}\,.\,\triangle\mathbf{u}=e\mathbf{E}\,.\,\triangle\mathbf{u}=-e\nabla\varphi\,.\,\triangle\mathbf{u}=-e\triangle\varphi. \quad \ldots\ldots \quad (12)$$

Similarly, if a dipole $\mathbf{p}$ in an electric field $\mathbf{E}$ be given a differential displacement $\triangle\mathbf{u}$ the work done by the mechanical force (5), which acts on it, is

$$\mathbf{F}\,.\,\triangle\mathbf{u}=((\mathbf{p}\,.\,\nabla)\mathbf{E})\,.\,\triangle\mathbf{u}=(\mathbf{p}\,.\,\nabla)(\mathbf{E}\,.\,\triangle\mathbf{u})=-(\mathbf{p}\,.\,\nabla)\triangle\varphi$$

$$=-\mathbf{p}\,.\,\triangle(\nabla\varphi)=\mathbf{p}\,.\,\triangle\mathbf{E}. \quad \ldots\ldots\ldots\ldots \quad (13)$$

In these statements $\triangle\varphi$ and $\triangle\mathbf{E}$ are the differentials of the auxiliary space functions φ, $\mathbf{E}$ corresponding to the independent differentials of the co-ordinates of e or $\mathbf{p}$.

5. The General Work Formula.

Consider now a variation of the electrical system of charges $e_1, \ldots, e_n$ and dipoles $\mathbf{p}_1, \ldots, \mathbf{p}_m$ at points $P_1, \ldots, P_n$ and $Q_1, \ldots, Q_m$. This variation consists of an infinitesimal displacement of the charges and dipoles and also, in accordance with the explanation at the end of §3, an infinitesimal change in the dipole moments $\mathbf{p}_i$. Thus the independent variables are the $3n$ cartesian coordinates of the charges e_i, the $3m$ cartesian coordinates of the dipoles $\mathbf{p}_i$, and the $3m$ rectangular components of the vectors $\mathbf{p}_i$. The following notation for differentials will be used.

$\triangle$ is a total differential with respect to all independent variables ;

$\triangle'$ is a partial differential with respect to the spatial coordinates of the charges and dipoles ;

$\triangle''$ is a partial differential with respect to the components of the vectors $\mathbf{p}_i$;

$\triangle^{e_i}$ is a partial differential with respect to the coordinates of e_i ;

$\triangle^{\mathbf{p}_i}$ is a partial differential with respect to the coordinates of $\mathbf{p}_i$.

Then, symbolically,

$$\triangle = \triangle' + \triangle'', \qquad \ldots\ldots\ldots\ldots \quad (14)$$

$$\triangle' = \sum_i \triangle^{e_i} + \sum_i \triangle^{\mathbf{p}_i}. \qquad \ldots\ldots\ldots\ldots \quad (15)$$

Consider the function

$$V = \tfrac{1}{2}\Sigma e\varphi - \tfrac{1}{2}\Sigma \mathbf{p} \cdot \mathbf{E}. \qquad \ldots\ldots\ldots\ldots \quad (16)$$

If we write $e'_i = e_i$, $\mathbf{p}'_i = \mathbf{p}_i$ in (10) and divide by 2, we have

$$V = \sum_{C} \frac{e_i e_j}{q_{ij}} - \sum_{i,j} \frac{e_i \mathbf{p}_j \cdot \mathbf{r}_{ij}}{r_{ij}^3} + \sum_{C} \frac{\mathbf{p}_i \cdot \mathbf{p}_j}{s_{ji}^3}$$
$$- 3\sum_{C} \frac{(\mathbf{p}_j \cdot \mathbf{s}_{ji})(\mathbf{p}_i \cdot \mathbf{s}_{ji})}{s_{ji}^5}, \qquad \ldots\ldots\ldots\ldots \quad (17)$$

where $\sum\limits_{i,j}$ is a summation in which i runs through $1, \ldots, n$ and j runs through $1, \ldots, m$; and $\sum\limits_{C}$ is a summation in which the pair i, j runs through all combinations, two at a time, of $1, \ldots, n$ or $1, \ldots, m$ as the case may be. In (17) the coordinates of e_i are involved only in the terms

$$e_i \sum_j{}' \frac{e_j}{q_{ij}} - e_i \sum_j \frac{\mathbf{p}_j \cdot \mathbf{r}_{ij}}{r_{ij}^3} = e_i \varphi_i.$$

Hence

$$\triangle^{e_i} V = e_i \triangle^{e_i} \varphi_i.$$

Similarly, in (17), the coordinates of $\mathbf{p}_i$ are involved only in the terms

$$-\mathbf{p}_i \cdot \sum_j \frac{e_j \mathbf{r}_{ji}}{r_{ji}^3} + \mathbf{p}_i \cdot \sum_j{}' \frac{\mathbf{p}_j}{s_{ji}^3} - \mathbf{p}_i \cdot 3\sum_j{}' \frac{(\mathbf{p}_j \cdot \mathbf{s}_{ji})\mathbf{s}_{ji}}{s_{ji}^5}$$
$$= -\mathbf{p}_i \cdot \mathbf{E}_i.$$

Hence

$$\triangle^{\mathbf{p}_i} V = -\mathbf{p}_i \cdot \triangle^{\mathbf{p}_i} \mathbf{E}_i.$$

So from (15)

$$-\triangle' V = -\sum_i e_i \triangle^{e_i} \varphi_i + \sum_i \mathbf{p}_i \cdot \triangle^{\mathbf{p}_i} \mathbf{E}_i,$$

and then, by (12) and (13), $-\triangle' V$ is the total work done in the displacement by all the mechanical forces acting on the charges and dipoles in the system.

In (11)

$$\mathbf{p} \cdot \mathbf{E}' - \mathbf{p}' \cdot \mathbf{E} = \mathbf{p} \cdot (\mathbf{E}' - \mathbf{E}) - (\mathbf{p}' - \mathbf{p}) \cdot \mathbf{E}.$$

So, for a differential variation of the dipoles,

$$\Sigma\, e \triangle'' \varphi = \Sigma\, (\mathbf{p} \,.\, \triangle''\mathbf{E} - \mathbf{E} \,.\, \triangle''\mathbf{p}).$$

Then, differentiating (16)

$$\begin{aligned} \triangle'' V &= \tfrac{1}{2}\Sigma\, e \triangle''\varphi - \tfrac{1}{2}\Sigma\, (\mathbf{p} \,.\, \triangle''\mathbf{E} + \mathbf{E} \,.\, \triangle''\mathbf{p}) \\ &= \tfrac{1}{2}\Sigma\, (\mathbf{p} \,.\, \triangle''\mathbf{E} - \mathbf{E} \,.\, \triangle''\mathbf{p}) - \tfrac{1}{2}\Sigma\, (\mathbf{p} \,.\, \triangle''\mathbf{E} + \mathbf{E} \,.\, \triangle''\mathbf{p}) \\ &= -\Sigma\, \mathbf{E} \,.\, \triangle''\mathbf{p} = -\Sigma\, \mathbf{E} \,.\, \triangle\mathbf{p}, \end{aligned}$$

since $\triangle''\mathbf{p} = \triangle\mathbf{p}$.

From (14)

$$-\triangle' V = -\triangle V + \triangle'' V = -\triangle V - \Sigma\, \mathbf{E} \,.\, \triangle\mathbf{p}.$$

Thus, if we denote by $\triangle W$ the work done by the mechanical forces acting on the charges and the dipoles, we have

$$\triangle W = -\triangle V - \Sigma\, \mathbf{E} \,.\, \triangle\mathbf{p}. \quad \ldots\ldots\ldots\ldots \quad (18)$$

This is the *fundamental work formula*. Its importance springs from the generality of the circumstances to which it applies. It gives a means of determining whether certain electrical systems are or are not mechanically conservative. It may be remarked explicitly that we have not included in $\triangle W$ any work which might be done by the mechanical couples which act on the dipoles of the system. It would be possible, with suitable conventions, to modify (18) so as to take account of the work done by the couples, but such a modification is not important in the present connection. In the case of the theory of continuous distributions, the formula which includes the work done by the couples is important, and it will be obtained in that connection later.

Introducing the function

$$U = \tfrac{1}{2}\, \Sigma\, e\varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (19)$$

we find from (18),

$$\triangle W = -\triangle U + \tfrac{1}{2}\, \Sigma\, (\mathbf{p} \,.\, \triangle\mathbf{E} - \mathbf{E} \,.\, \triangle\mathbf{p}), \quad \ldots\ldots\ldots\ldots \quad (20)$$

which is another form of the fundamental work formula.

6. INDUCTIVE SYSTEMS.

We call a system of point charges and point dipoles an *inductive* system if the dipole moments $\mathbf{p}_i$ depend upon and are determined by the magnitudes of the charges $e_1, \ldots, e_n$ and the configuration of the points $P_1, \ldots, P_n$, $Q_1, \ldots, Q_m$. Systems in which the dipole moments are all constants, and systems of charges only may be regarded as special cases.

For a system of charges only, $U = V$ and the formula (18) gives $\triangle W = -\triangle U$. Thus a system of point charges is mechanically conservative and U is its *mechanical potential energy function*. This is the result mentioned in §2.

For a system of charges and dipoles in which the dipole moments are fixed we have $\triangle W = -\triangle V$. So this system, also, is mechanically conservative, and V is its mechanical potential energy function.

Next examine the possibilities of a *linear* inductive system in which the dipole moments $\mathbf{p}_i$ are determined by the conditions

$$\mathbf{p}_i = \lambda_i \mathbf{E}_i, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (21)$$

where the λ_i are constants, or more generally, depend upon the configuration of the points $P_1, \ldots, P_n$, $Q_1, \ldots, Q_m$. The equations (21) in which the $\mathbf{E}_i$ are replaced by the expressions (8), comprise $3m$ linear equations to determine the $3m$ components of the vectors $\mathbf{p}_i$. In an infinitesimal displacement of the charges and dipoles of this system, we have from (21),

$$\mathbf{p} \,.\, \triangle\mathbf{E} - \mathbf{E} \,.\, \triangle\mathbf{p} = -E^2 \triangle\lambda,$$

and then from (20), the work done by the mechanical forces acting on the elements of the system is

$$\triangle W = -\triangle U - \tfrac{1}{2}\Sigma E^2 \triangle\lambda. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

The simplest case is that in which the coefficients λ are constants. Then $\triangle W = -\triangle U$, and the system is mechanically conservative, and the function U is its *mechanical potential energy function.*

When the coefficients λ are not constants a new situation arises. Consider a linear inductive system in which these coefficients depend upon the dipole configuration $Q_1, \ldots, Q_m$, only being independent of the positions of $P_1, .., P_n$. As has been shown in detail for a special case, such a system is mechanically conservative if and only if the coefficients λ are all constants (Smith-White, 1952). If the λ vary with the configuration $Q_1, \ldots, Q_m$, the system is *not mechanically conservative.* However, for a displacement of the charges only, the configuration of the dipoles remaining fixed, equation (22) gives $\triangle W = -\triangle U$. Thus, *provided the dipoles have a fixed configuration*, but in this case only, the system is mechanically conservative, and U is the mechanical potential energy function. A system of this kind may be called *semi-conservative.*

Such semi-conservative systems occur also in the theory of continuous distributions, but the semi-conservatism has not before been recognized. The energy-method in the theory of dielectric forces, due to Korteweg and Helmholtz, which is expounded and elaborated in modern text books on the theory of electricity, is fundamentally unsound, because it treats as completely conservative systems which are in fact merely semi-conservative. These systems are conservative only if the dielectrics in them are held rigid.

7. CONTINUOUS DISTRIBUTIONS.

We give an account of the theory of continuous distributions of electric charge and electric moment which is mathematically similar to the theory of discrete systems presented in the foregoing sections. This similarity makes the present account of continuous distributions essentially different from any that has been given before. As indicated already, the view is taken that the proper starting point for electrostatic theory is a statement of the mechanical forces which act on the electrical elements considered. Coulomb's law provides such a statement when the elements in question are point charges, but it cannot be applied immediately to continuous distributions of electric charge, and still less to continuous distributions of electric moment. The required statements are obtained by an *induction* from the primitive law, and are not regarded as proved by the arguments given. They are regarded rather as extensions of Coulomb's law, as hypotheses, appropriate to the continuous distributions concerned.

That the theory constructed is, mathematically, the analogue, for continuous systems, of what has been given for discrete systems, there can be no question. The thesis presented is, that this theory is the proper and complete interpretation of the hypothesis due to Poisson and Kelvin. This, of course, is a matter of judgment ; but in the final analysis, the adequacy of the theory, to account for the electrical behaviour of bodies, is to be judged by a comparison of its consequences with the results of observation.

Consider first a distribution of charge with density ρ inside a volume v. Let dv' be a volume element at P, in v, so that this element contains a charge $\rho' dv'$. If $\mathbf{F} dv'$ is the mechanical force which acts on the charge in dv', our problem is to state the force $\mathbf{F}$ in terms of the whole charge distribution. For this purpose we imagine the distribution to be divided into a large number of small volume elements and apply Coulomb's law to write down the force acting on the charge in dv' due to the charges in each of the other volume elements. If dv at Q is one of these other elements, the force on dv' due to the charge in dv is

$$-\rho' dv' \rho dv \frac{\mathbf{r}}{r^3}$$

where $PQ=\mathbf{r}$. Integrating over the charge distribution we find

$$\mathbf{F}dv' = -\rho' dv' \int_v \frac{\rho \mathbf{r}}{r^3} dv \cdot$$

So we write, dropping the prime, since there is now no possibility of confusion, for the body force acting on the charge at P,

$$\mathbf{F} = -\rho \int_v \frac{\rho \mathbf{r}}{r^3} dv. \quad \ldots\ldots\ldots\ldots \quad (23)$$

The above discussion is too crude to be regarded as an analytical proof of this force formula. Further, it seems that no amount of refinement of the argument can give a *proof*, that a perfectly continuous distribution of charge, if such a thing existed, would experience the mechanical force (23). We therefore take (23) as the statement of an hypothesis ; and regard it as the extension of Coulomb's law appropriate to a continuous distribution of charge.

Having made clear the position adopted it can be noted that an alternative, mathematically equivalent, specification of the force (23) is possible by means of auxiliary space functions, the potential φ and the field $\mathbf{E}$. If we define

$$\varphi = \varphi(P) = \int_v \frac{\rho dv}{r} \quad \ldots\ldots\ldots\ldots \quad (24)$$

and put $\mathbf{E} = -\nabla \varphi$, the force (23) is given by

$$\mathbf{F} = \rho \mathbf{E}. \quad \ldots\ldots\ldots\ldots \quad (25)$$

Next consider a distribution of electric moment with density $\mathbf{P}$ inside a volume v. If we start from the law of mechanical action between two dipoles and attempt to find the mechanical force $\mathbf{F}dv'$ which acts on the electric moment inside dv' by an integration over v, as we have just done for a charge distribution, we find, as is well known, that the integrals which present themselves are not convergent. So, if we are to persist in the attempt to construct a theory of continuous distributions of electric moment, which will be similar to that already given for a system of discrete dipoles, we must suggest another method of finding an appropriate hypothesis for the mechanical effect on the moment distribution. It happens that the alternative specification, by means of the potential and electric field, remains mathematically significant for continuous distributions of electric moment. But, of course, this specification is no longer an alternative one ; it is the only one available. Following the suggestions of the formulae (4), (5) and (6) we define

$$\varphi = \varphi(P) = \int_v \mathbf{P} \cdot \nabla \left(\frac{1}{r}\right) dv, \quad \ldots\ldots\ldots \quad (26)$$

and $\mathbf{E} = -\nabla \varphi$. Then, *by hypothesis*, we take for the mechanical force per unit volume which acts on an element of the moment distribution, the value

$$\mathbf{F} = (\mathbf{P} \cdot \nabla)\mathbf{E}, \quad \ldots\ldots\ldots\ldots \quad (27)$$

and for the mechanical couple per unit volume, which acts on the same element, the value

$$\mathbf{G} = \mathbf{P} \times \mathbf{E}. \quad \ldots\ldots\ldots\ldots \quad (28)$$

Consider then the conditions at the surface f of v. Across this surface the polarisation is discontinuous, being $\mathbf{P}$ just inside the surface and $\mathbf{O}$ just outside the surface. The limiting form of (27) gives a surface traction on f,

$$\mathbf{T}=\tfrac{1}{2}\mathbf{P}\,.\,(\mathbf{E}_{+}-\mathbf{E}_{-})\mathbf{n}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (29)$$

where $\mathbf{n}$ is the unit normal outward from v and $\mathbf{E}_{+}$, $\mathbf{E}_{-}$ are the electric fields just outside and just inside v. For the derivation of (29) see Smith-White (1949). Ultimately of course (29) rests on the same footing as (27) and (28); it is an hypothesis, the extension of Coulomb's law appropriate to the surface discontinuity of the polarisation across f.

In general, when we have a charge distribution with density ρ in v_1, and a moment distribution with density $\mathbf{P}$ in v_2, we define

$$\varphi=\int_{v_1}\frac{\rho dv}{r}+\int_{v_2}\mathbf{P}\,.\,\nabla\left(\frac{1}{r}\right)dv \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (30)$$

and $\mathbf{E}=-\nabla\varphi$, as before. Then the mechanical effects in v_1, v_2 and on f_2 are given by the formulae (25), (27), (28) and (29). The functions φ and $\mathbf{E}$ are mere auxiliaries to these statements of the mechanical effects.

8. Formal Transformations.

The following formal transformations are based solely on the formula (30) and so belong equally to the theory commonly expounded, as well as to the theory presented in this paper.

Transforming (30) by Green's theorem,

$$\varphi=\int_{v_1}\frac{\rho dv}{r}+\int_{v_2}\frac{-\text{div }\mathbf{P}}{r}dv+\int_{f_2}\frac{P_{\text{n}}}{r}df, \quad \ldots\ldots\ldots\ldots\ldots \quad (31)$$

where P_{n} is the component of $\mathbf{P}$ along the outward normal on f_2. Thus φ is expressed as a Newtonian potential; so by the analytical theory

$$\text{div }\mathbf{E}=-\nabla^2\varphi=\begin{cases}4\pi\rho, \text{ in } v_1\\ -4\pi \text{ div }\mathbf{P}, \text{ in } v_2,\\ 0, \text{ elsewhere,}\end{cases} \quad \ldots\ldots\ldots \quad (32)$$

and, on f_2,

$$\text{divs }\mathbf{E}=4\pi P_{\text{n}}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (33)$$

where divs $\mathbf{E}$ is a surface divergence, and is equal to the discontinuity in the normal component of $\mathbf{E}$ as we pass outward through f_2. Introducing the vector $\mathbf{D}$ defined by

$$\mathbf{D}=\mathbf{E}+4\pi\mathbf{P}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (34)$$

so $\mathbf{D}=\mathbf{E}$ outside v_2, we have

$$\text{div }\mathbf{D}=\begin{cases}4\pi\rho, \text{ in } v_1\\ 0, \text{ elsewhere,}\end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (35)$$

and

$$\text{divs }\mathbf{D}=0, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (36)$$

on f_1 and f_2.

For any volume v, bounded by surface f,

$$\int_f D_{\text{n}}df=\int_v \text{div }\mathbf{D}\,dv=4\pi\int_v \rho dv=4\pi q, \quad \ldots\ldots\ldots \quad (37)$$

where q is the total charge contained in v. This is Gauss' theorem on the total normal induction as extended to dielectrics.

Consider a second distribution; charge with density ρ' in v_1, and moment with density $\mathbf{P}'$ in v_2. Let φ', $\mathbf{E}'$, $\mathbf{D}'$ be the auxiliary functions belonging to this second distribution. The identity

$$\varphi \operatorname{div} \mathbf{D}' = \operatorname{div} (\varphi \mathbf{D}') - \mathbf{D}' . \nabla \varphi$$

gives

$$4\pi\rho'\varphi = \operatorname{div} (\varphi \mathbf{D}') + \mathbf{D}' . \mathbf{E}.$$

Applying Green's theorem to each of the three components of space separated by the surfaces f_1 and f_2 and adding, we have

$$\int_{v_1} \rho'\varphi dv = \frac{1}{4\pi}\int_{s} \mathbf{D}' . \mathbf{E} dv, \quad \ldots\ldots\ldots\ldots\ldots \quad (38)$$

where $\int_s$ signifies an integration over the whole of space.

In (38) write $\rho' = \rho$, $\mathbf{D}' = \mathbf{D}$, then

$$\int_{v_1} \rho\varphi dv = \frac{1}{4\pi}\int_{s} \mathbf{D} . \mathbf{E} dv. \quad \ldots\ldots\ldots\ldots\ldots \quad (39)$$

Subtracting from (38),

$$\int_{v_1} (\rho' - \rho)\varphi dv = \frac{1}{4\pi}\int_{s} (\mathbf{D}' - \mathbf{D}) . \mathbf{E} dv. \quad \ldots\ldots \quad (40)$$

For a differential variation $\rho \to \rho + \delta\rho$, $\mathbf{D} \to \mathbf{D} + \delta\mathbf{D}$, this gives

$$\int_{v_1} \varphi\delta\rho dv = \frac{1}{4\pi}\int_{s} \mathbf{E} . \delta\mathbf{D} dv. \quad \ldots\ldots\ldots\ldots \quad (41)$$

Interchange dashed and undashed letters in (38) and subtract the new result from it. So

$$\int_{v_1} (\rho'\varphi - \rho\varphi')dv = \frac{1}{4\pi}\int_{s} (\mathbf{D}' . \mathbf{E} - \mathbf{D} . \mathbf{E}')dv$$

$$= \frac{1}{4\pi}\int_{v_2} (\mathbf{D}' . \mathbf{E} - \mathbf{D} . \mathbf{E}')dv \quad \ldots\ldots\ldots \quad (42)$$

$$= \int_{v_2} (\mathbf{P}' . \mathbf{E} - \mathbf{P} . \mathbf{E}')dv. \quad \ldots\ldots\ldots \quad (43)$$

For a differential variation $\rho \to \rho + \delta\rho$, $\mathbf{P} \to \mathbf{P} + \delta\mathbf{P}$ and $\mathbf{D} \to \mathbf{D} + \delta\mathbf{D}$ this gives

$$\int_{v_1} (\varphi\delta\rho - \rho\delta\varphi)dv = \frac{1}{4\pi}\int_{v_2} (\mathbf{E} . \delta\mathbf{D} - \mathbf{D} . \delta\mathbf{E})dv \quad \ldots\ldots \quad (44)$$

$$= \int_{v_2} (\mathbf{E} . \delta\mathbf{P} - \mathbf{P} . \delta\mathbf{E})dv \quad \ldots\ldots \quad (45)$$

If in (42) we take $\rho' = \rho$ and write

$$\mathbf{D} = K\mathbf{E}, \quad \mathbf{D}' = K'\mathbf{E}',$$

we have

$$\int_{v_1} \rho(\varphi - \varphi')dv = \frac{1}{4\pi}\int_{v_2} (K' - K)\mathbf{E}' . \mathbf{E} dv. \quad \ldots\ldots\ldots\ldots\ldots \quad (46)$$

For a differential variation $K \rightarrow K+\delta K$ this gives

$$\int_{v_1} \rho\delta\varphi dv = -\frac{1}{4\pi}\int_{v_2} \mathbf{E}^2\delta K dv. \qquad (47)$$

The identity

$$\mathbf{P}\,.\nabla\,\varphi = \text{div}\,(\varphi\mathbf{P}) - \varphi\,\text{div}\,\mathbf{P}$$

gives

$$-\mathbf{P}\,.\,\mathbf{E} = \text{div}\,(\varphi\mathbf{P}) - \varphi\,\text{div}\,\mathbf{P}.$$

Integrating over v_2 and applying Green's theorem

$$-\int_{v_2} \mathbf{P}\,.\,\mathbf{E}dv = \int_{f_2} \varphi P_n df - \int_{v_2} \varphi\,\text{div}\,\mathbf{P}dv.$$

Now define functions U, V by

$$U = \tfrac{1}{2}\int_{v_1} \rho\varphi dv, \qquad (48)$$

$$V = \tfrac{1}{2}\int_{v_1} \rho\varphi dv - \tfrac{1}{2}\int_{v_2} \mathbf{P}\,.\,\mathbf{E}dv. \qquad (49)$$

Then, by (39)

$$U = \frac{1}{8\pi}\int_{s} \mathbf{D}\,.\,\mathbf{E}dv, \qquad (50)$$

$$= \frac{1}{8\pi}\int_{s} (\mathbf{E}+4\pi\mathbf{P})\,.\,\mathbf{E}dv$$

$$= \tfrac{1}{2}\int_{v_2} \mathbf{P}\,.\,\mathbf{E}dv + \frac{1}{8\pi}\int_{s} E^2 dv.$$

And

$$V = \tfrac{1}{2}\int_{v_1} \rho\varphi dv + \tfrac{1}{2}\int_{f_2} \varphi P_n df - \tfrac{1}{2}\int_{v_2} \varphi\,\text{div}\,\mathbf{P}dv, \qquad (51)$$

$$= \frac{1}{8\pi}\int_{s} E^2 dv. \qquad (52)$$

9. Discussion of the Literature.

It is an essential part of the purpose of this paper to compare the present formulation of electrostatic theory with that given in the literature. There we find that the formulae (27) and (28) are mentioned only incidentally, their fundamental significance is unrecognized, and in many accounts they are neglected entirely. In no case are they made to play any part in the construction of the theory. Indeed most accounts give a force formula in dielectrics which is quite different from (27) and which is derived as an end result of the theory. I shall refer to this again below. On the other hand, the potential formula (30), which we regard as a mere auxiliary to the fundamental statements of mechanical effect, is usually regarded as embodying the whole content of the Poisson-Kelvin hypothesis. And then the moment distribution is replaced by the equivalent charge distributions of Poisson:

$$\rho = -\text{div}\,\mathbf{P}, \qquad (53)$$

$$\sigma = P_n. \qquad (54)$$

For the purpose of the following remarks it is convenient to recognize two main classes among the accounts of the theory of dielectrics which are available in the literature. On the one side there are those which attempt to keep the discussion quite general and assume no special relation between the vectors **P** and **E** ; on the other side there are those which restrict all further discussion to the linear inductive case, assuming that the vectors **P** and **E** are linearly related and in particular than $\mathbf{P}=k\mathbf{E}$. It seems simplest to comment on the work of some recognized authors.

Consider first de Donder (1925). He begins with the expression (3) as the " energy " of a system of point charges, and transfers it to continuous distributions by the obvious procedure of replacing the sum by an integral. At the same time he regards the polarisation in v_2 as equivalent to the distributions of Poisson. In this process the exact notion of a mechanical potential energy function is obscured, but de Donder, not having emphasized this aspect, has not noticed the loss. By the transfer de Donder obtains his " energy from the microscopic point of view ", viz.

$$\tfrac{1}{2}\int_{v_1}\rho\varphi dv+\tfrac{1}{2}\int_{f_2}\sigma\varphi df+\tfrac{1}{2}\int_{v_2}\rho\varphi dv,$$

and by (53), (54) and (51) this is the function V. By (52) this " microscopic energy " is distributed with a density

$$\frac{E^2}{8\pi}. \qquad \dots\dots\dots\dots\dots\dots\dots\dots \quad (55)$$

By " neglecting the energy belonging to the moment distribution ", de Donder also finds an " energy from the macroscopic point of view ", viz.

$$\tfrac{1}{2}\int_{v_1}\rho\varphi dv,$$

and by (48) this is the function U. By (50) this " macroscopic energy " is distributed with a density

$$\frac{1}{8\pi}\mathbf{D}\,.\,\mathbf{E}. \qquad \dots\dots\dots\dots\dots\dots\dots\dots \quad (56)$$

de Donder does not make clear which, if either, of his two energies is to be regarded as a mechanical potential energy function. It would seem a little incongruous to suppose an energy *function* to be distributed in space. de Donder remarks in his preface " Quand on étudie *l'énergie électrique* localisée dans un champ électrique dû à des volumes polarisés, il se présente une réelle difficulté ; nous la surmontons en nous plaçant respectivement au point de vue *microscopique* et au point de vue *macroscopique.*" We can admit the difficulty, due to the misinterpretation of the Poisson-Kelvin hypothesis, that has been presented by the notion of energy in dielectrics, but it is not clear what difficulties are overcome by de Donder's device of having *two* energies.

The following is effectively the argument given by Stratton (1941). Suppose we have a dielectric occupying a volume v_2 and we accumulate gradually a charge to density ρ, in the volume v_1. To increase the charge density by $\delta\rho$ in the element dv the work done is $\varphi\delta\rho dv$ and the total work done in increasing the charge by $\delta\rho$ in v_1 is

$$\int_{v_1}\varphi\delta\rho dv. \qquad \dots\dots\dots\dots\dots\dots\dots \quad (57)$$

On the other hand the increase in charge inside v_1 will increase the electrical potential by $\delta\varphi$ with the consequent increase of energy of the charge ρdv in dv, by an amount $\rho\delta\varphi dv$. So the total increment of energy is

$$\int_{v_1} \rho\delta\varphi dv. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (58)$$

But the work done is equal to the increment of energy ; and so each is equal to

$$\tfrac{1}{2}\int_{v_1} (\varphi\delta\rho+\rho\delta\varphi)dv.$$

Integrating we find for the energy of the system the amount

$$U=\tfrac{1}{2}\int_{v_1} \rho\varphi dv.$$

So, this is de Donder's " macroscopic " energy. The error in the above argument is apparent if we refer to formula (45). In general we have no grounds for asserting that the right side of (45) is zero.

Stratton proceeds in his next paragraph to derive a different formula for the energy of an electrostatic system, and makes no comment on its inconsistency with his first result. Corresponding to the increase of charge $\delta\rho$ in v_1 the work done is given by (57) ; and this is taken to be the increment of electrostatic energy. Transforming this by (41), the increment of energy is

$$\frac{1}{4\pi}\int_{s} \mathbf{E}\,.\,\delta\mathbf{D}dv,$$

and the total energy is

$$\frac{1}{4\pi}\int_{s} dv\int_{0}^{\mathbf{D}} \mathbf{E}\,.\,\delta\mathbf{D}, \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (59)$$

on assuming that, at each point in the dielectric, **D** depends on **E** in such a way that **E** . δ**D** is a perfect differential. The expression (59) is regarded as the general result and the corresponding energy density is

$$\frac{1}{4\pi}\int_{0}^{\mathbf{D}} \mathbf{E}\,.\,\delta\mathbf{D}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (60)$$

We recognize then three different energy expressions in the literature. There are de Donder's two expressions (55) and (56), of which the second arises also from an erroneous argument of Stratton. These two expressions are obtained without contemplating any functional relation between **D** and **E**. The third expression is (60), which is supposed to hold for a certain kind of functional relation between **D** and **E**.

The text books of Jeans (1927) and of Abraham-Becker (1932), and the Lectures on Theoretical Physics by H. A. Lorentz (1931) discuss only the case when **D** and **E** are linearly related. Jeans and Lorentz do not mention the Poisson-Kelvin hypothesis in relation to dielectrics. The basis for the theory of dielectrics is effectively the assumption of Gauss' theorem (37). Abraham-Becker derive Gauss' theorem as above, but this is the only use they make of the Poisson-Kelvin hypothesis. With regard to the energy in dielectric systems Jeans and Abraham-Becker merely assume that results which are found by considering a simple parallel plate condenser will hold quite generally. In this way it is found that (56) represents the energy density in the medium, then by (50) that the whole energy of the system is U. It seems to be worth quoting

Abraham-Becker to see the importance they attach to the expression (56). " The justification of the expression for the energy density of the field assumed in (4) (*i.e.* (56) above) will form an essential part of the following sections. Let it be remarked at once, however, that the assumption reaches far beyond electrostatics, and in particular that it remains valid even for fields which vary with the time. The main point is that it gives us a general method of calculating the forces which occur in the electrostatic field. For this application, we start from the fundamental theorem that the work done by the field in any arbitrary displacement of the charges is equal to the loss of field energy." In fact these authors apply their " fundamental theorem " to deformations of the dielectrics as well as displacements of the charges and in this they are not justified.

Lorentz derives the same energy by an argument similar to the second one given for (3) above. He considers a system of conductors separated by dielectrics which need not be homogeneous nor isotropic. Assuming only that the vectors **D** and **E** are linearly related at each point of the dielectric, it is found that the work done to accumulate the charges on each conductor, gradually and proportionally, is U. So U is taken for the energy of the system. But the argument is not satisfactory, for it makes no use of a condition which is essential to the validity of the result. Using suffixes to distinguish the components of a vector, and using also the summation convention, we may write

$$D_i = K_{i\alpha} E_\alpha . \qquad \text{(61)}$$

The result is invalid unless the coefficient matrix K_{ij} is symmetric. Quite generally U is the work done when the charge is accumulated *in the manner specified*, but unless the condition of symmetry is satisfied, other ways of charging the conductors would involve different amounts of work. This of course is the reason why we assert that K_{ij} *must* be symmetric for physical reasons, *viz.* the denial of perpetual motion.

In the practically important case, when **D** and **E** are linearly related, the energy given by any of the above discussions is the same, excluding only de Donder's microscopic energy; and this peculiarity seems to have been responsible, in part, for the failure to recognize the inadequacy of them all. It is not shown, in any account, that the energy obtained is a mechanical potential energy function for the system considered. That it is commonly assumed to be so will be evident from the discussion below.

Consider next the body force acting in the dielectric or polarized medium. As has been said, the force (27) is usually neglected in the literature. It has been suggested that the body-force should be derived from Poisson's equivalent distribution; Chipart (1935). This would give a body-force

$$-\mathbf{E} \operatorname{div} \mathbf{P}, \qquad \text{(62)}$$

and corresponding surface traction

$$\mathbf{E} P_n . \qquad \text{(63)}$$

The suggestion has the merit of consistency if Poisson's distributions be really considered as equivalent to the distribution of electric moment. It may be noted that these formulae would give a total force and couple acting on the whole volume of the dielectric which is statically equivalent to that given by (27), (28) and (29).

The usual account of the body-force in dielectrics is that due to Korteweg and Helmholtz and developed by Lorberg, Kirchoff, Hertz and others. It is expounded by Abraham-Becker, Cohn, Jeans, Stratton and also in the articles by Lorentz, Gans and Pockels in the *Encyclopadie der Mathmatichen Wissenschaften.* It is included in the recent text book on theoretical physics by Weizel

(1949). This theory begins with the *assumption* that the energy as found above is a *mechanical potential energy function* for the electrical system, valid as such even when the dielectrics in the system are deformable. This assumption is of course not stated explicitly; rather, it is said, that the work done by the body-force in a deformation of the dielectrics *must*, by the physical principle of conservation of energy, equal the decrease in the energy of the system. This is a mistake. These systems are semi-conservative in the sense of §6, and they are not conservative when deformations of the dielectrics in them are allowed.

The argument is simplest in the case of a fluid dielectric. Let the medium in v_2 be subjected to an infinitesimal deformation specified by the vector **u**. Here **u** is a function of position in v_2, and we suppose for simplicity that the normal component of **u** on the boundary of v_2 is zero. The charge in v_1 is supposed to remain fixed. We suppose also that $\mathbf{D}=K\mathbf{E}$, where the dielectric constant K may vary from place to place in the fluid; and, for any particular element of the fluid, K may depend on the fluid density τ. The energy of the system is U; and so if $\mathbf{F}^{(h)}$ denote the body-force in the dielectric we have

$$\int_{v_2} \mathbf{F}^{(h)}.\,\mathbf{u}dv=-\delta U. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (64)$$

From (48) and (47)

$$\delta U=\tfrac{1}{2}\int_{v_1} \rho\delta\varphi dv=-\frac{1}{8\pi}\int_{v_2} E^2\delta K dv.$$

To calculate δK in terms of the displacement **u**, refer to rectangular coordinates OX_1, OX_2, OX_3 and suppose **u** has components u_1, u_2, u_3. If $\triangle K$ be the increment of K " following the deformation " we have

$$\triangle K=\delta K+\frac{\partial K}{\partial x_\alpha}u_\alpha,$$

$$=\frac{\partial K}{\partial \tau}\triangle\tau,$$

and

$$\triangle\tau=-\tau\frac{\partial u_\alpha}{\partial x_\alpha}.$$

The last is effectively the hydrodynamical equation of continuity. So we find

$$\delta K=-\frac{\partial K}{\partial x_\alpha}u_\alpha-\tau\frac{\partial K}{\partial \tau}\,\frac{\partial u_\alpha}{\partial x_\alpha}.$$

Thus

$$\delta U=\frac{1}{8\pi}\int_{v_2} E^2\frac{\partial K}{\partial x_\alpha}u_\alpha dv+\frac{1}{8\pi}\int_{v_2} E^2\tau\frac{\partial K}{\partial \tau}\,\frac{\partial u_\alpha}{\partial x_\alpha}dv.$$

Finally, owing to the special restriction on **u** at the boundary of f_2, Green's theorem gives

$$\int_{v_2} \frac{\partial}{\partial x_\alpha}\left(E^2\tau\frac{\partial K}{\partial \tau}u_\alpha\right)dv=0,$$

so that

$$\int_{v_2} E^2\tau\,\frac{\partial K}{\partial \tau}\,\frac{\partial u_\alpha}{\partial x_\alpha}dv=-\int_{v_2} \frac{\partial}{\partial x_\alpha}\left(E^2\tau\,\frac{\partial K}{\partial \tau}\right)u_\alpha dv.$$

Hence

$$\delta U=\frac{1}{8\pi}\int_{v_2}\left\{E^2\frac{\partial K}{\partial x_\alpha}-\frac{\partial}{\partial x_\alpha}\left(E^2\tau\frac{\partial K}{\partial\tau}\right)\right\}u_\alpha dv$$

$$=\frac{1}{8\pi}\int_{v_2}\left\{E^2\nabla K-\nabla\left(E^2\tau\frac{\partial K}{\partial\tau}\right)\right\}.\mathbf{u}dv. \quad \ldots\ldots\ldots \quad (65)$$

Comparing (64) and (65), on account of the arbitrariness of **u** inside v_2, we have

$$\mathbf{F}^{(\mathrm{h})}=-\frac{1}{8\pi}E^2\nabla K+\frac{1}{8\pi}\nabla\left(E^2\tau\frac{\partial K}{\partial\tau}\right). \quad \ldots\ldots\ldots\ldots\ldots \quad (66)$$

This is the force formula of Helmholtz which replaces (27) for fluid dielectrics. If we write $K=1+4\pi k$, $\mathbf{P}=k\mathbf{E}$, we have

$$\mathbf{F}^{(\mathrm{h})}-\mathbf{F}=\tfrac{1}{2}\nabla\left(E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right)\right), \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (67)$$

which shows that $\mathbf{F}$ and $\mathbf{F}^{(\mathrm{h})}$ are in general different.

Still another force-formula is common in the literature. Many authors ignore the variation of K with τ and take the body force to be

$$\mathbf{F}_0^{(\mathrm{h})}=-\frac{E^2}{8\pi}\nabla K. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (68)$$

This result is sometimes obtained independently of the above argument by connecting it with Maxwell's stresses in the dielectric.

10. DEFORMATION OF CONTINUOUS DISTRIBUTIONS.

After the digression of the preceding section we return to the development of the theory based on the force formulae of §7. The distribution of electric moment is non-conservative in a sense already explained (§3) and it is necessary to study the deformation of such distributions.

A deformation $\triangle$ of a continuous medium is determined when the displacement of every particle of the medium is specified. Taking a fixed rectangular system of axes, if y_1, y_2, y_3 be the coordinates of the particle which originally occupied the position x_1, x_2, x_3 then the deformation of a region is given by the three functions

$$y_i=y_i\,(x_1, x_2, x_3),\ \ i=1, 2, 3$$

defined throughout the region. If we suppose this deformation has been reached by a continuous movement from the initial to the final position then $\triangle$ will be regarded as a member of a family of deformations $\triangle(t)$ which depend continuously on a parameter t:

$$y_i=y_i\,(x_1, x_2, x_3, t),\ \ i=1, 2, 3.$$

We take $t=0$ to correspond to zero deformation. The Jacobian

$$\nu=\nu(t)=\frac{\partial(y_1, y_2, y_3)}{\partial(x_1, x_2, x_3)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (69)$$

is positive.

An infinitesimal deformation is specified by the differentials

$$u_i=\frac{\partial y_i}{\partial t}\triangle t,\ \ i=1, 2, 3. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (70)$$

We shall be concerned with infinitesimal deformations from the undeformed state; then the partial derivatives in (70) are taken for the value $t=0$, and $y_i=x_i$, and $\nu=1$.

Associated with the deformation there is an infinitesimal rotation. The strain is specified by the symmetric tensor

$$\triangle\nu_{ij}=\tfrac{1}{2}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right), \qquad \text{(71)}$$

and the rotation by the anti-symmetric tensor

$$\theta_{ij}=\tfrac{1}{2}\left(\frac{\partial u_j}{\partial x_i}-\frac{\partial u_i}{\partial x_j}\right). \qquad \text{(72)}$$

In vector notation, with the axes OX_1, OX_2, OX_3 supposed to be right-handed, we represent the rotation by

$$\Theta=\tfrac{1}{2}\operatorname{curl}\mathbf{u}, \qquad \text{(73)}$$

where $\mathbf{u}$ has components u_i, Θ has components θ_i, and $\theta_1=\theta_{23}=-\theta_{32}$, etc.

Let φ be a function of position in the medium and suppose that φ depends also on the deformation, *i.e.* on t. Denote by $\delta\varphi$ the differential of φ at a fixed point in space and by $\triangle\varphi$ the differential of φ " following the displacement ". Then

$$\delta\varphi=-\frac{\partial\varphi}{\partial x_\alpha}u_\alpha+\triangle\varphi. \qquad \text{(74)}$$

For a vector function $\mathbf{E}$ let $\triangle\mathbf{E}$ denote its differential " following the displacement " and referred to axes which *partake of the infinitesimal rotation* Θ. Then applying (74) to each of the components of $\mathbf{E}$ and allowing for the rotation, we find

$$\delta\mathbf{E}=-\frac{\partial\mathbf{E}}{\partial x_\alpha}u_\alpha+\Theta\times\mathbf{E}+\triangle\mathbf{E}. \qquad \text{(75)}$$

Consider now a distribution of a " quantity " Q throughout a deformable medium. Let P be the density of the distribution and let p be the " density " reckoned *per unit volume of the undeformed state.* Then

$$p=\nu P.$$

For $t=0$, $\nu=1$, $p=P$, and

$$\triangle\nu=\frac{\partial u_\alpha}{\partial x_\alpha}. \qquad \text{(76)}$$

So

$$\triangle p=\triangle P+P\triangle\nu=\triangle P+P\frac{\partial u_\alpha}{\partial x_\alpha}.$$

From (74),

$$\delta P=-\frac{\partial P}{\partial x_\alpha}u_\alpha+\triangle P.$$

Hence

$$\begin{aligned}\delta P&=-\frac{\partial P}{\partial x_\alpha}u_\alpha-P\frac{\partial u_\alpha}{\partial x_\alpha}+\triangle p\\&=-\frac{\partial}{\partial x_\alpha}(Pu_\alpha)+\triangle p. \qquad \text{(77)}\end{aligned}$$

For the density **P** of distribution of a vector quantity, denote by $\triangle\mathbf{p}$ a differential referred to axes which partake of the rotation Θ. Then, corresponding to (77),

$$\delta\mathbf{P}=-\frac{\partial}{\partial x_\alpha}(\mathbf{P}u_\alpha)+\Theta\times\mathbf{P}+\triangle\mathbf{p}. \qquad (78)$$

For the density ρ of a conservative quantity (77) gives

$$\delta\rho=-\frac{\partial}{\partial x_\alpha}(\rho u_\alpha), \qquad (79)$$

which is again the hydrodynamical equation of continuity.

11. The General Work Formula.

Consider again an electrical system consisting of a continuous charge distribution with density ρ in v_1, and a continuous moment distribution with density **P** in v_2. In the case of the non-conservative moment distribution it is useful to think of the electric moment as " attached " to a medium ; in fact the formulae of §10 apply to this situation. The force and couple acting in the moment distribution are supposed then to be *transferred to this* medium. In the application the medium will be the material substance of a dielectric body regarded as continuous. For the conservative charge distribution the notion of such a " medium of reference " is unnecessary ; or we may say that the medium is the " continuous electricity " itself.

A variation of the electrical system consists of moving the charge in v_1 and deforming the reference medium in v_2. At the same time the electric moment associated with the parts of the medium may alter. An infinitesimal variation would be specified by defining the displacement vector **u** in v_1 and v_2 and by defining $\triangle\mathbf{p}$ throughout v_2. At the same time the medium in v_2 experiences the infinitesimal rotation Θ. The work done by the forces and couples acting on the parts of the system is

$$\triangle W=\int_{v_1}\mathbf{F}\,.\,\mathbf{u}dv+\int_{v_2}\mathbf{F}\,.\,\mathbf{u}dv+\int_{v_2}\mathbf{G}\,.\,\Theta dv+\int_{f_2}\mathbf{T}.\ \mathbf{u}df, \qquad (80)$$

where **F**, **F**, **G** and **T** are given by (25), (27), (28) and (29).

This work may be transformed as follows. If n_1 be the direction cosines of the outward normal to f_1 or f_2 as the case may be, we have, using Green's theorem,

$$\int_{v_1}\mathbf{F}\,.\,\mathbf{u}dv=\int_{v_1}\rho\mathbf{E}\,.\,\mathbf{u}dv=-\int_{v_1}\rho\frac{\partial\varphi}{\partial x_\alpha}u_\alpha dv$$

$$=-\int_{v_1}\frac{\partial}{\partial x_\alpha}(\rho\varphi u_\alpha)dv+\int_{v_1}\varphi\frac{\partial}{\partial x_\alpha}(\rho u_\alpha)dv$$

$$=-\int_{f_1}\rho\varphi n_\alpha u_\alpha df-\int_{v_1}\varphi\delta\rho dv,$$

by (79).

$$\int_{v_2}\mathbf{F}\,.\,\mathbf{u}dv=\int_{v_2}((\mathbf{P}\,.\,\nabla)\mathbf{E})\,.\,\mathbf{u}dv=\int_{v_2}P_\beta\frac{\partial E_\alpha}{\partial x_\beta}u_\alpha dv=\int_{v_2}P_\beta\frac{\partial E_\beta}{\partial x_\alpha}u_\alpha dv$$

$$=\int_{v_2}\mathbf{P}\,.\,\frac{\partial\mathbf{E}}{\partial x_\alpha}u_\alpha dv=\int_{v_2}\frac{\partial}{\partial x_\alpha}(\mathbf{P}\,.\,\mathbf{E}u_\alpha)dv-\int_{v_2}\mathbf{E}\,.\,\frac{\partial}{\partial x_\alpha}(\mathbf{P}u_\alpha)dv$$

$$=\int_{f_2}\mathbf{P}\,.\,\mathbf{E}_{-}\,n_\alpha u_\alpha df+\int_{v_2}\mathbf{E}\,.\,\delta\mathbf{P}dv-\int_{v_2}\mathbf{E}.\ \triangle\mathbf{p}dv-\int_{v_2}\mathbf{E}\,.\,\Theta\times\mathbf{P}dv,$$

by (78).

$$\int_{v_2} \mathbf{G}\,.\,\Theta dv = \int_{v} \mathbf{P}\times\mathbf{E}\,.\,\Theta dv = \int_{v_2} \mathbf{E}\,.\,\Theta\times\mathbf{P} dv,$$

and

$$\int_{f_2} \mathbf{T}\,.\,\mathbf{u} df = \tfrac{1}{2}\int_{f_2} \mathbf{P}\,.\,(\mathbf{E}_+-\mathbf{E}_-)\mathbf{n}\,.\,\mathbf{u} df = \tfrac{1}{2}\int_{f_2} \mathbf{P}\,.\,(\mathbf{E}_+-\mathbf{E}_-)n_\alpha u_\alpha df.$$

Also from (49)

$$\triangle V = \tfrac{1}{2}\int_{v_1} (\rho\delta\varphi+\varphi\delta\rho)dv + \tfrac{1}{2}\int_{f_1} \rho\varphi n_\alpha u_\alpha df$$
$$-\tfrac{1}{2}\int_{v_2} (\mathbf{P}\,.\,\delta\mathbf{E}+\mathbf{E}\,.\,\delta\mathbf{P})dv - \tfrac{1}{2}\int_{f_2} \mathbf{P}\,.\,\mathbf{E}_- n_\alpha u_\alpha df.$$

Hence, from (80),

$$\triangle W + \triangle V + \int_{v_2} \mathbf{E}\,.\,\triangle\mathbf{p} dv = \tfrac{1}{2}\int_{v_1} (\rho\delta\varphi-\varphi\delta\rho)dv - \tfrac{1}{2}\int_{f_1} \rho\varphi n_\alpha u_\alpha df$$
$$-\tfrac{1}{2}\int_{v_2} (\mathbf{P}\,.\,\delta\mathbf{E}-\mathbf{E}\,.\,\delta\mathbf{P})dv + \tfrac{1}{2}\int_{f_2} \mathbf{P}\,.\,\mathbf{E}_+ n_\alpha u_\alpha df.$$

Now the right member of this equation is zero. This follows from (45) if the deformation is such that the boundaries f_1 and f_2 remain unmoved. It follows generally from the extended form of (45) which I have given elsewhere (Smith-White, 1949).

Thus

$$\triangle W = -\triangle V - \int_{v_2} \mathbf{E}\,.\,\triangle\mathbf{p} dv. \qquad \dots\dots\dots\dots \quad (81)$$

This is the general work formula, the analogue, for continuous distributions, of the formula (18) for discrete systems.

From (48), (49), (75), (78),

$$\triangle V = \triangle U - \tfrac{1}{2}\int_{v_2} (\mathbf{P}\,.\,\delta\mathbf{E}+\mathbf{E}\,.\,\delta\mathbf{P})dv - \tfrac{1}{2}\int_{f_2} \mathbf{P}\,.\,\mathbf{E}_- n_\alpha u_\alpha df$$
$$= \triangle U + \tfrac{1}{2}\int_{v_2} \frac{\partial}{\partial x_\alpha}(\mathbf{P}\,.\,\mathbf{E}u_\alpha)dv - \tfrac{1}{2}\int_{f_2} \mathbf{P}\,.\,\mathbf{E}_- n_\alpha u_\alpha df$$
$$-\tfrac{1}{2}\int_{v_2} (\mathbf{p}\,.\,\triangle\mathbf{E}+\mathbf{E}\,.\,\triangle\mathbf{p})dv$$
$$= \triangle U - \tfrac{1}{2}\int_{v_2} (\mathbf{p}\,.\,\triangle\mathbf{E}+\mathbf{E}\,.\,\triangle\mathbf{p})dv,$$

since $\mathbf{P}=\mathbf{p}$ in the initial state. So we find

$$\triangle W = -\triangle U + \tfrac{1}{2}\int_{v_2} (\mathbf{p}\,.\,\triangle\mathbf{E}-\mathbf{E}\,.\,\triangle\mathbf{p})dv, \qquad \dots\dots\dots \quad (82)$$

which corresponds to (20).

12. THE THEORY OF DIELECTRICS.

The considerations presented so far may be regarded as a purely analytical theory of continuous electrical distributions of charge and moment, based on the formulae for the mechanical effects given in §7. Now, by means of the physical hypothesis of Poisson and Kelvin, as we interpret it, and the physical assumption that **P** is determined by **E**, we make this analytical theory into a mathematical theory of the physical behaviour of dielectrics. The way in which **E** determines **P** at any point in the dielectric depends on the physical state of the substance at that point, including the condition of strain in the substance reckoned from some standard configuration.

In the simplest circumstances we may suppose

$$\mathbf{P}=k\mathbf{E}.$$

If the substance of the dielectric is not homogeneous then k varies from place to place in it. If the substance be deformable the value of k for a particular element of the material may depend on its deformation from some standard state. A simple assumption, appropriate to the case of a liquid dielectric, is to suppose that k depends on the density τ only.

Then

$$\mathbf{p}=\nu\mathbf{P}=\nu k\mathbf{E},$$

and we find, for an infinitesimal deformation specified by the vector $\mathbf{u}$,

$$\mathbf{p}\,.\,\triangle\mathbf{E}-\mathbf{E}\,.\,\triangle\mathbf{p}=E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right)\frac{\partial u_\alpha}{\partial x_\alpha}.$$

Formula (82) becomes

$$\triangle W=-\triangle U+\tfrac{1}{2}\int_{v_2}E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right)\frac{\partial u_\alpha}{\partial x_\alpha}dv.$$

If, everywhere in the dielectric, $k\propto\tau$, then $\triangle W=-\triangle U$. In this case the system is mechanically conservative and U is its potential energy function. In general, however, the system is only semi-conservative; if the dielectric is held rigid, $\triangle W=-\triangle U$, and the function U is again the potential energy function.

The recognition of such non-conservative systems is a new feature in electrostatics. To make such systems acceptable from the physical point of view we must show how to fit them into a wider physical scheme in which physical energy is conserved. This offers no difficulty any more than it does in ordinary mechanics, where we are quite familiar with the fact that real mechanical systems are never completely conservative, but are always, to a greater or less degree, dissipative.

In a system which is not mechanically conservative there will exist cyclic processes in which the work done by the forces acting in the system is not zero. We assert simply that such a non-conservative cycle of operations in our dielectric system is irreversible; the cycle can be performed only in that way which dissipates mechanical energy. In the next section we consider the physical conservation of energy; and then it appears that the irreversibility asserted above is a formal consequence of the second law of thermodynamics.

Consider the case in which **P** is uniquely determined by **E** and in which the dielectric body is held rigid. In this case the only variation in the system is a movement of the influencing charge. All cycles in the system are reversible. Formula (81) gives

$$\triangle W=-\triangle V-\int_{v_2}\mathbf{E}\,.\,\delta\mathbf{P}dv, \qquad \ldots\ldots\ldots \quad (83)$$

and the denial of perpetual motion now requires that in any cycle

$$\int_{v_2} dv \oint \mathbf{E} \, . \, \delta \mathbf{P} = 0.$$

This result may be applied to any volume element of the dielectric and so we must suppose that at each point of the dielectric $\mathbf{E} \, . \, \delta \mathbf{P}$ is a perfect differential. From (52)

$$\triangle V = \frac{1}{4\pi} \int_s \mathbf{E} \, . \, \delta \mathbf{E} dv,$$

and combining this with (83)

$$\triangle W = -\frac{1}{4\pi} \int_s \mathbf{E} \, . \, \delta \mathbf{D} dv.$$

Now, also, $\mathbf{E} \, . \, \delta \mathbf{D}$ is a perfect differential, and the system is mechanically conservative with the energy function (59). This justifies one common formula for the " energy " as a mechanical potential energy function *providing the dielectrics are held rigid.* The system is really semi-conservative in the nomenclature we have used before.

In particular, if the relation between **D** and **E** is linear, and represented by (61), the condition that $\mathbf{E} \, . \, \delta \mathbf{D}$ be a perfect differential requires that $K_{ij} = K_{ji}$, and then $\mathbf{E} \, . \, \delta \mathbf{D} = \frac{1}{2} \delta (\mathbf{D} \, . \, \mathbf{E})$. The energy function of the semi-conservative system is then

$$\frac{1}{8\pi} \int_s \mathbf{D} \, . \, \mathbf{E} dv = U,$$

by (50). Jeans (1927) reverses the above argument; he makes the proof that K_{ij} is symmetric depend upon the assumption that the energy density is $\frac{1}{8\pi} \mathbf{D} \, . \, \mathbf{E}$.

13. THE CONSERVATION OF ENERGY.

Consider a piece of dielectric substance in volume v_2 under the electric influence of a charge distribution in volume v_1, and held in equilibrium by suitable " pressures " applied to its boundary f_2. On the element df of f_2 acts the external force Πdf. Inside the dielectric the mechanical force and couple of electrical origin, *i.e.* **F** and **G** given by formulae (27) and (28), must be balanced by the mechanical stress in the substance. The statical conditions for this internal equilibrium are written most concisely in tensor notation. Let F_i, G_i be the components of **F**, **G** in directions OX_i, and if the axes OX_1, OX_2, OX_3 be right-handed, write $G_1 = G_{23} = -G_{32}$, etc. Then the couple **G** is represented by the anti-symmetric tensor G_{ij}. Let s_{ij} be the mechanical stress tensor specified, at any point A in the dielectric, thus : Draw at A a plane perpendicular to OX_i, then s_{ij} is the component, in the direction OX_j, of the force per unit area acting on the matter on the negative side of this plane, due to the matter on the positive side of it. The equilibrium equations are

$$\frac{\partial s_{\alpha i}}{\partial x_\alpha} + F_i = 0, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (84)$$

$$s_{ij} - s_{ji} + G_{ij} = 0. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (85)$$

On the boundary f_2 there act the force **T** given by (29), the external force Π mentioned above, and a force due to the mechanical stress inside v_2. If T_i, Π_i

are the components of **T**, Π and if n_i are the direction cosines of a normal to f_2, outward from v_2, the conditions of equilibrium of an element df of f_2 give

$$-n_{\alpha}s_{\alpha i}+T_i+\Pi_i=0. \qquad \dots\dots\dots\dots \quad (86)$$

With regard to the charge distribution in v_1, its sole purpose now is to provide the source of the electrical influence on the dielectric. We are not concerned to examine the internal equilibrium of the charge distribution in the way analogous to that for the dielectric. It is sufficient to suppose that the charge is maintained in position by some " external agency " which provides a force, on each volume element dv of the charge, just sufficient to balance the force **F**dv given by (25).

For the electrical energy of the system we take the quantity

$$V=\frac{1}{8\pi}\int_s E^2dv. \qquad \dots\dots\dots\dots \quad (87)$$

This is *not* now a mechanical potential energy function, but is energy in a physical sense. Only in a special case is V a mechanical potential energy function. This choice for the energy of an electrical system amounts to a definite physical assumption ; and it is justified by its consequences. There is no other obvious choice for the electrical energy of a system. It may be noted that this energy is the energy of de Donder from a microscopic point of view.

We may now formulate the physical equation of energy, expressing the first law of thermodynamics, in a variation of the physical system consisting of a dielectric under the influence of electric charge. We suppose that the variation consists of a movement of the charge, a deformation of the dielectric, and an absorption or emission of heat by the dielectric substance. An infinitesimal variation is specified by the displacement vector **u** defined in v_1 and v_2. If $\triangle Q$ be the heat absorbed by the dielectric, this is accounted for by

(i) an increase $\triangle I$ of the " internal energy " of the dielectric,

(ii) an increase $\triangle V$ of the electrical energy of the system,

(iii) the work

$$\int_{v_1}\mathbf{F}\,.\,\mathbf{u}dv$$

done against the external agency holding the charge,

(iv) the work

$$-\int_{f_2}\Pi\,.\,\mathbf{u}df$$

done against the external forces holding the dielectric boundary.

So

$$\triangle Q=\triangle I+\triangle V+\int_{v_1}\mathbf{F}\,.\,\mathbf{u}dv-\int_{f_2}\Pi\,.\,\mathbf{u}df. \qquad \dots\dots \quad (88)$$

Now set

$$\tilde{\omega}_{ij}=\tfrac{1}{2}(s_{ij}+s_{ji}), \qquad \dots\dots\dots\dots \quad (89)$$

$$a_{ij}=\tfrac{1}{2}(s_{ij}-s_{ji})\ ; \qquad \dots\dots\dots\dots \quad (90)$$

so that $\tilde{\omega}_{ij}$, a_{ij} are the symmetric and anti-symmetric parts of the mechanical stress tensor. Then by (71), (72), and (85)

$$s_{\alpha\beta}\frac{\partial u_{\beta}}{\partial x_{\alpha}}=(\tilde{\omega}_{\alpha\beta}+a_{\alpha\beta})(\triangle\nu_{\alpha\beta}+\theta_{\alpha\beta})=\tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}+a_{\alpha\beta}\theta_{\alpha\beta}$$

$$=\tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}-G_{\beta}\theta_{\beta}.$$

From (86), using Green's theorem, and (84)

$$-\int_{f_2} \mathbf{\Pi}\,.\,\mathbf{u}df=\int_{f_2} T_\beta u_\beta df-\int_{f_2} n_\alpha s_{\alpha\beta}u_\beta df$$

$$=\int_{f_2} T_\beta u_\beta df-\int_{v_2} \frac{\partial}{\partial x_\alpha}(s_{\alpha\beta}u_\beta)dv$$

$$=\int_{f_2} T_\beta u_\beta df-\int_{v_2} \frac{\partial s_{\alpha\beta}}{\partial x_\alpha}u_\beta dv-\int_{v_2} s_{\alpha\beta}\frac{\partial u_\beta}{\partial x_\alpha}dv$$

$$=\int_{f_2} T_\beta u_\beta df+\int_{v_2} F_\beta u_\beta dv+\int_{v_2} G_\beta \theta_\beta dv-\int_{v_2} \tilde{\omega}_{\varkappa\beta}\triangle\nu_{\alpha\beta}dv$$

$$=\int_{f_2} \mathbf{T}\,.\,\mathbf{u}df+\int_{v_2} \mathbf{F}\,.\,\mathbf{u}dv+\int_{v_2} \mathbf{G}\,.\,\Theta dv-\int_{v_2} \tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}dv.$$

Hence, from (80) and (88),

$$\triangle Q=\triangle I+\triangle V+\triangle W-\int_{v_2} \tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}dv$$

$$=\triangle I-\int_{v_2} \tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}dv-\int_{v_2} \mathbf{E}\,.\,\triangle\mathbf{p}dv, \quad \ldots\ldots \quad (91)$$

by (81). This result applies to any piece of dielectric substance whatever its dimensions. We infer the elementary relation

$$\triangle q=\triangle i-\tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}-\mathbf{E}\,.\,\triangle\mathbf{p}, \quad \ldots\ldots\ldots\ldots \quad (92)$$

where i is the internal energy per unit volume, and $\triangle q$ is the heat adsorbed per unit volume at any place in the dielectric.

In a fluid $\tilde{\omega}_{ij}=-\tilde{\omega}\delta_{ij}$, where $\tilde{\omega}$ is the hydrostatic pressure, and $\delta_{ij}=1$ or 0 as $i=j$ or $i\neq j$.

Then

$$\tilde{\omega}_{\alpha\beta}\triangle\nu_{\alpha\beta}=-\tilde{\omega}\delta_{\alpha\beta}\triangle\nu_{\alpha\beta}=-\tilde{\omega}\triangle\nu_{\alpha\alpha}=-\tilde{\omega}\triangle\nu$$

by (71) and (76). So (92) becomes

$$\triangle q=\triangle i+\tilde{\omega}\triangle\nu-\mathbf{E}\,.\,\triangle\mathbf{p}. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (93)$$

Here $\triangle\nu$ is the differential of a variable ν determined by the state of the fluid; whereas in (92) the $\triangle\nu_{ij}$ are not differentials of such variables of state.

Consider finally a dielectric held rigid but in which **P** is not uniquely determined by **E**. For a variation of the influencing charge we now write (81) and (91)

$$\delta W=-\delta V-\int_{v_2} \mathbf{E}\,.\,\delta\mathbf{P}dv,$$

and

$$\delta Q=\delta I-\int_{v_2} \mathbf{E}\,.\,\delta\mathbf{P}dv.$$

Integrating over a cycle in which the influencing charge returns to its initial position and the dielectric returns to its original state, we have

$$Q=W=-\int_{v_2} dv\oint\mathbf{E}\,.\,\delta\mathbf{P}.$$

In this cycle heat Q is absorbed by the dielectric and an equal amount of work W is done by the mechanical forces acting on the influencing charge. The second law of thermodynamics requires that in any such physically possible cycle Q and W should both be negative. We infer that for any physically possible cycle

$$\oint \mathbf{E} \,.\, \delta\mathbf{P} \geqq 0$$

at each place in the dielectric; and the left member is the heat generated per unit volume in such a cycle.

14. Electrostatic Stress.

The notion that all electric action between charged bodies is transmitted by and through the dielectric, or intervening medium between them, is due to Faraday. Following him, Maxwell showed how to represent this action analytically by an appropriate system of stresses. At first the idea was that Maxwell's stresses should be interpreted as real physical stresses in the medium, and attempts were made to assign physical properties to the medium so that these stresses might be considered to be induced by the electric " displacement " **D** in much the same way as ordinary elastic stresses in material bodies are induced by deformation of the substance of the bodies. This view has been abandoned, but unfortunately Maxwell's stresses are often still described as the " stresses *in the medium* " or as the " *dielectric stresses* ". These descriptions, being based on notions now rejected, are misleading. The electrostatic stress tensor merely provides an alternative and analytically equivalent way of describing the mechanical action on electrified bodies which is described otherwise by the body force (27) and the body couple (28). The analytical situation is quite analogous to the use of a scalar potential φ to describe a vector field **E**. In order to emphasize the purely formal aspect of the matter we develop the analytical relations, at first, independently of the application.

Given a second order tensor s_{ij}, write

$$F_i = \frac{\partial s_{\alpha i}}{\partial x_\alpha}, \quad G_{ij} = s_{ij} - s_{ji}. \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (94)$$

Let δ_{ijk} be the third order tensor for positive orthogonal transformations, defined by

$$\delta_{ijk} = \begin{cases} 0, \text{ if } i, j, k \text{ are not all different,} \\ 1, \text{ if } i, j, k \text{ is an even permutation of } 1, 2, 3 \\ -1, \text{ if } i, j, k \text{ is an odd permutation of } 1, 2, 3. \end{cases}$$

Then the F_i are components of a vector **F**; and $G_i = \frac{1}{2}\delta_{i\alpha\beta}G_{\alpha\beta}$ are components of a vector **G**. Using a " mechanical " terminology we call s_{ij} a *stress* tensor and the ordered vector pair **F**, **G** the *mechanical field* of the stress s_{ij}. We call **F** the body force and **G** the body couple belonging to this stress. The representation of such a mechanical field by its stress tensor is analogous to the representation of an irrotational vector field by its scalar potential.

Consider a direction at a point A specified by the direction cosines n_i. The vector

$$T_i = n_\alpha s_{\alpha i}$$

may be called the *traction* of the stress s_{ij} at A in the direction n_i. Then we have the following " mechanical " theorem. If **F**, **G** is any mechanical field derived from the stress s_{ij}, then the *total mechanical action* of the field on any volume v is statically equivalent to the *total traction* of the stress over its boundary f.

Thus, the mechanical *force* acting on v has components

$$\int_v F_i dv = \int_v \frac{\partial s_{\alpha i}}{\partial x_\alpha} dv = \int_f n_\alpha s_{\alpha i} df = \int_f T_i df\,;$$

i.e. the total force acting on v is equal to the total traction of the stress on f. Also, the *moment with respect to the origin* has components

$$\begin{aligned}\int_v (x_i F_j - x_j F_i + G_{ij}) dv &= \int_v \left(x_i \frac{\partial s_{\alpha j}}{\partial x_\alpha} - x_j \frac{\partial s_{\alpha i}}{\partial x_\alpha} + G_{ij} \right) dv \\ &= \int_v \left\{ \frac{\partial}{\partial x_\alpha}(x_i s_{\alpha j} - x_j s_{\alpha i}) + s_{ji} - s_{ij} + G_{ij} \right\} dv \\ &= \int_f n_\alpha (x_i s_{\alpha j} - x_j s_{\alpha i}) df = \int_f (x_i T_j - x_j T_i) df,\end{aligned}$$

and the last member represents the components of the moment about the origin of the traction of the stress on f. These two formulae establish the statical equivalence stated above. It may be remarked that the stresses usually considered in, say, the theory of elasticity, are always supposed to be symmetric so that the above simple general theorem has scarcely been noticed.

Consider now a dielectric under the influence of electric charge. Up till now we have supposed the electric charge and the dielectric to occupy different volumes v_1 and v_2; *i.e.* we have supposed the dielectric to be uncharged. But we may contemplate a charged dielectric. The whole discussion remains unaltered if we suppose that, in variations of the system, the charge may move through the dielectric independently of the deformation of the latter. But, in the charged dielectric, we now suppose the body force (25) transferred to the material substance of the dielectric. Then the complete expression for the body force is

$$\mathbf{F} = \rho \mathbf{E} + (\mathbf{P} \cdot \nabla)\mathbf{E}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (95)$$

and the body couple is

$$\mathbf{G} = \mathbf{P} \times \mathbf{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (96)$$

as before.

The expressions (95) and (96) define a mechanical field which may be specified by a suitable stress tensor by means of relations (94). Thus, since now div $\mathbf{D} = 4\pi\rho$, we have

$$\begin{aligned}F_i &= \frac{E_i}{4\pi}\frac{\partial D_\alpha}{\partial x_\alpha} + P_\alpha \frac{\partial E_i}{\partial x_\alpha} \\ &= \frac{E_i}{4\pi}\frac{\partial D_\alpha}{\partial x_\alpha} + \frac{D_\alpha - E_\alpha}{4\pi}\frac{\partial E_i}{\partial x_\alpha} \\ &= \frac{1}{4\pi}\frac{\partial}{\partial x_\alpha}(D_\alpha E_i) - \frac{E_\alpha}{4\pi}\frac{\partial E_\alpha}{\partial x_i} \\ &= \frac{1}{4\pi}\frac{\partial}{\partial x_\alpha}(D_\alpha E_i) - \frac{1}{4\pi}\frac{\partial}{\partial x_i}(\tfrac{1}{2}E^2) \\ &= \frac{\partial}{\partial x_\alpha}\left(\frac{D_\alpha E_i - \frac{1}{2}E^2 \delta_{\alpha i}}{4\pi}\right) = \frac{\partial s_{\alpha i}}{\partial x_\alpha}\end{aligned}$$

where

$$s_{ij}=(D_iE_j-\tfrac{1}{2}E^2\delta_{ij})/4\pi \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (97)$$

Then also we find

$$s_{ij}-s_{ji}=(D_iE_j-D_jE_i)/4\pi=P_iE_j-P_jE_i=G_{ij},$$

where G_{ij} is the antisymmetric tensor which corresponds to the vector **G** in (96). Thus the mechanical field **F**, **G**, representing the mechanical action on the dielectric, may be derived from the stress (97), which we call the *electrostatic stress.* It is Maxwell's stress as given by Livens (1926).

For the case in which $\mathbf{D}=K\mathbf{E}$ the stress (97) is

$$s_{ij}=(KE_iE_j-\tfrac{1}{2}E^2\delta_{ij})/4\pi. \quad\ldots\ldots\ldots\ldots\ldots\ldots\quad (98)$$

In the literature the discussion is usually restricted to this case; and instead of (98) the electrostatic stress is found to be either

$$M_{ij}^{(0)}=K(E_iE_j-\tfrac{1}{2}E^2\delta_{ij})/4\pi, \quad\ldots\ldots\ldots\ldots\quad (99)$$

which corresponds to the body force

$$\mathbf{F}_0^{(h)}=\rho\mathbf{E}-\frac{E^2}{8\pi}\nabla K, \quad\ldots\ldots\ldots\ldots\ldots\ldots\quad (100)$$

or

$$M_{ij}=K(E_iE_j-\tfrac{1}{2}E^2\delta_{ij})/4\pi+\frac{1}{8\pi}E^2\tau\frac{\partial K}{\partial\tau}\delta_{ij}, \quad\ldots\ldots\ldots\ldots\quad (101)$$

which corresponds to the body force

$$\mathbf{F}^{(h)}=\rho\mathbf{E}-\frac{E^2}{8\pi}\nabla K+\frac{1}{8\pi}\nabla\left(E^2\tau\frac{\partial K}{\partial\tau}\right). \quad\ldots\ldots\ldots\ldots\quad (102)$$

Consider a fluid dielectric in equilibrium in an electric field. Then the mechanical forces of electric origin acting on the fluid must be balanced by the hydrostatic pressure $\tilde{\omega}$ developed in the fluid; if the electrostatic field be gradually established in the fluid and if equilibrium be maintained throughout the process, the fluid will be deformed so as to generate the pressure required to compensate the above mechanical forces. For the uncharged isotropic dielectric in which $\mathbf{P}=k\mathbf{E}$ we have, from (27)

$$\nabla\tilde{\omega}=\tfrac{1}{2}k\nabla E^2, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (103)$$

or, on the usual theory, from (66)

$$\nabla\tilde{\omega}^{(h)}=-\tfrac{1}{2}E^2\nabla k+\tfrac{1}{2}\nabla\left(E^2\tau\frac{\partial k}{\partial\tau}\right). \quad\ldots\ldots\ldots\ldots\quad (104)$$

In these formulae k and τ refer to the actual deformed state of the dielectric in the existing field.

For a fluid which is originally homogeneous and in which k and τ are functions of the pressure only, the equations (103) and (104) may be integrated, giving

$$\int\frac{d\tilde{\omega}}{k}=\tfrac{1}{2}E^2,$$

and

$$\int\frac{d\tilde{\omega}^{(h)}}{\tau}=\tfrac{1}{2}E^2\frac{\partial k}{\partial\tau},$$

respectively. If, in addition, the fluid be effectively incompressible, we have

$$\tilde{\omega}=\tfrac{1}{2}kE^2+\tilde{\omega}_0, \qquad (105)$$

and

$$\tilde{\omega}^{(h)}=\tfrac{1}{2}E^2\tau\frac{\partial k}{\partial \tau}+\tilde{\omega}_0. \qquad (106)$$

Thus

$$\tilde{\omega}^{(h)}-\tilde{\omega}=\tfrac{1}{2}E^2\tau^2\frac{\partial}{\partial\tau}\left(\frac{k}{\tau}\right).$$

If k is not proportional to τ the two theories give *different values for the pressure in the dielectric.*

Suppose we have a solid body immersed in a homogeneous fluid, the system being held in equilibrium by a suitable constraining force and couple applied to the body. The fluid develops the pressure $\tilde{\omega}$. The force exerted directly by the electric field on the body has components

$$\int_f n_\alpha s_{\alpha i}df$$

where s_{ij} is the tensor (98) and the integration is over the surface of the body. The reaction of the pressure in the fluid has components

$$\int_f \tilde{\omega}n_i df=\int_f \tilde{\omega}\delta_{\alpha i}n_\alpha df.$$

Hence the resultant force acting on the body, which must be balanced by the constraint, has components

$$\int_f (s_{\alpha i}-\tilde{\omega}\delta_{\alpha i})n_\alpha df. \qquad (107)$$

On the usual theory this force has components

$$\int_f (M_{\alpha i}-\tilde{\omega}^{(h)}\delta_{\alpha i})n_\alpha df. \qquad (108)$$

Now from (98) and (105) or from (101) and (106)

$$s_{ij}-\tilde{\omega}\delta_{ij}=M^{(0)}_{ij}-\tilde{\omega}_0\delta_{ij},$$

$$M_{ij}-\tilde{\omega}^{(h)}\delta_{ij}=M^{(0)}_{ij}-\tilde{\omega}_0\delta_{ij},$$

so that (107) and (108) reduce to the same expression

$$\int_f M^{(0)}_{\alpha i}n_\alpha df. \qquad (109)$$

Thus the two theories give the same nett force acting on the solid. In a homogeneous fluid the stress $M^{(0)}_{ij}$ is self-equilibrating, *i.e.* it corresponds to no body force. Then the integral (109) may be taken over any surface f in the fluid which encloses the body.

From (99) the force components (109) are those of the vector

$$\frac{K}{4\pi}\int_f (\mathbf{E}(\mathbf{E}\,.\,\mathbf{n})-\tfrac{1}{2}E^2\mathbf{n})df \qquad (110)$$

where $\mathbf{n}$ is the unit outward normal on f. This is the usual expression for the force acting on a body immersed in a fluid.

Finally, if we suppose that the coordinate axis OX_1 coincides with the direction of the electric force vector we see that the principal components of $M^{(0)}_{ij}$ are $\frac{KE^2}{8\pi}$, $-\frac{KE^2}{8\pi}$, $-\frac{KE^2}{8\pi}$, and so this stress may be described as a tension along the lines of force of amount $\frac{KE^2}{8\pi}$ together with an equal lateral compression. This is Faraday's description of the mechanical action of an electric field; but we see that it gives the nett force acting on the body which is the resultant of that due directly to its electrification and the reaction of the pressure induced in the surrounding fluid. In consequence this description has no fundamental physical significance.

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THE CHEMISTRY OF OSMIUM.

PART VIII. THE PREPARATION OF SOME HEXAMMINE OSMIUM III SALTS.

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Manuscript received, August 2, 1951. Read, September 5, 1951.

It was shown previously (F. P. Dwyer and J. W. Hogarth, 1951) that when ammonium bromosmate IV was heated at 285° C. in an autoclave under two atmospheres of ammonia, bromopentammine osmium III bromide could be extracted from the residue of the reaction. It has now been found that hexammine osmium III bromide is also formed in the reaction but, being much more soluble in water, is eliminated during the purification of the former substance. By the use of a test tube to contain the ammonium bromosmate instead of small platinum boats, using a higher pressure of ammonia and allowing the autoclave to cool slowly, approximately 50% yields of the hexammine compound could be obtained. The hexammine bromide could be isolated from the reaction residue by extraction with cold water, when most of the pentammine compound remained insoluble, followed by repeated crystallization of the almost white precipitate thrown out by the alcohol from the aqueous extract. A better procedure depended on the very sparing solubility of hexammine osmium III iodide sulphate $[Os(NH_3)_6]I.SO_4$, which separated as white micro-cubes on the addition of sodium iodide and ammonium sulphate to the aqueous extract of the reaction residue. The iodide sulphate was transformed to the iodide $[Os(NH_3)_6]I_3$ by treatment with barium chloride, to eliminate the sulphate ion, followed by the addition of excess sodium iodide, when yellow cubes separated. Other salts were made by double decomposition from the iodide. These were colourless or white unless the anion was coloured and much more soluble in water than the pentammine salts. The complex cation showed a very notable tendency to crystallize with mixed anions such as bromide-iodide, bromide sulphate, bromide bromosmate, etc. This behaviour recalls that of the hexammine cobalt III cation. The salts reduced silver nitrate to the metal on warming. One molecule of ammonia was easily lost when heated above 100° C. in the dry state or boiled with water. The pyrolysis of these substances is being investigated.

The free base could not be obtained from the hexammine iodide solution and silver oxide. The silver oxide was partly reduced to the metal, whilst the dark coloured solution failed to reprecipitate the iodide after treatment with acid and potassium bromide. The hexammine could not be detected in the residue from heating ammonium hexachlorosmate IV and ammonia—the only product being the yellow substance dichloro-octammine-μ-μnitrilo-diosmium trichloride described previously.

EXPERIMENTAL.

Hexammine Osmium III Iodide Sulphate.

Ammonium bromosmate (2·0 g.) was placed in a test tube of 7 ml. capacity (4 cm. × 1·5 cm.), placed in the centre of the autoclave described previously. The air was displaced with ammonia gas and the full pressure of the cylinder (90–100 lb./sq. in.) applied for one hour. The pressure was then reduced to 40 lb./sq. in. (2½ atmospheres) and the autoclave heated in an oil bath so that a temperature of 285–290° C. was attained in the centre. After one hour at this temperature, the heating was removed and the autoclave allowed to cool overnight at room temperature in the oil bath.

The greyish-green mass of residue and liquid ammonia was allowed to stand in the air until the ammonia had boiled off, and was then ground up finely. The resulting almost white powder was extracted with water (25 ml.) three times and the filtered extract, which was orange coloured, treated with solid sodium iodide until a slight permanent precipitate resulted. The precipitate (probably bromopentammine osmium III iodide) was removed and solid ammonium sulphate (5 g.) added to the clear solution. The resulting almost white precipitate of the hexammine iodide sulphate was washed with 5% sodium iodide solution and recrystallized from hot water in the presence of a few drops of ammonia. Occasionally the substance had a rose colour due to traces of an unidentified impurity. It could also be recrystallized by shaking with a suspension of silver chloride to eliminate the iodide ion, and then addition of sodium iodide and ammonium sulphate to the clear solution. The substance crystallized in dense colourless or white cubes, which lost ammonia on heating to 110–120° with slight darkening of colour. The warm aqueous solution rapidly reduced silver nitrate solution to the metal, but only slowly decolourized potassium permanganate solution or bromine water.

Found: $I=25\cdot0\%$; $N=16\cdot5\%$.

Calculated for $[Os(NH_3)_6]I.SO_4$: $I=24\cdot65\%$, $N=16\cdot3\%$.

Hexammine Osmium III Iodide.

The iodide sulphate (0·5 g.) was suspended in warm water (30 ml.) and normal barium chloride solution (5 ml.) added. The mixture was shaken for ten minutes and the barium sulphate filtered off. Addition of sodium iodide to the filtrate gave a yellow precipitate of the impure iodide, which was recrystallized twice from warm water by the addition of sodium iodide.

The substance crystallized in dense bright yellow cubes. The aqueous solution was colourless.

Found: $Os=28\cdot5\%$, $I=56\cdot2\%$, $N=12\cdot6\%$.

Calculated for $[Os(NH_3)_6]I_3$: $Os=28\cdot25\%$, $I=56\cdot59\%$, $N=12\cdot47\%$.

Hexammine Osmium III Chloride.

The iodide was shaken with a suspension of silver chloride in warm water, and the filtrate precipitated with acetone and one drop of dilute hydrochloric acid. The substance crystallized in micro-cubes, and was deliquescent.

Found: $Os=47\cdot3\%$; $Cl=26\cdot7\%$.

Calculated for $[Os(NH_3)_6]Cl_3$: $Os=47\cdot7\%$; $Cl=26\cdot5\%$.

Hexammine Osmium III Bromide.

The residue from the autoclave was extracted with the minimum volume of cold water, the extract cooled in ice and treated with alcohol. The rose-coloured crystalline precipitate was dissolved in the minimum amount of water, cooled and the slight precipitate of bromopentammine osmium bromide rejected. The pink solution was treated with solid ammonium bromide and alcohol to reprecipitate the hexammine bromide.

Alternatively a concentrated solution of hexammine osmium III chloride was treated with ammonium bromide and the impure bromide containing bromide-chloride dissolved in water and reprecipitated with ammonium bromide and alcohol.

The substance crystallized in white cubes. The aqueous solution treated with ammonium sulphate gave the sparingly soluble cubic bromide sulphate, which was not studied further.

Found: $Os=35\cdot7\%$; $Br=44\cdot8\%$; $N=15\cdot7\%$.

Calculated for $[Os(NH_3)_6]Br_3$: $Os=35\cdot73\%$; $Br=45\cdot08\%$; $N=15\cdot79\%$.

Hexammine Osmium III Bromide-Hexabromosmate IV Monohydrate.

Hexammine osmium III iodide (0·2 g.) was shaken with a suspension of silver chloride in water (30 ml.), and to the filtrate was added ammonium hexabromosmate IV (0·2 g.) in water (25 ml.) containing concentrated hydrobromic acid (0·5 ml.). The dark brown solution, on scratching, deposited black stellate prisms.

Found: Os=36·2%, Br=52·5%.

Calculated for $[Os(NH_3)_6]Br[OsBr_6].H_2O$: Os=35·9%, Br=52·81%.

SUMMARY.

The reaction between ammonium hexabromosmate IV and ammonia under 2·5 atmospheres at 285° C. has been found to yield hexammine osmium II bromide as well as bromopentammine osmium III bromide. The salts of the hexammine osmium III cation are usually white and much more soluble in water than the pentammine salts.

ACKNOWLEDGEMENT.

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PALLADIUM COMPLEXES.

PART III. BRIDGED COMPOUNDS OF PALLADIUM CONTAINING OTHER METAL ATOMS; COMPLEXES OF O-METHYL-MERCAPTOBENZOIC ACID WITH OTHER METALS.

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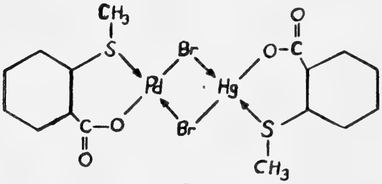
Manuscript received, August 9, 1951. Read, September 5, 1951.

Bridged palladium complexes have been reported by Mann and Purdie (1935, 1936), and similar compounds of cadmium and of mercury by Evans, Mann, Peiser and Purdie (1940). In all these complexes the metal atoms are the same, but Mann and Purdie (1940) prepared compounds containing both palladium and mercury, and cadmium and mercury, bridged by bromine atoms. Allison and Mann (1949) reported two bridged structures of tetravalent tin which contained mercury and palladium respectively.

In our previous communication—Livingstone and Plowman (1951)—we reported bridged chloro and bromo derivatives of palladium containing o-methyl-mercaptobenzoic acid as a chelating group. Using the same chelating group and a similar method of preparation we have succeeded in preparing bridged compounds of palladium with mercury or copper as the second metal atom. They are: (i) bis(o-methyl-mercaptobenzoato)-μ-dibromo-palladium (II)-mercury (II), and (ii) bis(o-methyl-mercaptobenzoato)-μ-dibromo-palladium (II)-copper (II) 2-hydrate.



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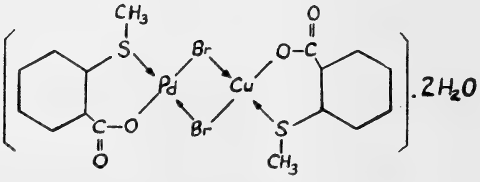


II

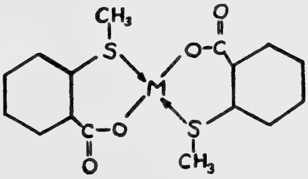
The compounds are insoluble in water, very sparingly soluble in hot alcohol and chloroform, but insoluble in benzene, toluene and acetone.

These compounds are interesting in view of the fact that, in the case of the bridged dipalladium and the bridged palladium-copper compounds, the configurations of both metal atoms should be planar, whereas in the case of the analogous palladium-mercury compound the palladium should be planar while the mercury atom would be expected to be tetrahedral, since divalent mercury invariably exhibits the tetrahedral configuration. Compound ii appears to be the first bridged compound of copper containing another metal that has been reported. It is theoretically capable of existing in two isomeric forms *cis* and *trans*, but since only one form was obtained, it is assumed that it has the *trans* configuration.

Mann and Purdie (*loc. cit.*) were unable to prepare bridged compounds of mercury and palladium, using mercury (II) chloride and mercury (II) iodide; also these workers were unsuccessful in making a mixed palladium-cadmium bridged compound. During the course of this investigation attempts were made to prepare mixed palladium-mercury bridged compounds using mercury (II) chloride and mercury (II) iodide in place of mercury (II) bromide with bis(o-methyl-mercaptobenzoato) palladium (II) but all attempts failed. Similarly no analogous palladium-cadmium compound could be prepared using cadmium (II) bromide.

It has been stated by Mann and Purdie (*loc. cit.*) that the formation of a bridged compound containing two different metals must be dependent to a certain extent on the valency lengths and intervalency angles of each of the four-covalent metallic complexes. Livingstone and Plowman (*loc. cit.*) also demonstrated that the formation of bridged compounds of palladium is highly specific in its dependence on the nature of the attached ligand, since they were unable to obtain bridging using several other chelating groups attached to palladium. Similar specificity was found by Mann and Purdie (1935) in that bridged compounds of palladium were formed with trialkyl-phosphines and arsines, but not with dialkyl sulphides. Further evidence for the above statements is afforded by the fact that, in this investigation, bridged compounds were obtained with palladium and mercury, and also with palladium and copper, but no analogous compound was obtained containing palladium and cadmium, using similar procedures.

The reaction of the chelating group o-methyl-mercapto-benzoic acid with metals other than palladium was investigated. The palladium compound has been previously described—Livingstone, Plowman and Sorensen (1951). The only metallic salts which were found to give insoluble compounds with o-methyl-mercaptobenzoic acid were those of Cu^{II}, Hg^{II}, Cd^{II} and Ag^{I}. The compounds obtained were: (iii) bis(o-methyl-mercaptobenzoato) copper (II); (iv) bis-(o-methyl-mercaptobenzoato) mercury (II); (v) bis(o-methyl-mercapto-benzoato) cadmium (II); (vi) silver (I) o-methyl-mercaptobenzoate.



Where M = Cu, Hg and Cd

Whether o-methyl-mercaptobenzoic acid acts as a chelating group in the case of the silver compound (vi) is open to question. The mercury compound has been previously reported by Sachs and Ott (1926), who gave the melting point as 158–9° C. We found the melting point to be 165–165·5° C.

While Pd^{II}, Cu^{II}, Hg^{II} and Cd^{II} form stable insoluble compounds with o-methyl-mercaptobenzoic acid, only Cu^{II} and Hg^{II} were found to give bridged compounds with Pd^{II}.

EXPERIMENTAL.

(i) *Bis(o-methyl-mercaptobenzoato)-μ-dibromo-palladium (II)-mercury (II).*

Mercury (II) bromide (0·6 g.) dissolved in water (40 ml.) was added slowly to a boiling aqueous solution (180 ml.) of bis(o-methyl-mercaptobenzoato) palladium (II) (0·9 g.). After ten minutes heating at the boiling point crystals began to form. After a further fifteen minutes' heating, the product was filtered and washed well with hot water, then acetone. The yield of 1·21 g. consisted of deep yellow tetragonal prisms of m.pt. 212° C., which were insoluble in water, acetone, benzene, toluene and only very sparingly soluble in boiling alcohol and chloroform.

Found: Pd, 13·4%; Hg, 25·0%; Br, 19·97%.

$(C_8H_7O_2S)_2PdHgBr_2$ requires: Pd, 13·31%; Hg, 25·03%; Br, 19·94%.

(ii) *Bis(o-methyl-mercaptobenzoato)-μ-dibromo-palladium (II)-copper (II) 2-hydrate.*

To a boiling aqueous solution (120 ml.) containing bis(o-methyl-mercaptobenzoato)palladium (II) (0·5 g.) and potassium bromide (5 g.) was added a solution of copper (II) bromide (1·2 g.) and potassium bromide (8 g.) in 25 ml. water. After five minutes crystallization commenced and after a further fifteen minutes' heating, the chocolate brown crystalline product (0·65 g.) was filtered hot, washed well with alcohol, then acetone and dried over P_2O_5; m.pt. 208° C. On heating in a closed tube, water is evolved at a temperature just below decomposition.

Found: Pd, 15·3%; Cu, 9·3%; Br, (i) 22·0%, (ii) 22·0% (on a separate preparation).

$(C_8H_7O_2S)_2PdCuBr_2.2H_2O$ requires: Pd, 15·24%; Cu, 9·08%; Br, 22·82%.

It was found that in the absence of potassium bromide, products were obtained which had low Br and slightly high Pd content. These results are consistent with the possibility that one Br bridge is replaced to a small extent by an OH bridge, this effect leing lessened by the presence of an excess of bromide ion. A similar tendency was observed in the preparation of bis(o-methyl-mercaptobenzoato)-μ-dibromo-dipalladium (II) (Livingstone and Plowman, 1951).

(iii) *Bis(o-methyl-mercaptobenzoato) copper (II).*

o-Methyl-mercaptobenzoic acid (0·33 g.) dissolved in one equivalent of sodium hydroxide solution was added to a warm aqueous solution (10 ml.) of copper (II) bromide (0·33 g.). The crystalline product (iii) precipitated immediately as bright green prisms, insoluble in water and decomposing at 152° C.

Found: Cu, 15·95%.

$Cu(C_8H_7O_2S)_2$ requires 15·97%.

(iv) *Bis(o-methyl-mercaptobenzoato) mercury (II).*

o-Methyl-mercaptobenzoic acid (0·33 g.) dissolved in one equivalent of sodium hydroxide, was added to a hot aqueous solution of mercury (II) chloride (0·27 g.). The compound (iv) gradually precipitated, yielding 0·31 g. of thin colourless needles, often bunched together in brushes, and insoluble in water; m.pt. 165–165·5° C.

Found: Hg, 37·8%.

$Hg(C_8H_7O_2S)_2$ requires: Hg, 37·50%.

(v) *Bis(o-methyl-mercaptobenzoato) cadmium (II).*

To a boiling solution of o-methyl-mercaptobenzoic acid (0·75 g.) in one equivalent of aqueous sodium hydroxide (20 ml.) was added slowly an aqueous solution (10 ml.) of cadmium (II) chloride 2·5-hydrate (0·51 g.). After two minutes well-formed colourless dendritic crystals (0·9 g.) were deposited. M.pt. 286° C.

Found: Cd, 25·2%.

$Cd(C_8H_7O_2S)_2$ requires: Cd, 25·16%.

(vi) *Silver (I) o-methyl-mercaptobenzoate.*

(*a*) Silver acetate (0·4 g.) was dissolved in 50% ethyl alcohol (40 ml.) and added slowly to a boiling alcoholic solution (30 ml.) of o-methyl-mercaptobenzoic acid (0·4 g.). Thin colourless needles of m.pt. 234° C. were deposited.

Found: Ag, 39·4%.

$AgC_8H_7O_2S$ requires: Ag, 39·22%.

(*b*) A solution of o-methyl-mercaptobenzoic acid (0·4 g.) in one equivalent of aqueous sodium hydroxide (20 ml.) was added to a hot aqueous solution (20 ml.) of silver nitrate (0·4 g.). Colourless needles of compound (vi) were deposited. M.pt. 232° C.

Found: Ag, 39·4%.

SUMMARY.

Bromo bridged compounds containing palladium and mercury, and palladium and copper, with o-methyl-mercaptobenzoic acid, $C_8H_8O_2S$, as a chelating group, have been prepared; viz. (i) $(C_8H_7O_2S)_2PdHgBr_2$ and (ii) $(C_8H_7O_2S)_2PdCuBr_2.2H_2O$. Compounds of o-methyl-mercaptobenzoic acid with the following metals: copper (II), mercury (II), cadmium and silver—(iii) $Cu(C_8H_7O_2S)_2$; (iv) $Hg(C_8H_7O_2S)_2$; (v) $Cd(C_8H_7O_2S)_2$; and (vi) $AgC_8H_7O_2S$ are also described.

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THE ESSENTIAL OIL OF A PHYSIOLOGICAL FORM OF *EUCALYPTUS CITRIODORA* HOOK.

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Following the announcement of the occurrence of a physiological form of *Eucalyptus citriodora* by two of the authors (Penfold and Morrison, 1948), the investigation described hereunder was undertaken.

The results obtained have confirmed those obtained in the preliminary experiments that the chief constituent of the oil of *E. citriodora* (Type), namely citronellal, has been largely replaced in the new form by an equivalent amount of citronellol and its esters. The amount of foliage available for investigation has been insufficient for a determination of the minor constituents, but these will be dealt with in a subsequent communication. The principal components so far identified are citronellol and its acetic and citronellic acid esters, and citronellal.

Also under investigation are oils from individual trees containing percentages of aldehyde varying from 40 to 50 per cent., percentages which indicate an intermediate position between the form described in this paper and the " Type " oil.

It is worthy of note that the trees, whose foliage yielded essential oils containing only about 10 per cent. citronellal, were observed in their natural habitat growing in close environmental association with trees of normal oil composition (65–85 per cent. citronellal) referred to in this paper as the " Type ".

All the trees examined were found to be morphologically indistinguishable from one another, but for purposes of identification, the physiological form described in this paper will be referred to as *Variety* " *A* ".

The Essential Oil.

The essential oils obtained by steam distillation of the foliage of eight individual forest trees were almost water white in colour. All possessed a pleasant odour of citronellol modified by that of its esters. The odour differed markedly from the sharp aldehydic odour of citronellal, which is characteristic of the oil of the type species. The yields and range of physico-chemical characteristics, together with those of the " Type " oil for comparison, are shown in Table 1.

TABLE I.

Eucalyptus citriodora Hook., Variety " A ".
Eight Trees from Cordalba, Queensland.

Tree No.	Date Received.	Yield, % on Sample as Received.	$d^{15^\circ}_{15}$	$n^{20^\circ}_{D}$	$\alpha^{20^\circ}_{D}$	Solubility in 70% w/w alc. Vol.	Ester No. 1½ hrs. Hot Sap.	Ester No. after Acetylation.	Aldehyde Content. %	Remarks.
1	12/ 7/48	1·4	0·8855	1·4569	+2·55°	—	120·00	231	0·9	Air dry, leaf only.
2	30/ 7/48	0·8	0·8876	1·4608	+2·1°	—	149·5	228	6·1	Fresh leaves and terminal branchlets.
3	2/11/48	2·0	0·8825	1·4570	+1·5°	1·25	86·5	271	11·0	Do.
4	11/ 1/49	1·8	0·8830	1·4544	+0·7°	1·3	116·0	265	14·0	Fresh leaf only.
5	11/ 1/49	1·6	0·8864	1·4556	+0·8°	1·3	127·0	249	12·0	Do.
6	23/ 1/50	3·0	0·8872	1·4507	+1·01°	1·4	191·4	258	6·0	Air dry, leaf only.
7	23/ 1/50	1·5	0·8736	1·4541	−0·90°	1·7	149·5	270	11·0	Do.
8	13/ 6/50	3·4	0·8853	1·4521	−0·7°	1·5	163·0	277	14·0	Do.
Type oil		0·5 to 0·75%	0·8640 to 0·8770	1·4511 to 1·4570	+3° to −3°	1·3 to 1·5	12 to 60	230 to to 292	65 to 85%	Fresh leaves and terminal branchlets.

EXPERIMENTAL.

The oil from tree No. 8 was selected for examination. The aldehyde content was determined by the hydroxylamine method of the Essential Oil Sub-Committee of the Society of Public Analysts (1932). The ester number after acetylation was equivaleent to 96·2% of acetylizable substances (calculated as $C_{10}H_{18}O$) in the original oil.

Forty millilitres of the crude oil were fractionally distilled at 10 mm., the fractions obtained having the characteristics shown in Table II

TABLE II.

Fraction No.	B.p.	Vol., ml.	$d^{15^\circ}_{15}$	$n^{20^\circ}_{D}$	$\alpha^{20^\circ}_{D}$
1	70– 96°	6	0·8666	1·4544	−5·6°
2	95–106°	6	0·8772	1·4536	−4·4°
3	107–109°	24	0·8839	1·4504	+0·64°
Residue	—	3			

Determination of Citronellal.

Fraction 1 yielded a semicarbazone, m.p. 84° from petroleum ether, and a yellow 2 : 4-dinitrophenylhydrazone, m.p. 80° from ethanol, both alone and in admixture with authentic specimens of these derivatives. Fraction 1 thus appears to consist principally of citronellal.

Determination of Citronellol.

A portion (20·5 ml.) of the crude oil was saponified with 0·5N alcoholic potassium hydroxide (250 ml.) at room temperature for two days. After dilution with water, 18 ml. of oil were recovered from the solution of potassium salts of the acids derived from the esters. The oil (15 ml.) after drying with anhydrous Na_2SO_4, was heated for two hours on the steam bath, under a reflux with phthalic anhydride (15 g.) and benzene (15 ml.). The cold reaction mixture was neutralized with aqueous potassium hydroxide and freed from unchanged oil by extraction with ether. After removal of ether the alcohol was recovered by steam-distillation with excess of sodium hydroxide. Ten millilitres of a colourless oil of pleasant rose-odour were obtained having $d_{15}^{15^\circ}$ 0·8620, $n_D^{20^\circ}$ 1·4556, α_D +1·71°. These constants correspond closely with those of citronellol. Supporting evidence for the presence of this alcohol was obtained by the preparation of the allophanate, m.p. 106–107°, and the silver salt of the acid phthalate, m.p. 126°. (Mixed melting points showed no depression.) Hence the primary alcohol, free, and combined as ester, consists entirely of citronellol.

Determination of Acids (Citronellic and Acetic) Combined with Citronellol.

The solution of potassium salts of the acids derived from the esters was evaporated to a small volume and extracted with ether to remove traces of oil. After removal of residual ether, the solution was acidified with dilute sulphuric acid. About 1·5 ml. of an oily acid separated which was converted directly to its silver salt.

0·1003 g. silver salt yielded 0·0393 g. silver=39·18% Ag.

Silver citronellate requires 38·99% Ag.

A further specimen of the oily acid was isolated, and had b_{10} 140–153°, $d_{15}^{15^\circ}$ 0·9431, $n_D^{20^\circ}$ 1·4591, α_D +1·0°.

The benzylthiuronium ester was prepared, m.p. 146–147°, both alone and in admixture with an authentic specimen. This acid is therefore citronellic acid.

The aqueous solution from the separation of the oily acid was steam distilled, the distillate being collected in three fractions. After neutralization with ammonia, each fraction was evaporated to a small volume and the silver salt of the acid prepared.

Fraction 1. 0·1004 g. Ag salt gave 0·0651 g. Ag=64·84% Ag .
„ 2. 0·2608 g. Ag salt gave 0·1692 g. Ag=64·88% Ag.
„ 3. 0·1966 g. Ag salt gave 0·1275 g. Ag=64·85% Ag.

Silver acetate requires 64·67% Ag.

From a mixture of the silver salts of each of the foregoing fractions an anilide was prepared, m.p. 114°, undepressed in admixture with an authentic specimen of acetanilide. This acid is therefore acetic acid.

No evidence was obtained for the presence of formic, butyric or valeric acids.

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Penfold, A. R., and Morrison, F. R., 1948. *Aust. J. Sci.,* **11,** 29.

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VOLUME LXXXV

Part IV

THE OCCURRENCE OF A PHYSIOLOGICAL FORM OF *BACKHOUSIA CITRIODORA* F. MUELL. AND ITS ESSENTIAL OIL.

By A. R. Penfold, F.A.C.I.,
F. R. Morrison, F.A.C.I.,
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Museum of Applied Arts and Sciences, Sydney.

Manuscript received, November 14, 1951. Read, December 5, 1951.

The species *Backhousia citriodora* has been described by Bentham (1866) and Bailey (1900). The tree is of medium size and occurs in restricted belts in the rain forests (" brush ") between Brisbane and Rockhampton, Queensland.

The essential oil was first described by the firm of Schimmel & Company of Miltitz, Germany (1888). It was shown to consist almost entirely (95 per cent.) of the aliphatic aldehyde, citral. In 1923 one of the present authors (A.R.P.) examined oils from trees cultivated at Ashfield, N.S.W., and confirmed the above finding.

Although the natural stands of this tree are not extensive, small quantities of the oil have been distilled and marketed spasmodically during the past sixty years. The oil was found to be very constant in composition, the citral content being within the range of 90–97 per cent.

Mr. J. R. Archbold of Maryborough, Queensland, whilst engaged in the production of oil from trees growing near Miriamvale, about 160 miles north-west of Maryborough, as recently as June, 1950, noticed a slight difference in odour of one of the distillates, which indicated that a different kind of oil was present in some of the leaves distilled.

Examination of additional single tree samples by the authors revealed the occurrence of a physiological form of *Backhousia citriodora*. The oil from these particular trees was found to consist largely of citronellal, in contradistinction to the Type, which contains 90–97 per cent. of citral. This observation was recorded by the authors in the *Australian Journal of Science* (1950). It is of interest to note that this is the first recorded occurrence of *lævo*-citronellal in an Australian essential oil. The citronellal isolated from this source possesses the highest optical rotation yet recorded, viz. α_D $-14 \cdot 21°$.

A survey of the area was made by two of the authors (F.R.M. and J.L.W.) in June, 1951. The trees were found scattered throughout an area of about ten acres on a steep, rocky hillside in dense rain forest (" brush "). Some of the trees were very large, one in particular being 92 ft. high, with a girth at breast height of 6 ft. 8 ins. ; the average tree, however, was about 12 ins. in diameter.

The variant trees were located in two pockets, each containing about a dozen trees, of which six or seven were variants and the remainder normal. All the trees examined were found to be morphologically indistinguishable from one another, but for the purposes of identification the physiological form described in this paper will be referred to as Variety " A ".

TABLE I.

Backhousia citriodora F. Muell., Variety " A ".

Date Received.	Locality.	Sample No.	Weight of Leaves. Lb.	Yield of Oil %	$d_{15}^{15^\circ}$	$\alpha_D^{20^\circ}$	$n_D^{20^\circ}$	Solubility in 70% Alcohol. (W/W.)	Ester No. 1½ hours Hot Sap.	Citronellal Content.	Remarks.
19/6/50	Miriamvale, Qld. ..	1	13	0·54	0·8734	−9·85°	1·4566	1·6 vols.	11·5	66·7%	Collected by J. R. Archbold.
19/6/50	,, ,,	2	16¾	0·45	0·8738	−9·80°	1·4571	1·8 ,,	10·1	62·5%	,, ,, ,,
19/6/50	,, ,,	3	15	0·83	0·8668	−12·15°	1·4527	1·65 ,,	9·3	78·4%	,, ,, ,,
19/6/50	,, ,,	4	14	0·71	0·8678	−11·74°	1·4541	1·7 ,,	10·4	79·2%	,, ,, ,,
28/8/50	,, ,,	5	20½	0·86	0·8705	−11·52°	1·4526	1·6 ,,	11·0	73·0%	,, ,, ,,
4/6/51	,, ,,	6	9	0·84	0·8671	−12·36°	1·4526	1·6 ,,		79·7	Collected by F. R. Morrison and J. L. Willis.

NOTE.—Sample No. 5, after acetylation, had an ester number of 290, equivalent to 100 per cent. acetylizable constituents.

TABLE II.

Backhousia citriodora, F. Muell., Type.

Date.	Locality.	Sample No.	Weight of Leaves. Lb.	Yield of Oil. %	$d_{15}^{15^\circ}$	$\alpha_D^{20^\circ}$	$n_D^{20^\circ}$	Solubility in 70% Alcohol. (W/W.)	Citral Content %	Remarks.
28/8/50	Miriamvale, Qld. ..	1	21½	0·33	0·8909	+0·17°	1·4870	1·3 vols.	92	Collected by J. R. Archbold.
4/6/51	,, ,,	2	5	0·34	0·8981	+0·08°	1·4874	1·0 ,,	91	Collected by F. R. Morrison and J. L. Willis.
4/6/51	,, ,,	3	5	0·64	0·8990	+0·4°	1·4882	1·1 ,,	91	,, ,, ,,

THE ESSENTIAL OIL.

The essential oils obtained by steam distillation of the foliage of individual forest trees were of a pale lemon tint, and possessed the characteristic odour of citronellal. The oil, in fact, is almost identical with that of the Type oil of *Eucalyptus citriodora*, which has been marketed for many years.

The yields and physico-chemical characteristics are shown in Table I.

The principal constituents identified were *l*-citronellal and *d*-isopulegol. Small quantities of citronellol and esters were present.

For comparative purposes, the essential oils obtained from trees of the Type species growing alongside the physiological form were also examined. The principal constituent was citral (91–92 per cent.). The results are shown in Table II.

EXPERIMENTAL.

Backhousia citriodora, Variety " A ".

A total of 88 lb. of leaves and terminal branchlets was subjected to distillation in steam, six separate distillations being conducted. The respective crude oils were individually examined, and the results obtained are summarized hereunder.

Determination of l-*citronellal.*

The percentage of aldehyde present in each sample of oil was determined by the hydroxylamine method of the Essential Oil Sub-Committee of the Society of Public Analysts (1932). Samples 3 and 4 were used for the separation and identification of citronellal. The oil was shaken with sodium bisulphite solution, and the crystalline compound separated, washed with ether-alcohol mixture, and dried. It was subjected to steam distillation in the presence of an excess of sodium carbonate, the citronellal thus isolated possessing the following constants: $b_{10\cdot5}$ 88°, $d_{15}^{15°}$ 0·8555, $n_D^{20°}$ 1·4477, α_D —14·21°. It yielded a semicarbazone, m.p. 83·5° after recrystallization from hexane, and a 2 : 4 dinitrophenylhydrazone, m.p. 81° after recrystallization from ethanol. Mixed melting point determinations with authentic specimens of these derivatives showed no depression.

Determination of d-*isopulegol.*

(*a*) Sample No. 6 (25 g.) was heated with an equal weight of phthalic anhydride in benzene solution on the steam bath for eight hours. The phthalic acid ester was subjected to steam distillation in the presence of an excess of sodium hydroxide. A water-white oil (3·6 ml.), possessing the characteristic odour of isopulegol, was isolated. It had the following constants: $d_{15}^{15°}$ 0·9235, $n_D^{20°}$ 1·4700, α_D +8·68°. It yielded, with naphthyl-*iso*cyanate, a well defined α-naphthyl urethane, m.p. 120°, after recrystallization from methanol. A mixed melting point determination with an authentic specimen from another source showed no depression.

(*b*) Sample No. 5 (29 g.) cooled to 0° C. was added to a solution of hydroxylamine hydrochloride (40 g.) and potassium carbonate (40 g.) in 200 ml. water at 0° C. After 2½ hours' agitation, the oximated oil was separated, dried and fractionated at 14 mm. Fraction 1 (3 ml.) had b. 94–98°/14 mm. and $d_{15}^{15°}$ 0·9147, $n_D^{20°}$ 1·4726, α_D +4·08°. Fraction 2 (2 ml.) had b. 98–110°/14 mm., whilst the remainder of the oil, the oxime of citronellal, distilled at 136–146°/14 mm.

The physical constants of Fraction 1 agree well with those for isopulegol, and the identity of this alcohol was confirmed by its yielding with α-naphthyl-*iso*cyanate an α-naphthyl-urethane of m.p. 120–121° from methanol.

Determination of Citronellol.

The citronellal was removed from samples No. 1 and 2 by distillation at 9·5 mm. The residue was treated with an equal weight of phthalic anhydride in benzene solution on a steam bath for two hours. A small quantity of phthalic acid ester was isolated, which, on steam distillation with an excess of sodium hydroxide, yielded 1 ml. of an alcohol possessing the characteristic rose odour of citronellol. On treatment with cyanic acid, the allophanate was obtained, m.p. 104·5°, which was undepressed in admixture with an authentic specimen from another source.

Backhousia citriodora, Type.

Identification of the Principal Constituent, Citral.

Citral was determined as the major constituent of the oils of the Type trees growing adjacent to the trees of *Backhousia citriodora*, variety " A ". The oils from the Type (see Table II) were mixed, treated with 35 per cent. neutral sodium sulphite solution, and the citral isolated in the usual manner. The citral so obtained was water-white and had b_{11} 105–107°, $d_{15}^{15°}$ 0·8920, $n_D^{20°}$ 1·4885, α_D $\pm 0°$. It yielded a citryl-β-naphthocinchoninic acid, m.p. 199–200° on recrystallization from alcohol, unchanged in admixture with an authentic specimen from another source.

SUMMARY.

A physiological form of *Backhousia citriodora* F. Muell., has been observed in the rain forest near Miriamvale, Queensland, growing in association with the Type species, and has been designated Variety " A ". The essential oil contains *l*-citronellal (62–80 per cent.), *d*-isopulegol, citronellol, and ester. The Type species from the same area contains 91–92 per cent. of citral.

ACKNOWLEDGEMENTS.

Thanks are due to Mr. J. R. Archbold, who drew our attention to the occurrence of this form, and for his co-operation and assistance during the visit to Miriamvale.

To the Queensland Forest Service, and particularly to Mr. W. R. Suttie, District Forest Officer at Maryborough, Queensland, and his staff, we are greatly indebted for their wholehearted co-operation in this investigation.

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GRAPTOLITE ZONES IN THE SILURIAN OF THE YASS–BOWNING DISTRICT OF NEW SOUTH WALES.

By IDA A. BROWN,* D.Sc.,
and KATHLEEN M. SHERRARD, M.Sc.

With Plates VII and VIII and two text-figures.

Manuscript received, November 14, 1951. Read, December 5, 1951.

PART I. STRATIGRAPHY.

(I.A.B. and K.M.S.)

INTRODUCTION.

The Yass District has been well known for its shelly faunas, especially those from Hatton's Corner, since fossils were first recorded from Yass Plains by Strzelecki in 1845. Graptolites, however, were not recorded from the area until Mitchell (1886*a*) exhibited to the Linnean Society of New South Wales, from Bowning, near Yass, " . . . specimens of Graptolites, probably undescribed, and certainly the first recorded from N.S.W., showing that the formations there which have hitherto been regarded as Devonian are in reality Silurian."

In the same year Mitchell (1886*b*) published an account and illustrative section of the Bowning beds, but did not refer to the graptolites. His section showed the Bowning beds folded into a syncline. In 1888(*a*) he exhibited further graptolites from Bowning and " Belle Vale ". He also noted (1888*b*) " several graptolites from micaceous sandstones in the Lower Trilobite Bed on the eastern side of the syncline ; and in shaly sandstone on the western side, in the Great Shale bed." No exact locality was given, nor were the graptolites named specifically or generically.

In 1902 T. S. Hall identified " *Monograptus* allied to *M. dubius* " in specimens collected by Mitchell from the Lower Trilobite bed at " Belle Vale ", a large property lying between Yass and Bowning. Shearsby (1912) recorded among the fossils in the Barrandella shales at Yass, *Monograptus* (?) and *Dendrograptus*.

In 1915 Mr. Shearsby (Sherrard and Keble, 1937) discovered *Monograptus* cf. *vomerinus* in a spoil-heap made near Bowning railway station during railway works. In 1937 Sherrard and Keble described several species of *Monograptus* from Silverdale, two miles east-north-east of Bowning and seven miles north-north-west of Yass (indicated as " Graptolite Bed " on Plate VII). These were the first graptolites described from the district whose exact source was known. The graptolite most abundant at this locality, as will be shown in this paper, is *Monograptus salweyi* from the zone of *M. scanicus* in the Silurian of Britain.

An account of the stratigraphy of the Yass-Bowning District was published by one of us (Brown, 1941), in which all previous work was summarized and all recorded fossils from the district were assigned to their proper stratigraphical

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* Mrs. W. R. Browne.

horizons. The field-mapping indicated that the *Monograptus* horizon of Sherrard and Keble, 1937, is stratigraphically above the " Dalmanites Bed " (=" Phacops Bed " of Jenkins, 1878 ; =" Middle Trilobite Bed " of Mitchell, 1886*b*), as clearly stated in the paper (Brown, 1941, pp. 320, 324, 328, 333, 334, Plate XIV). The Dalmanites bed contains abundance of *Dalmanites meridianus* Eth. & Mitchell, 1895, and there is thus no justification for Gill's assumption (1948) that the age of this trilobite is not Silurian.

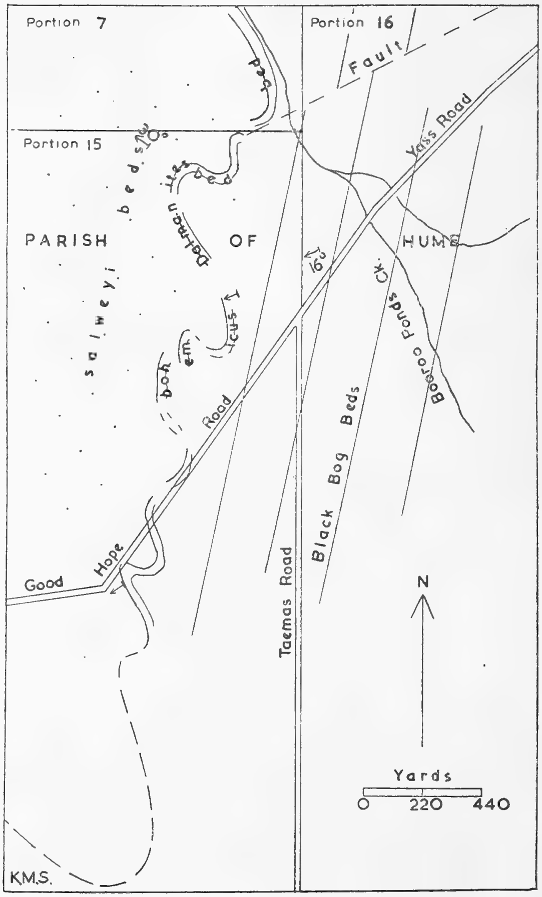

Fig. 1.—Sketch-map to show relationship of graptolite-bearing beds in Portion 15, Par. Hume, near junction of Good Hope and Taemas roads.

In 1947 Messrs. G. Packham and J. Veevers, under the guidance of Mr. A. J. Shearsby, discovered *Monograptus bohemicus* in shale immediately below the Dalmanites bed, west of Hatton's Corner, two miles west of Yass. Subsequent collecting by Mr. Shearsby and the two present writers has confirmed this discovery and shown that the *bohemicus* bed persistently underlies the Dalmanites bed, wherever the latter is shown on the accompanying map (Plate VII). Miss G. L. Elles of the Sedgwick Museum, Cambridge, has kindly examined specimens from this bed and states they are of the type of *M. bohemicus* which is characteristic of the top of the *M. nilssoni* zone of the Silurian.

Furthermore, the sandstone described by Sherrard and Keble (1937) with graptolites from the zone of *Monograptus scanicus* has since been located at several places about two miles south of Hatton's Corner, not far from the eastern edge of Portion 15, Parish of Hume, near the junction of Taemas and Good Hope roads (Text-fig. 1 ; Plate VIII, figs. *a*, *b*). On the side of a grassy hill near this point Monograptids, though rare, have been found on at least three horizons, up to 200 feet stratigraphically above the Dalmanites bed, which outcrops below the sandstone with *M. scanicus* zone graptolites. Beneath the Dalmanites bed is found shale with *M. bohemicus.*

Finally, *Monograptus vomerinus* has been found about the middle of the Black Bog shales in the western branch of Reedy Creek near its crossing by the Good Hope road (Plate VII).

SEQUENCE AND CORRELATION.

The Silurian sequence in the Yass-Bowning district has been described by one of us (Brown, 1941). The sedimentary rocks have been divided into the Bango, Yass and Hume Series in ascending stratigraphical order, separated from each other by rocks of igneous origin.

Graptolites have been found in the Hume Series alone, which is therefore the only one considered in this paper. This series consists of limestones, shales, sandstones and conglomerates arranged in the following descending order :

	Approximate Thickness (in Feet).	Accompanying Graptolites.
Tuffaceous conglomerate	150	
Shale and sandstone	50 (?)	
Upper Trilobite bed	20	
Shale and conglomerate	100	
Sandstone	12–20	*Monograptus salweyi, M.* cf. *tumescens, Dictyonema.*
Sandstone	200	*M. salweyi.*
Middle Trilobite bed (Dalmanites bed)	4	
bohemicus bed	6	*M. bohemicus, M. nilssoni, M. crinitus, M. roemeri, Dictyonema.*
Black Bog Shales	200	*M. vomerinus.*
Hume Limestone (=Lower Trilobite bed)	0–20	*Monograptus* allied to *M. dubius.*
Barrandella Shales	5–150	*Monograptus* (?).
Bowspring Limestone	0–100	

Although it has been generally recognized, and particularly by Etheridge (1891) and Dr. Dorothy Hill (1940), that the shelly fossils of the Hume and Bowspring Limestones and the associated beds are approximately of the same age as those of the Wenlock (Etheridge) or Wenlock-Ludlow boundary (Hill) of Britain, few, if any, of the species are identical. On the other hand the graptolitic fauna, which has now been found in close association with the shelly fauna, includes on one horizon (the *bohemicus* bed) four species of *Monograptus* which are all restricted to the zone of *M. nilssoni* of the Lower Ludlow of Britain. The same assemblage is found in the Henryhouse Shale of Oklahoma, U.S.A. (Decker, 1935). Moreover, the dominant graptolite of the overlying *salweyi* beds at Yass-Bowning is highly characteristic of the *M. scanicus* zone of Britain.

The graptolites thus permit a more exact correlation of the Yass-Bowning and British sequences as indicated below:

	Zones in Britain.	Equivalents in Hume Series.
LOWER LUDLOW.	*Monograptus scanicus.* *Monograptus nilssoni.*	*M. salweyi* (in sandstone). Dalmanites (Middle Trilobite) bed. *M. bohemicus* (in shale).
WENLOCK.	*Cyrtograptus lundgreni* to *Cyrtograptus murchisoni.*	*M. vomerinus* (in Black Bog Shales). *Monograptus* allied to *M. dubius* (in Lower Trilobite Bed). *Monograptus* (?) (in Barrandella Shales).

It will be seen, however, that there appears to be no marked break in the sedimentation at Yass between the equivalents of the Wenlock and Ludlow, since about half-way up the thick Black Bog Shales occurs *Monograptus vomerinus*, which is found throughout the Wenlock succession in Britain, while immediately above the Black Bog Shales is the six-feet *bohemicus* bed with its assemblage of graptolites restricted to the *M. nilssoni* zone of the Lower Ludlow in that country.

PART II. SYSTEMATIC DESCRIPTIONS.

(K.M.S.)

Order GRAPTOLOIDEA

Family **Monograptidæ** Lapworth, 1873.

Genus **Monograptus** Geinitz restricted, 1852.

Monograptus bohemicus (Barrande, 1850).

Plate VIII, Fig. *d*; Text-fig. 2, *d*.

Monograptus bohemicus (Barrande), Elles and Wood, 1911, 367, pl. xxxvi, figs. 4*a-d*.

Rhabdosomes up to 7 cm., but more usually about 2 cm. long and 1·3–2 mm. wide. Strong ventral curvature of the rhabdosome continuous throughout length in the short examples, but with straight distal section in the few long ones. Thecæ 10 to 14 in 10 mm., up to 2 mm. long and 0·5–0·7 mm. wide. Proximal thecæ sometimes seem longest and are impressed into a sigmoidal bulge by the overlying thecæ where the rhabdosome is most curved. Distal thecæ are straight. Apertures of thecæ in proximal region appear convex, but become concave distally. Overlap one-third to one-half. Inclination 35 to 40 degrees. Sicula 1 mm. long and 1 mm. wide at its base, with virgella 0·7 mm. long. Gregarious habit.

Associates: *M. nilssoni*, *M. roemeri*, *M. crinitus*, *Dictyonema*, cf. *Orbiculoidea*, *Pterinea retroflexa*, *Cardiola fibrosa*, Eurypterid.

Localities: Beneath Dalmanites bed, 200 yards south of Yass River, west of Hatton's Corner, Portion 7, Par. Hume; Portion 15, Par. Hume, near junction Good Hope and Taemas roads; Portion 5, Par. Yass, on Black Range road, beneath the Dalmanites bed outcropping near this road between the Hume Highway and 1½ miles south-south-west of it.

Monograptus nilssoni (Barrande).

(Plate VIII, figs. *c*, *f*; text-figs. 2*e*, *g*. *h*.)

Monograptus nilssoni (Barrande), Elles and Wood, 1911, 369, pl. xxxvii, figs. 1*a*-*e*.

Linograptus nilssoni (Barr.) Frech, 1897. *Lethæa palæozoica*, i, 662, Taf. A, fig. 7.

Rhabdosome 5 cm. long with slight concave curvature. Width 1 mm., thecæ 8 in 10 mm., just under 2 mm. long and 0·4 mm. wide. Overlap a quarter. Thecæ have convex ventral walls and an aperture at right angles. Inclination 20 degrees.

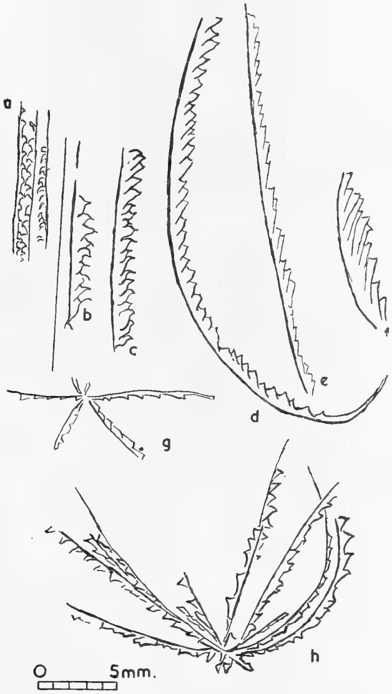

Fig. 2.

(*a*) *Monograptus crinitus* Wood, Portion 7, Par. Hume. (A.M., F44615.)
(*b*) (*c*) *M. salweyi* (Hopkinson), Portion 15, Par. Hume.
(*d*) *M. bohemicus* (Barrande), Portion 7, Par. Hume.
(*e*) *M. nilssoni* (Barrande), Portion 7, Par. Hume.
(*f*) *M. roemeri* (Barrande), Portion 7, Par. Hume.
(*g*) (*h*) *M. nilssoni* (Barrande) "*Linograptus*", Portion 7, Par. Hume. (A.M., F44613.)

Monograptus nilssoni also occurs in groups of rhabdosomes branching off from near sicula forming what has been called "*Linograptus*" (Frech, 1897; Boucek, 1932). Four, six or more branches radiate from a small central plate with webs joining each stipe near the point of bifurcation. Very slight curvature, thecæ developed (8 in 10 mm.) on inner side of curve, overlap negligible. Branches 0·3 to 0·5 mm. wide and up to 7 mm. long. Thecal apertures slightly concave.

Associates and locality: As for *M. bohemicus*.

Monograptus salweyi (Hopkinson).

(Plate VIII, figs. *a*, *b*; text-figs. 2*b*, *c*.)

Monograptus chimæra var. *salweyi* (Hopkinson), Elles and Wood, 1911, 400, pl. xxxix, figs. 5*a-d*.

Monograptus salweyi (Hopkinson), Elles, 1944. *Geol. Mag.* lxxxi, 275.

Monograptus flemingii (Salter), Sherrard and Keble, 1937, 313.

Rhabdosome up to 2·0 cm. long, sometimes showing slight dorsal curvature proximally, which is probably due to the graptolites being observed from a dorsal aspect. Width, proximally 0·8 mm., distally 1·6 mm. Sicula, including virgella, 1 mm. long, reaching to opposite aperture of first theca. Thecæ 13–11 in 10 mm., up to 2·5 mm. long, with a spine which is usually curved and is up to 1 mm. long. Proximally spines occupy one-half to one-third width of rhabdosome, distally one-quarter to one-fifth. Overlap one-half to two-thirds. Thecæ 0·4 to 0·6 mm. wide. Thecal apertures sometimes concave, sometimes convex. When convex and the aperture has a curved spine, the appearance of a hook is suggested. Proximally, the walls of thecæ are first convexly curved then bent over in a concave curve. Virgula prolonged 3 mm. beyond rhabdosome, as is characteristic of *M. salweyi*. *M. salweyi* from Silverdale (Portion 34, Par. Derringullen) is slightly wider and longer and has fewer thecæ in 10 mm. than those from the Parish of Hume. Those from the former locality show a more pronounced S-shaped curvature of their thecal walls, which when continued into a spine almost amounts to a hook.

Associates: *Monograptus* cf. *tumescens*, *Dictyonema*, *Craniops*, (?) *Zygospira*, cf. *Lissatrypa*, cf. *Parmorthis*, *Howellella*, Plectodontid, *Serpulites*.

Localities: Portion 15, Par. Hume; Black Range road, Portion 125, Par. Yass; Portion 34, Par. Derringullen.

Discussion.—At Silverdale the sandstone, in which this graptolite was first found, is not underlain by the *Dalmanites* bed nor by shale with *M. bohemicus*, so that its age relative to the *bohemicus* band is not obvious. When first found, this graptolite was identified as *M. flemingii* (Sherrard and Keble, 1937). However, in 1950, when Miss Elles generously made available for comparison type specimens of *M. chimæra* var. *salweyi* (Hopk. m.s.), it was evident that the graptolite from Silverdale, previously named *M. flemingii*, is actually *M. salweyi* (Elles, 1944), occurring here in the rigid form which is characteristic of the zone of *M. scanicus*. At Silverdale, these graptolites are imbedded in the sandstone in such a way that a certain amount of torsion has occurred, giving a hooked appearance to the thecæ in some views. The discovery, near the junction of Good Hope and Taemas roads, of *M. bohemicus* (characteristic of the zone of *M. nilssoni*) in a bed conformably underlying sandstone containing the graptolite under discussion, is confirmation that the latter must belong to the zone of *M. nilssoni* or higher, and therefore cannot be *M. flemingii*, which does not range higher than the zone of *M. vulgaris*.

Monograptus crinitus Wood.

(Text-fig. 2*a*.)

Monograptus crinitus Wood, Elles and Wood, 1913, 435, pl. xliv, 3*a-c*.

Rhabdosomes 2 cm. long, 0·5 mm. wide. Usually occurs as bundles of fragments. Slight ventral curvature. Thecæ 9–10 in 10 mm., 1·5 mm. long, 0·3 mm. wide. Overlap less than half. Angle of inclination 25 degrees. Apertures horizontal, sometimes pressed out to denticles.

Associates and locality: As for *M. bohemicus*.

Monograptus vomerinus (Nicholson).

Monograptus vomerinus (Nicholson), Elles and Wood, 1911, 409, pl. xli, 1*a-e*.

Rhabdosome straight, 1·5 cm. long, 1 mm. wide. Distal fragments only preserved, with virgula. Thecæ 13 in 10 mm., nearly 2 mm. long, 0·5 mm. wide. Thecæ have convex ventral margin with well-marked thecal edge, overlap one-half to one-third. Inclination 30 degrees. Aperture concave, almost pouch-like with denticle or spine occasionally suggested.

Locality : Reedy Creek crossing of Good Hope Road, in Black Bog Shale.

Monograptus roemeri (Barrande).

(Plate VIII, fig. *g* ; text-fig. 2*f*.)

Monograptus roemeri (Barrande), Elles and Wood, 1911, 397, pl. xxxix, 2*a-d*.

Rhabdosome under 2 mm. wide with ventral curvature. Thecæ 18 in 10 mm., each 2 mm. long, 0·3 mm. wide, overlap three-quarters.

Associate : *M. bohemicus.*

Locality : As for *M. bohemicus.*

Order DENDROIDEA.

Dictyonema sp.

(Plate VIII, fig. *e*.)

One poorly preserved fragment, 2·5 cm. long, 1 cm. wide, apparently flabelliform, but incompletely preserved. Branches 8 in 10 mm., each branch about 0·3 mm. wide and 0·25 mm. apart. Dissepiments up to 20 in 10 mm., mesh 0·5 mm. long and 0·3 mm. wide. *Monograptus bohemicus* is superimposed on specimen ; from bed below *Dalmanites* bed. *Dictyonema* sp. also occurs at Silverdale with *M. salweyi.*

ACKNOWLEDGEMENTS.

Facilities for carrying out this work have been kindly made available to the writers by Professor C. E. Marshall, D.Sc., Ph.D., of the University of Sydney. Professor W. B. R. King, F.R.S., of the University of Cambridge, England, was good enough to allow one of us (K.M.S.) to examine graptolites in the collections of the Sedgwick Museum. She also wishes to thank Miss G. L. Elles of the Sedgwick Museum for the generous help and advice she gave her.

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EXPLANATION OF PLATES.

PLATE VII.

Geological sketch-map of the Yass District. (Reprinted from These Proceedings, Vol. LXXIV, 1941, Plate XIV.)

PLATE VIII.

All photographs taken by I. A. Brown.

The numbers refer to specimens registered in the collections of the Australian Museum, Sydney.

(*a*) *Monograptus salweyi* (Hopkinson), Portion 15, Par. Hume. No. F44607. Mag. ×2.3.

(*b*) *M. salweyi* (Hopkinson), Portion 15, Par. Hume, No. F44608. Mag. ×2.3. (Note extension of virgula).

(*c*) *M. nilssoni* (Barrande), Portion 7, Par. Hume. F44609. Coll. Messrs. G. Packham and J. Veevers. Mag. ×2.3.

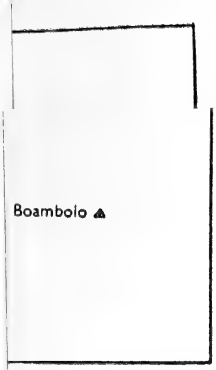
(*d*) *M. bohemicus* (Barrande), Portion 7, Par. Hume. F44610. Coll. A. J. Shearsby. Mag. ×2.3.

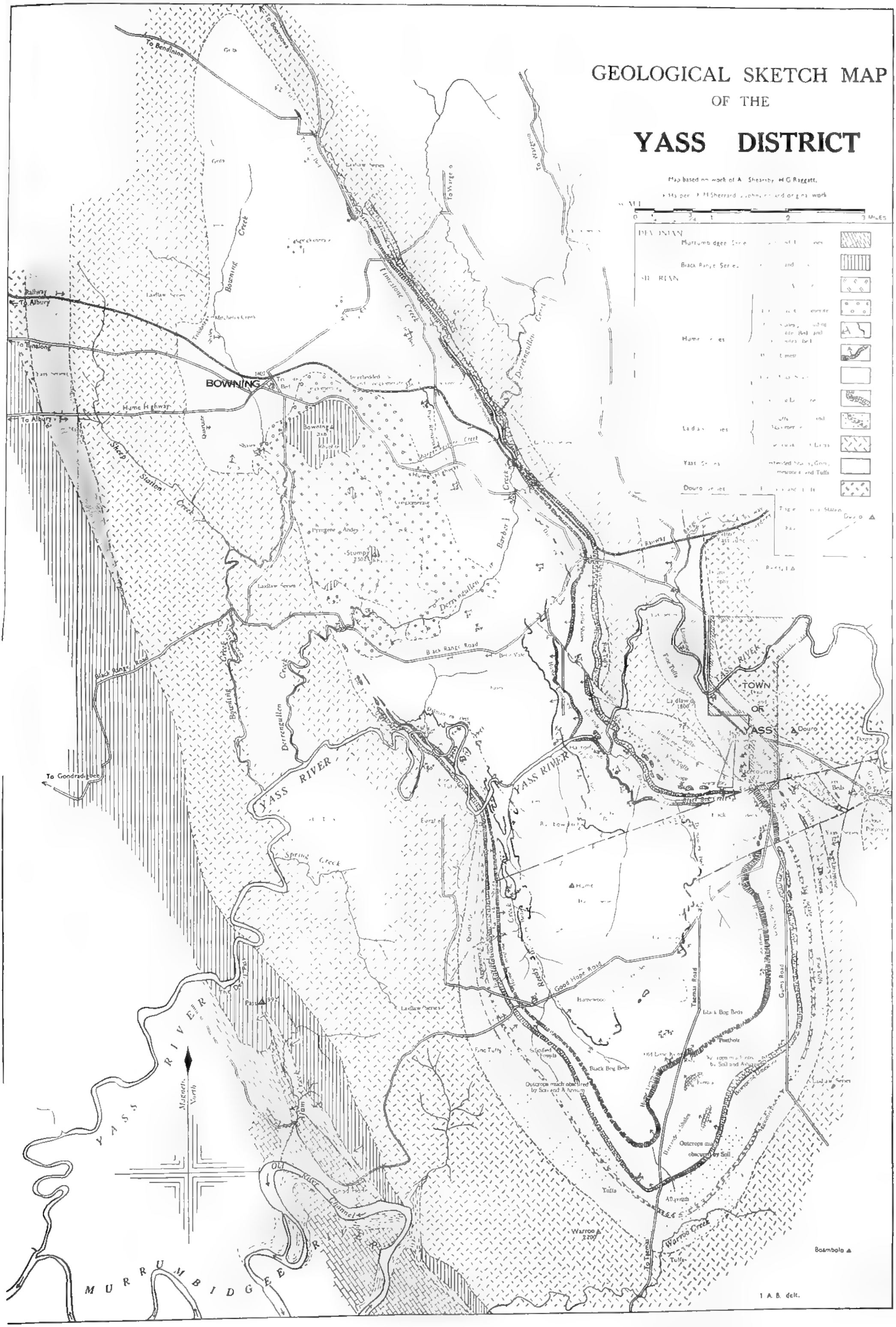
(*e*) *Dictyonema* sp. and *M. bohemicus*, Portion 7, Par. Hume. F44611. Coll. Messrs. G. Packham and J. Veevers. Mag. ×2·3.

(*f*) *M. nilssoni* (Barrande) "*Linograptus*", Portion 7, Par. Hume. F44612. Coll. Mr. C. V. G. Phipps. Mag. ×2.3.

(*g*) *M. roemeri* (Barrande), Portion 7, Par. Hume. No. F44614. Mag. ×2.3.

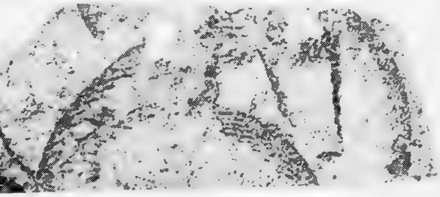
(*h*) Dalmanites bed and underlying *bohemicus* bed, showing true dip. Half mile south of Yass River and half mile west of Hatton's Corner, Portion 7, Parish of Hume.


Boambolo ▲


GEOLOGICAL SKETCH MAP
OF THE
YASS DISTRICT
Map based on work of A. Shearsby, H. G. Raggatt.
SCALE
0
1
2
3 MILES
DEVONIAN
Murrumbidgee Series
Black Range Series
SILURIAN
Hume Series
Laidlaw Series
Yass Series
Interbedded Shales, Grits, Limestones and Tuffs
Douro Series
Trig. Station
Douro
To Bendinine
To Booroowa
Grits
Laidlaw Series
To Wargeo
Bowning Creek
Limestone Creek
Derringullen Creek
Railway
To Albury
To Binalong
Mitchell's Creek
BOWNING
Hume Highway
Sheep Station Creek
Bowning
Conglomerate
Stumpy
2302
Barber's Creek
Black Range Road
Derringullen Creek
YASS RIVER
To Goodradigbee
Spring Creek
Laidlaw Series
TOWN OF YASS
Douro
Laidlaw
1800
Fine Tuffs
Black Bog Beds
Hume
Good Hope Road
Reids Creek
Tuffs
Fine Tuffs
Outcrops much obscured by Soil and Alluvium
Black Bog Beds
Outcrops much obscured by Soil
Tuffs
Tuffs
Gums Road
Taemas Road
Laidlaw Series
Warroo
2200
Warroo Creek
To Taemas
Booroomba
YASS RIVER
Magnetic North
Old River Channel
MURRUMBIDGEE RIVER
Pass
1993
To Sydney
I. A. B. delt.

h

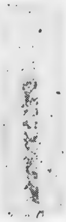
c



g

e

a



b

f

d

THE RESOLUTION OF TRIS–2 : 2′–DIPYRIDYL METAL COMPLEXES THROUGH THE IODIDE ANTIMONYL TARTRATES.

By F. P. DWYER, D.Sc.,
and (MISS) E. C. GYARFAS, M.Sc., Ph.D.

Manuscript received, November 13, 1951. Read, December 5, 1951.

In a previous paper (Dwyer and Gyarfas, 1950) it was shown that when a solution of *d*,*l*-tris-2 : 2′-dipyridyl ruthenium II antimonyl tartrate was fractionally precipitated with potassium iodide solution, *l*,tris-2 : 2′-dipyridyl ruthenium II iodide antimonyl tartrate $[Ru(dipy)_3]_3.I_2.(SbO.Tart)_4.18\ H_2O$ separated as the least soluble fraction. Subsequently, *d*-tris-2 : 2′-dipyridyl ruthenium II iodide separated. This is the most convenient method of resolution of the ruthenium compound. It has now been found that the crystallization of the iodide antimonyl tartrates is the most efficient method of resolution of the analogous dipyridyl complexes of iron II, osmium II and nickel. The three complex ion groups in the lattice compound always have the same configuration—*laevo* in the Na-D line, except the iron compound, which is *dextro* owing to rotatory dispersion.

The iron II and nickel II compounds have been resolved previously, like the ruthenium II compound, through the tartrates (Werner, 1912 ; Morgan and Burstall, 1931). The tartrates, however, have a high water solubility, and as a result Werner isolated only the *laevo* form of tris-2 : 2′-dipyridyl iron II iodide ; whilst Morgan and Burstall were forced to use both *d* and *l* ammonium tartrates in order to obtain both forms of the nickel compound. A further complication with both of the above compounds is the rapid racemization of the enantiomorphous forms. In the resolution of the osmium compound (Burstall, Dwyer and Gyarfas, 1950) through the antimonyl tartrates, both diastereoisomerides were very soluble in water and difficulty was encountered in preparing the pure optical forms.

The sparingly soluble iodide antimonyl tartrates can be obtained by several procedures. The racemic iodide can be transformed to the antimonyl tartrate with silver antimonyl tartrate, and the resulting solution treated fractionally with potassium iodide. Alternatively a solution of the racemic chloride can be treated with excess of potassium antimonyl tartrate, and with potassium iodide.

The addition of alkali after approximately half of the complex salt has precipitated destroys the antimonyl tartrate radicle, and ensures a high degree of purity for the other antipode. Since the rate of racemization of the nickel and iron compounds is raised considerably by hydroxyl ions (Davies and Dwyer, 1952) after making alkaline, all operations must be conducted quickly. The lattice compound can be decomposed by either dilute acid, or alkali or sodium acetate solution. The rate of solution in sodium acetate is not high and usually requires warming. If acid is used it should be dilute sulphuric or nitric acid, since the halogen acids tend to form precipitates of the form $[M(dipy)_3][(SbX_4)_2]$. After solution and filtration of the antimony oxide, the active compounds can be precipitated as the iodide or perchlorate. Werner (*loc. cit.*) found

$[\alpha]_D^{20} = -440°$, and $-520°$ for *l*, $Fe(dipy)_3I_2.6H_2O$ and the bromide hexahydrate. By the new procedure both enantiomorphous forms of the iron compound have been obtained with almost ten times these rotations—$Fe(dipy)_3(ClO_4)_2.2H_2O$, $[\alpha]_D^{20} = +4{,}800$ and $-4{,}100°$.

EXPERIMENTAL.

1-Tris-2 : 2′-Dipyridyl Nickel Iodide Antimonyl Tartrate Octadecahydrate.

Nickel sulphate heptahydrate (1·35 g.) in water (50 cc.) was treated with dipyridyl (2·35 g.), and the mixture heated to dissolve the dipyridyl. The resulting red solution of the complex sulphate was cooled in ice and solid potassium iodide (0·2 g.) added. The slight precipitate of the racemic iodide was filtered and the clear solution treated with potassium antimonyl tartrate (4 g. in 25 cc. of water at 10° C.). On scratching the sides of the vessel, pink micaceous plates of the lattice compound separated. The precipitate was collected and washed with ice water and ether. Addition of potassium iodide fractionally to the filtrate gave a little more of the lattice compound, followed by the dextro iodide, and finally a little racemic iodide. A 0·04% solution of the lattice compound in N/20 sodium hydroxide gave $\alpha_{5461} = -0{\cdot}12°$ (2 dm. tube), whence $[\alpha]_{5461}^{15} = -150°$.

Found: Ni=5·34%; Sb=14·5%; I=7·7%.

Calculated for $Ni_3(C_{10}H_8N_2)_9(C_4H_4O_6SbO)_4I_2.18H_2O$: Ni=5·34%; Sb=14·72%; I=7·80%.

1-Tris-2 : 2′-Dipyridyl Nickel II Perchlorate Trihydrate.

This was obtained by dissolution of the lattice compound in 0·05N. sodium hydroxide at 10° C., and after removal of the antimony oxide, adding sodium perchlorate. The pink flakes were washed with ice water and ether. A 0·1% solution in water gave $\alpha_{5461} = -0{\cdot}96°$ (2 dm. tube), whence $[\alpha]_{5461}^{15} = -480°$.

Found: Ni=7·6%.

Calculated for $Ni(C_{10}H_8N_2)_3(ClO_4)_2.3H_2O$: Ni=7·53%.

d-Tris-2 : 2′-Dipyridyl Nickel II Perchlorate Trihydrate.

The *d* iodide obtained from the mother liquid of the lattice compound was ground up with an excess of silver chloride and a little ice water until double decomposition was complete. After filtration from silver halide, sodium perchlorate (20%) was added. A 0·1% solution in water gave $\alpha_{5461} = +0{\cdot}95°$, whence $[\alpha]_{5461}^{15} = +475°$.

Found: Ni=7·6%.

Calculated for $Ni(C_{10}H_8N_2)_3(ClO_4)_2.3H_2O$: Ni=7·53%.

1-Tris-2 : 2′-Dipyridyl Osmium II Iodide Antimonyl Tartrate Octadecahydrate.

The racemic iodide (0·8 g.) was transformed to the antimonyl tartrate by shaking with silver antimonyl tartrate (0·8 g.) in water (80 cc.). After filtration, a further amount of the racemic iodide (0·8 g.) was dissolved in this solution by warming. On cooling, the crystalline lattice compound separated in dark green micaceous plates. Alternatively the compound was prepared by transforming the whole of the racemic iodide to the antimonyl tartrate, and then fractionally precipitating with potassium iodide. *Laevo* tris-2 : 2′-dipyridyl osmium II iodide and the *dextro* compound, obtained respectively from the lattice compound and the filtrate, had the same rotation, as previously found (Burstall, Dwyer and Gyarfas, *loc. cit.*).

A 0·005% solution of the lattice compound gave $\alpha = -0{\cdot}07°$ (1 dm. tube), whence $[\alpha]_{5461}^{20} = -1400°$.

Found: Os=15·7%; Sb=13·6; I=7·3%.

Calculated for $Os_3(C_{10}H_8N_2)_9(C_4H_4O_6SbO)_4I_2.18H_2O$: Os=15·8%; Sb=13·5%; I=7·16%.

d-Tris-2 : 2′-Dipyridyl Iron II Iodide Antimonyl Tartrate Octadecahydrate.

The racemic iodide (2·6 g.) was shaken with silver chloride excess and water (25 cc.). After filtration and washing of the silver halide, the total volume was made up to 50 cc. and the solution cooled in ice. A solution of sodium iodide (0·9 g.) in water (20 cc.) was also cooled in ice. Potassium antimonyl tartrate (2 g.) was dissolved in the iron solution by stirring, and then 2 cc. of the iodide solution added with scratching the sides of the vessel. After two minutes the lattice compound was filtered, and washed with ice water. The remainder of the sodium iodide added in equal portions to the filtrate, filtering between each addition, and carrying out the operations as quickly as possible gave strongly *laevo* rotatory products for the first two fractions, and weakly *laevo* rotatory for the last. All fractions were washed with ice water, then ether.

A 0·01% solution of the deep red micaceous plates of the lattice compound gave $\alpha_D = +0{\cdot}21°$ (1 dm. tube), whence $[\alpha]_D^{15} = +2100°$.

Found: Fe=5·12%; Sb=14·6%; I=7·7%.

Calculated for $Fe_3(C_{10}H_8N_2)_9(C_4H_4O_6SbO)_4I_2.18H_2O$: Fe=5·08%; Sb=14·76%; I=7·81%.

d-*Tris-2 : 2′-Dipyridyl Iron II Perchlorate Dihydrate.*

The iodide antimonyl tartrate (1 g.) was dissolved in 0·05N sodium hydroxide (20 cc.) at 4° C. After filtration of the antimony oxide, and addition of sodium perchlorate, the *dextro* perchlorate was obtained as red micaceous plates. The active perchlorate was less soluble than the racemate. The substance was washed with ice water and ether.

A 0·01% solution in water gave $\alpha_D = +0{\cdot}48°$ (1 dm. tube), whence $[\alpha]_D^{15} = +4{,}800°$.

Found: Fe=6·8%.

Calculated for $Fe(C_{10}H_8N_2)_3(ClO_4)_2.2H_2O$: Fe=6·72%.

l-*Tris-2 : 2′-Dipyridyl Iron II Perchlorate Dihydrate.*

The *laevo* iodide fractions from the iodide antimonyl tartrate separation (*vide supra*) were ground up in a mortar with silver chloride and a little ice water. The silver halide precipitate was removed quickly, and the deep red solution of the active chloride precipitated with sodium perchlorate. Approximately 25% of the substance was left in the solution in order to avoid separation of any racemate.

A 0·01% solution in water gave $\alpha_D = -0{\cdot}41°$ (1 dm. tube), whence $[\alpha]_D^{15} = -4{,}100°$.

Found: Fe=6·62%.

Calculated for $Fe(C_{10}H_8N_2)_3(ClO_4)_2.2H_2O$: Fe=6·72%.

SUMMARY.

The complex ions $M(dipy)_3^{++}$, (M=Fe, Os, Ru, Ni) yield sparingly soluble isomorphous iodide antimonyl tartrates, *l*-$[M(dipy)_3]_3.I_2.(SbO.Tart.)_4.18\ H_2O$ and *d*-$[Fe(dipy)_3]_3.I_2.(SbO.Tart.)_4.18\ H_2O$. These curious lattice compounds have been found to be the most suitable substances for the resolution of the dipyridyl complexes. In this way both optical forms of the iron compound have been isolated, and their rotations are almost ten times that described by Werner for the *laevo* antipode.

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Sydney University.

COORDINATION COMPOUNDS OF COPPER.

PART III. COMPLEX IODO-CUPRATES (I) FROM ACETONE SOLUTION.

By C. M. HARRIS.

Manuscript received, November 12, 1951. Read, December 5, 1951.

Marsh and Rhymes (1913) found that silver iodide dissolved in acetone solutions of the iodides of ammonium and the alkali metals. They obtained from these solutions a series of compounds of the general type $M[Ag_2I_3].nC_3H_6O$ containing acetone of crystallization (where M=Cs and n=0; M=K and Rb and n=2; and M=Na and NH_4 and n=3) and from aqueous acetone, the compound $Rb[AgI_2].0{\cdot}5\ H_2O$. Copper (I) iodide dissolved in a similar manner but they failed to isolate any compounds. This communication reports the preparation of some complex iodo-cuprates (I) from acetone solution.

Saturation of an acetone-sodium iodide solution with copper (I) iodide and evaporation under a variety of conditions always led to precipitation of copper (I) iodide. A compound approximating to $Na[Cu_2I_3]$ (I) was isolated by pouring the above solution into anhydrous ether and drying the crystals that were deposited, at 100° C. This compound was extremely unstable to water and difficult to obtain pure.

An attempt was made to isolate more stable compounds using pyridinium and N-methyl-pyridinium iodides. Yellow prisms of pyridinium diiodo-cuprate (I), $[C_5H_5NH][CuI_2]$ (II), and N-methyl-pyridinium diiodo-cuprate (I), $[C_5H_5NCH_3][CuI_2]$ (III), were obtained on cooling a boiling acetone solution saturated with respect to both components. These compounds were obtained in an exactly similar manner from methyl ethyl ketone.

Compound III was also obtained by treating an acetone solution of copper (I) iodide and sodium iodide with N-methyl-pyridinium iodide. Red prisms of N-methyl-quinolinium diiodo-cuprate (I), $[C_9H_7NCH_3][CuI_2]$, were similarly obtained. This compound has previously been isolated from aqueous solution by Kohn (1912).

The reaction of either compound III or copper (I) iodide and sodium iodide, dissolved in acetone, with an aqueous acetone solution of bis(ethylenediamine)-copper (II) iodide, yielded mauve plates of bis(ethylenediamine)copper (II) triiodo-cuprate (I) 1·5 hydrate, $[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}I_3].1{\cdot}5\ H_2O$ (IV). An analogous propylenediamine compound $[Cu^{II}(CH_3CH(NH_2)CH_2NH_2)_2][Cu^{I}I_3].1{\cdot}5\ H_2O$ was also prepared. Both these compounds readily lose their water of hydration at 100° C.

It is interesting to note that compound IV is not obtained on reacting a hot aqueous solution of potassium iodide and copper (I) iodide with bis(ethylenediamine)copper (II) iodide. From aqueous solution, only brown prisms of bis(ethylenediamine)copper (II) diiodo-cuprate (I), $[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}I_2]_2$, have been obtained (Harris, 1948).

Compounds IV and V are decomposed by boiling water,

$$[Cu^{II}(A)_2][Cu^{I}I_3] \rightarrow [Cu^{II}(A)_2]^{2+}+2I^-+CuI,$$

depositing copper (I) iodide. By carrying out the decomposition with dilute acetic acid in the presence of potassium iodide the divalent copper liberates iodine

$$2[Cu^{II}(A)_2][Cu^{I}I_3]+8H^+ \rightarrow I_2+4[AH_2]^{2+}+4CuI,$$

which can be titrated with thiosulphate in the usual way. Compounds I–V reduce aqueous silver nitrate to metallic silver, instantly in the cold, due to the univalent copper they contain.

All copper (I) structures yet investigated have been shown to possess copper involved in either two linear or four tetrahedral bonds (Wells, 1945). Thus compounds II and III apparently contain the diiodo-cuprate (I) ion of which numerous derivatives have been obtained from aqueous solution (Abegg, 1908, and Mellor, 1923) and for which the linear configuration $[I–Cu–I]^-$ would be expected (Pauling, 1940). Compounds IV and V could possess one of a number of structures. They could contain $[CuI_3]^{2-}$ ions, bridged $[Cu_2I_6]^{4-}$ ions, or $[CuI_2]^-$ ions in the form of a mixed anionic compound $[Cu(A)_2][CuI_2]I$. The last two would appear the most likely since three covalent copper (I) complexes have not been verified by structure determinations.

EXPERIMENTAL.

(i) *The Reaction of an Acetone Solution of Sodium Iodide with Copper (I) Iodide.*

Excess of finely powdered copper (I) iodide was refluxed with a boiling acetone solution (10·0 ml.) of sodium iodide (0·60 g.). The solution, on saturation, was filtered into anhydrous ether (100 ml.) and the crystalline mass formed was broken up beneath the ethereal solution, filtered rapidly, and washed with anhydrous ether followed by anhydrous benzene. The benzene vapour was removed under vacuum over phosphorus pentoxide. Yield 1·5 g. On heating at 100° C. the compound lost 4·2 per cent. of its weight. The following analyses are calculated on a dry weight basis.

Found: Cu, 23·4; I, 71·1%.

$Na[Cu_2I_3]$ requires Cu, 23·9; I, 71·7%.

The compound is deliquescent and decomposed readily by moisture from the air. It is not completely soluble in acetone being partially decomposed to copper (I) iodide and thus requires some excess of sodium iodide for its preparation.

(ii) *Pyridinium Diiodo-cuprate (I).*

Acetone (200 ml.) was refluxed in the presence of excess pyridinium and copper (I) iodides. The resulting saturated solution was filtered hot and cooled to 15° C. The yellow prisms that were deposited were washed with anhydrous ether and dried under vacuum over phosphorus pentoxide. Yield 1·5 g. Methyl ethyl ketone (100 ml.) similarly gave 0·6 g.

Found: Cu, 16·1; I, 63·3%.

$[C_5H_5NH][CuI_2]$ requires Cu, 16·0; I, 63·8%.

The compound is decomposed by water. It can be recrystallized from acetone or methyl ethyl ketone. During the course of this work it was noted that copper (I) iodide was soluble in molten pyridinium iodide and on cooling and washing out excess pyridinium iodide yellow prisms remain. This compound is probably the same as the above.

(iii) *N-methyl-pyridinium Diiodo-cuprate (I).*

Prepared similarly to the previous compound, it also crystallized in the form of yellow prisms. Acetone (300 ml.) gave 1·8 g. and methyl ethyl ketone (650 ml.) 3·0 g.

Found: Cu, 15·4; I, 61·8%.

$[C_5H_5NCH_3][CuI_2]$ requires Cu, 15·45; I, 61·7%.

This compound was also readily obtained by adding a hot solution of N-methyl-pyridinium iodide (2·5 g. 0·011 g. mole) in acetone (10 ml.) and water (2·0 ml.) mixture to a boiling acetone (15 ml.) solution of sodium iodide (3·1 g. 0·021 g. mole) and copper (I) iodide (1·9 g. 0·010 g. mole). The yellow prisms that were deposited were washed with a small amount of acetone and dried under vacuum. Yield 3·0 g. (73%).

Found: Cu, 15·6; I, 61·8%.

The solubility of this compound in acetone and methyl ethyl ketone permits of its recrystallization from these solvents. It is decomposed by water, particularly on heating. Copper (I) iodide is also soluble in molten N-methyl-pyridinium iodide, presumably forming the above compound, and yellow prisms can be isolated by washing out the excess of pyridinium salt with methyl alcohol.

A solution of compound III in acetone was titrated conductimetrically with an acetone-sodium iodide solution but no evidence of ion formation, such as

$$[CuI_2]^- + I^- \leftrightharpoons [CuI_3]^{2-}$$

was obtained.

N-methyl-quinolinium Diiodo-cuprate (I).

Prepared similarly to compound III from an acetone solution of sodium iodide and copper (I) iodide by treatment with an aqueous acetone solution of N-methyl-quinolinium iodide. The compound which crystallized in bright red prisms was obtained in almost theoretical yield.

Found: Cu, 13·8; I, 54·6%.

Calculated: Cu, 13·77; I, 54·98%.

(iv) *Bis(ethylenediamine)copper (II) Triiodo-cuprate (I) 1·5 Hydrate.*

To a boiling solution of bis(ethylenediamine)copper (II) iodide dihydrate (1·5 g. 0·0032 g. mole: Morgan and Burstall, 1926) in water (25 ml.) and acetone (100 ml.) mixture was added a boiling solution of sodium iodide (4·0 g. 0·027 g. mole) and copper (I) iodide (0·61 g. 0·0032 g. mole) in acetone (75 ml.). The mauve hexagonal plates that were deposited on cooling were washed with cold acetone and air dried. Yield 1·4 g. (68%).

Found: Cu(total), 19·4; Cu^{2+}, 9·8; I, 57·5; H_2O at 100° C., 4·0%.

$[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}I_3].1\cdot5\,H_2O$ requires Cu(total), 19·4; Cu^{2+}, 9·7; I, 58·1; H_2O, 4·1%.

If too much sodium iodide is used in this preparation the compound fails to appear on cooling.

This compound was also readily obtained by treating a boiling solution of bis(ethylenediamine) copper (II) iodide dihydrate (0·90 g. 0·0019 g. mole) in water (20 ml.) acetone (75 ml.) mixture with a boiling acetone (200 ml.) solution of compound III (0·80 g. 0·0019 g. mole). The immediate precipitate of hexagonal plates was isolated and washed as before.

Found: Cu(total), 19·5; H_2O at 100° C., 3·6%.

The compound is slowly decomposed by water in the cold but instantly on boiling forming a purple solution of bis(ethylenediamine)copper (II) iodide and a white precipitate of copper (I) iodide. The compound is decomposed by acid as described previously. It reduces silver nitrate solution instantly to metallic silver due to the univalent copper it contains and on dehydration at 100° C. its colour deepens.

(v) *Bis(propylenediamine)copper (II) Triiodo-cuprate (I) 1·5 Hydrate.*

Bis(propylenediamine)copper (II) iodide dihydrate (0·88 g. 0·0018 g. mole) was dissolved in water (5·0 ml.) and acetone (35 ml.). After the addition of sodium iodide (1·0 g. 0·0067 g. mole) the solution was heated to boiling and treated with a boiling solution of copper (I) iodide (0·50 g. 0·0026 g. mole) and sodium iodide (2·0 g. 0·013 g. mole) in acetone (35 ml.). The solution was cooled to room temperature and the purplish crystals that were deposited were filtered, washed with acetone and air dried. Yield 0·5 g. (42%.)

Found: Cu(total), 18·6; Cu^{2+}, 9·1; I, 55·3; H_2O at 100° C., 3·64, 3·94%.

$[Cu(CH_3CH(NH_2)CH_2NH_2)_2][CuI_3].1\cdot5\,H_2O$ requires Cu(total), 18·61; Cu^{2+}, 9·3; I, 55·75; H_2O, 3·96%.

The properties of this compound are similar to its ethylenediamine analogue.

Bis(propylenediamine)copper (II) Iodide Dihydrate.

Prepared from pyopylenediamine and copper (I) iodide in a somewhat analogous manner to bis(ethylenediamine)copper (II) iodide dihydrate (Morgan and Burstall, *loc. cit.*). A mixture of copper (I) iodide (19 g. 0·10 g. mole), propylenediamine (10·0 ml. 0·12 g. mole) and water (40 ml.) was refluxed for 3 hours. The purple solution was filtered and concentrated till crystallization occurred. The purple crystals were filtered and washed with two small lots of acetone and air dried.

Found: Cu, 12·7; I, 50·0; H_2O at 100° C., 7·0%.

$[Cu(CH_3CH(NH_2)CH_2NH_2)_2]I_2.2H_2O$ requires Cu, 12·7; I, 50·6; H_2O, 7·2%.

This compound is very soluble in water and reasonably soluble in aqueous acetone and alcohol.

ANALYSES.

Copper was estimated volumetrically by the thiosulphate method. On the addition of potassium iodide to a solution containing divalent copper and pyridinium or quinolinium salts, there is precipitated a complex pyridinium or quinolinium tetraiodo-cuprate (II) (Datta, 1913; Datta and Ghosh, 1914), which removes portion of the divalent copper from solution. It was thus found necessary to first remove the pyridine or quinoline by boiling with a slight excess of sodium hydroxide solution for 30 minutes. Copper was determined on the remaining solution in the usual way, iodine being first removed by fuming with concentrated sulphuric acid containing small amounts of nitric acid.

The estimation of divalent copper in the presence of copper (I) in compounds IV and V was carried out as follows: The compounds were decomposed by a small amount of hot water (20 ml.) to yield a solution of the bis(amine)copper (II) iodide and a precipitate of copper (I) iodide. A small amount of potassium iodide (2·0 g.) was added to the cooled solution followed by acetic acid (1–3 ml. 17N). A large excess of potassium iodide (10 g.) was added to completely dissolve the copper (I) iodide and the liberated iodine then titrated with thiosulphate to a starch end-point in the usual way.

SUMMARY.

The preparation of three types of complex iodo-cuprates (I) from acetone or aqueous acetone solution has been described. These are (*a*) $Na[Cu_2I_3]$; (*b*) $[C_5H_5NX][CuI_2]$ (where X=H and CH_3); and (*c*) $[Cu^{II}(A)_2][Cu^{I}I_3].1\cdot5\ H_2O$ (where $A=C_2H_4(NH_2)_2$ and $CH_3CH(NH_2)CH_2NH_2$). They are all, except (*a*), well defined, coloured, crystalline compounds.

During the course of this work bis(propylenediamine)copper (II) iodide dihydrate $[Cu(CH_3CH(NH_2)CH_2NH_2)_2]I_2.2H_2O$, was prepared by the action of propylenediamine upon copper (I) iodide.

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SOME COMPLEXES DERIVED FROM SILVER HALIDES.

By C. M. HARRIS.

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It has been reported in a previous communication that copper (I) iodide dissolves in concentrated ammonium or alkali bromide solution (Harris, 1950). From these solutions tetramminecopper (II) and bis(ethylenediamine) copper (II) derivatives, $[Cu^{II}(A)_4][Cu^{I}IBr]_2$ (where $A=NH_3$ and $2A=C_2H_4(NH_2)_2$), were isolated. Reaction of these solutions with ammonia and ethylenediamine afforded indirect evidence that they were not mixtures of the $[CuI_2]^-$ and $[CuBr_2]^-$ ions (*loc. cit.*). This communication reports the result of a similar investigation using silver iodide in place of copper (I) iodide.

Silver iodide dissolves appreciably in boiling concentrated solutions of ammonium or alkali bromide presumably forming the bromo-iodo-argentate (I) ion,

$$AgI+Br^- \rightleftharpoons [AgIBr]^-,$$

similar to copper (I) iodide. Dilution decomposes the complex ion precipitating silver iodide. Purple crystals of bis(ethylenediamine) copper (II) bromo-iodo-argentate (I), $[Cu(C_2H_4(NH_2)_2)_2][AgIBr]_2$, and orange crystals of the analogous nickel (II) complex, $[Ni(C_2H_4(NH_2)_2)_2][AgIBr]_2$, were obtained by metathesis from these solutions.

The nickel complex was obtained by reaction of the argentate (I) solution with tris(ethylenediamine)nickel (II) bromide. The isolation of the bis(ethylenediamine) nickel (II) complex instead of the tris-compound is apparently due to the fact that in solutions of tris(ethylenediamine)nickel (II) salts there exists the equilibrium

$$[Ni(C_2H_4(NH_2)_2)_3]^{++} \rightleftharpoons [Ni(C_2H_4(NH_2)_2)_2]^{++}+C_2H_4(NH_2)_2$$

and, in this case, the bis-derivative is the least soluble. The failure of Bucknall and Wardlaw (1928) to resolve the octahedral tris(ethylenediamine)nickel (II) ion could be attributed to this equilibrium. Failure to resolve the tris(ethylenediamine)copper (II) ion is probably due to the same type of equilibrium. The existence of this equilibrium in the case of copper (II) is supported by the work of Amiel (1934), who found that copper (II) complexes such as $[Cu(C_2H_4(NH_2)_2)_3](ClO_4)_2.H_2O$ lose one diamine group to pass over into the more stable bis(ethylenediamine)copper (II) complex.

Both the above argentate (I) complexes are decomposed by water, particularly on heating, forming a solution of the complex copper (II) and nickel (II) bromide and a precipitate of silver iodide.

Whilst the corresponding bromo-iodo-cuprate (I) solution reacts immediately with ammonium hydroxide to yield a precipitate of $(CuI)_2.NH_3$ (*loc. cit.*) the bromo-iodo-argentate (I) solution failed to yield a similar compound. Ethylenediamine also gave no visible reaction.

A series of silver complexes, $(AgX)_2.C_2H_4(NH_2)_2$ (where $X=Cl$, Br and I), similar to the copper (I) complex $(CuI)_2.C_2H_4(NH_2)_2$ (*loc. cit.*), were obtained

during the course of this work by dissolving the appropriate silver halide in ethylenediamine and precipitating with alcohol. These compounds are unstable to water and acids and are light-sensitive. The corresponding propylenediamine compound with silver iodide was prepared but proved to be unstable, losing propylenediamine.

EXPERIMENTAL.

Bis(ethylenediamine)copper (II) Bromo-iodo-argentate (I).

A boiling solution of ammonium bromide (180 g.) and silver iodide (4·7 g. 0·020 g. mole) in water (185 ml.) was added with stirring to a boiling solution of bis(ethylenediamine)copper (II) bromide monohydrate (3·6 g. 0·010 mole : Johnson and Bryant, 1934) and ammonium bromide (10 g.) in water (25 ml.). An immediate purple precipitate appeared. The solution was cooled to 65° with stirring and the purple prisms were filtered, washed well with methanol to remove ammonium bromide followed by acetone and air dried. Yield, 3·9 g. (48%).

Found : Cu, 7·7 ; AgI, 57·2 ; Br, 19·7%.

$[Cu(C_2H_4(NH_2)_2)_2][AgIBr]_2$ requires Cu, 7·82 ; AgI, 57·76 ; Br, 19·66%.

Bis(ethylenediamine)nickel (II) Bromo-iodo-argentate (I).

Prepared similarly to the previous compound save that tris(ethylenediamine)nickel (II) bromide dihydrate (4·3 g. 0·010 g. mole) was used in place of the copper (II) complex and 200 ml. of water instead of 185 ml. The solution was cooled to 60° C. when the orange crystals that deposited were filtered and washed, and dried as before. Yield 2·6 g. (32%).

Found : Ni, 7·2 ; AgI, 58·6 ; Br, 19·6%.

$[Ni(C_2H_4(NH_2)_2)_2][AgIBr]_2$ requires Cu, 7·26 ; AgI, 58·1 ; Br, 19·78%.

The tris(ethylenediamine)nickel (II) bromide dihydrate used in the above preparation was prepared by treating a solution of nickel bromide with an excess of ethylenediamine and precipitating with alcohol. The compound was washed with acetone and air dried.

Found : Br, 37·0 ; H_2O, 7·9%.

Calculated for $[Ni(C_2H_4(NH_2)_2)_3]Br_2.2H_2O$; Br, 36·8 ; H_2O, 8·3%.

The Reaction of Silver Halides with Ethylenediamine.

The powdered silver halide was dissolved in anhydrous ethylenediamine by gentle warming and the solution filtered into 95% ethanol. The colourless crystals were washed with acetone and dried under vacuum.

Compound.	Silver Halide. (Found.)	Silver Halide. (Calculated.)
$(AgCl)_2.C_2H_4(NH_2)_2$	82·5	82·6
$(AgBr)_2.C_2H_4(NH_2)_2$	86·7	86·2
$(AgI)_2.C_2H_4(NH_2)_2$	88·1	88·6

These compounds are light-sensitive and decomposed by water. The silver halide was estimated by boiling the compound with dilute nitric acid and weighing the residue.

The Reaction of Silver Iodide with Propylenediamine.

Powdered silver iodide dissolved in propylenediamine at room temperature. Pale yellow micro-crystals were obtained by pouring into methanol. The product was washed with acetone and air dried to remove acetone. The compound smelt strongly of propylenediamine and it had evidently lost a considerable amount as was indicated by the analysis for silver iodide.

Found: AgI, 91·4%.

$(AgI)_2.CH_3CH(NH_2)CH_2NH_2$ requires AgI, 86·4%.

SUMMARY.

Silver iodide dissolves in the presence of a large excess of bromide ions to form colourless solutions containing the bromo-iodo-argentate (I) ion. Complex derivatives of this ion with bis(ethylenediamine)copper (II) and bis(ethylenediamine)nickel (II) ions have been prepared from such solutions by metathesis.

A series of compounds of general formula $(AgX)_2.C_2H_4(NH_2)_2$ was prepared from ethylenediamine and the silver halides. Propylenediamine forms an unstable silver iodide complex.

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COORDINATION COMPOUNDS OF COPPER.

Part IV. Some Cuprates (I) from Acetone Solution.

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In a previous communication, one of us (Harris, 1952) reported the preparation of various iodo-cuprates (I) from either acetone or aqueous acetone solution. This communication describes the following additional compounds :

I. $[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}Cl_3].1\cdot5\ H_2O$.
II. $[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}Br_3].2\cdot5\ H_2O$.
III. $[C_5H_5NH][CuIBr]$.
IV. $[C_5H_5NCH_3][CuI(CNS)]$.
V. $[C_5H_5NCH_3][Cu(CNS)_2]$.

Compounds I and II were prepared by reacting the appropriate copper (I) halide, dissolved in an aqueous solution of the corresponding ammonium halide, with the required bis(ethylenediamine)copper (II) halide. These two compounds are analogous to the complex iodo-cuprates (I), $[Cu^{II}(A)_2][Cu^{I}I_3].1\cdot5\ H_2O$ ($A=C_2H_4(NH_2)_2$ and $CH_3CH(NH_2)CH_2NH_2$) previously described (Harris, *loc. cit.*).

Copper (I) iodide dissolves in boiling acetone or methyl ethyl ketone solutions of pyridinium bromide. On cooling, yellow prisms of compound III, pyridinium bromo-iodo-cuprate (I), are deposited. This type of compound has recently been obtained from aqueous solution (Harris, 1951) in the form of the complex copper (II) cuprates (I), $[Cu^{II}(A)_4][Cu^{I}IBr]_2$ (where $A=NH_3$ and $2A=C_2H_4(NH_2)_2$).

Yellow prisms of compound IV, N-methyl-pyridinium iodo-thiocyanato-cuprate (I), were crystallized from an acetone solution of N-methyl-pyridinium iodide which had been saturated with copper (I) thiocyanate. The yellow dithiocyanato-cuprate)I) compound (V) was also prepared by treating an acetone solution of ammonium thiocyanate and copper (I) thiocyanate with N-methyl-pyridinium iodide.

These compounds are all decomposed by water, acids and alkali, particularly on heating. They are insoluble in organic solvents, such as benzene, chloroform and ether, and reduce aqueous silver nitrate solution to silver due to the univalent copper they contain.

Experimental.

(i) *Bis(ethylenediamine)copper (II) Trichloro-cuprate (I) 1·5 Hydrate.*

To a solution of bis(ethylenediamine)copper (II) chloride monohydrate (2·5 g. : Johnson and Bryant, 1934) and ammonium chloride (2·5 g.) in water (35 ml.) was added acetone (90 ml.). The solution was refluxed over a mixture of excess copper (I) chloride and copper powder for 10 minutes and on filtering was cooled rapidly to room temperature in an atmosphere of coal gas.

The purple needles that were deposited were filtered and washed with methyl alcohol followed by ether. The ether was removed under vacuum. Yield 0·6 g.

Found: Cu (total), 33·2; Cl, 27·7; H_2O at 100° C., 7·1%.

$[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}Cl_3].1\cdot5H_2O$ requires Cu(total), 33·4; Cl, 27·9; H_2O, 7·4%.

This compound is instantly decomposed by water to white copper (I) chloride and a purple solution of bis(ethylenediamine)copper (II) chloride. The compound is oxidized in moist air assuming a blue-green colour. It reduces silver nitrate solution to metallic silver.

(ii) *Bis(ethylenediamine)copper (II) Tribromo-cuprate (I) 2·5 Hydrate.*

To a solution of bis(ethylenediamine)copper (II) bromide monohydrate (3·6 g. 0·010 g. mole) in water (50 ml.) was added ammonium bromide (2·0 g.) followed by acetone (200 ml.) and the solution heated to boiling. To this solution was added a boiling solution of copper (I) bromide (1·6 g. 0·011 g. mole) in acetone (250 ml.) and water (50 ml.) containing ammonium bromide (4·0 g.) and one drop of 7N hydrobromic acid. The solution was cooled to 20° C. with stirring and the compound that was deposited was filtered and washed with 90% alcohol followed by ether. The ether was removed under vacuum. Yield 2·0 g. (40%) purple prisms.

Found: Cu(total), 24·2; Br, 44·9; H_2O at 100° C., 8·6%.

$[Cu^{II}(C_2H_4(NH_2)_2)_2][Cu^{I}Br_3].2\cdot5H_2O$ requires Cu(total), 23·9; Br, 45·1; H_2O, 8·5%.

This compound is decomposed by water depositing a white precipitate of copper (I) bromide and forming a purple solution of bis(ethylenediamine)copper (II) bromide. The compound is oxidized in moist air assuming a blue-green colour and it reduces silver nitrate solution instantly to metallic silver.

(iii) *Pyridinium Bromo-iodo-cuprate (I).*

Pyridinium bromide (3·0 g.) was refluxed with excess of powdered copper (I) iodide and methyl ethyl ketone (500 ml.). The yellow solution was filtered hot and cooled to 0° C. The yellow needles were filtered, washed with dry ether and dried under vacuum over phosphorus pentoxide. Yield 2·4 g. The compound can also be prepared in a similar manner from acetone.

Found: Cu, 18·1, 18·2%; 0·3518 g. complex gave 0·4246 g. AgI + AgBr.

$[C_5H_5NH][CuIBr]$ requires Cu, 18·1%; 0·3518 g. complex to give 0·4241 g. AgI + AgBr.

The compound is readily decomposed by water to copper (I) iodide and reduces silver nitrate solution to metallic silver. It is hygroscopic.

(iv) *N-methyl-pyridinium Iodo-thiocyanato-cuprate (I).*

Excess of copper (I) thiocyanate and N-methyl-pyridinium iodide were refluxed with acetone (500 ml.) to form a yellow solution. The filtered solution was cooled to 20° C. and the yellow crystals that were deposited were washed with a small amount of cold acetone and dried under vacuum over phosphorus pentoxide.

Found: Cu, 18·3%; 0·243 g. complex gave 0·283 g. AgI + AgCNS.

$[C_5H_5NCH_3][CuI(CNS)]$ requires Cu, 18·56%; 0·243 g. complex to give 0·284 g. AgI + AgCNS.

The compound is readily decomposed by water and reduces silver nitrate solution to metallic silver.

(v) *N-methyl-pyridinium Dithiocyanato-cuprate (I).*

Copper (I) thiocyanate (1·2 g. 0·010 g. mole) was dissolved in a boiling solution of ammonium thiocyanate (7·0 g.) in acetone (50 ml.). To this was added a hot solution of N-methyl-pyridinium iodide (3·3 g. 0·015 g. mole) dissolved in a mixture of acetone (20 ml.) and water (3·0 ml.). The clear yellow solution on standing overnight deposited golden yellow crystals which were filtered off, washed with acetone and dried under vacuum. Yield 1·3 g. (47%).

Found: Cu, 23·1; CNS, 43·4%.

$[C_5H_5NCH_3][Cu(CNS)_2]$ requires Cu, 23·3; CNS, 42·4%.

The compound was contaminated slightly with iodide, giving a high value for thiocyanate which was determined as its silver salt. The compound is decomposed by water slowly in the cold and readily on heating and reduces silver nitrate solution to metallic silver.

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SOME HALOGENOARGENTATES (I) AND HALOGENOPLUMBATES (II) FROM ACETONE SOLUTION.

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In previous communications (Harris, 1952; Harris and Schafer, 1952) the preparation from acetone or aqueous acetone solution of various types of cuprates (I) has been described. This communication records the preparation of the following halogenoargentates and halogenoplumbates (II):

I. $[Cu(C_2H_4(NH_2)_2)_2][AgBr_2]_2$.
II. $[C_5H_5NCH_3][AgI_2]$.
III. $[C_5H_5NCH_3][Ag_2I_3]$.
IV. $[C_5H_5NCH_3][PbI_3]$.
V. $[Cu(C_2H_4(NH_2)_2)_2][PbBr_4]$.
VI. $[Cu(C_2H_4(NH_2)_2)_2][PbI_4]$.
VII. $[Cu(C_2H_4(NH_2)_2)_2][PbI_2Br]_2$.

Compounds I, II, IV, V, VI and VII were obtained by treating an aqueous acetone solution of the silver or lead halide and sodium or ammonium halide with the appropriate N-methyl-pyridinium or bis(ethylenediamine)copper (II) halide. Compound III was obtained from an aqueous acetone solution of ammonium and silver thiocyanate by treatment with N-methyl-pyridinium iodide. If bis(ethylenediamine)copper (II) bromide or iodide was added in place of N-methyl-pyridinium iodide, compound I or its iodine analogue, bis(ethylenediamine)copper (II) diiodo-argentate (I), was obtained. This last compound has previously been prepared by Spacu and Spacu (1931) as well as the propylenediamine analogue (Spacu and Spacu, 1932).

Compounds of the general type $M[Ag_2I_3]$ have been prepared before from acetone solution by Marsh and Rhymes (1913) and the compound $Rb[AgI_2].0{\cdot}5\,H_2O$ obtained by them from aqueous acetone. It is interesting to note that with copper (I) halides three types of complexes, $M[Cu_2X_3]$, $M[CuX_2]$, and $M_2[CuX_3]$ have been obtained (*loc. cit.*) from either acetone or aqueous acetone.

All the above compounds are unstable to water, on boiling, and insoluble in common organic solvents such as benzene and chloroform.

EXPERIMENTAL.

(i) *Bis(ethylenediamine)copper (II) Dibromo-argentate (I).*

To a boiling solution of bis(ethylenediamine)copper (II) bromide monohydrate (1·0 g.: Johnson and Bryant, 1934) and ammonium bromide (2·0 g.) in a mixture of water (15 ml.) and acetone (100 ml.) was added a boiling solution of ammonium bromide (10 g.) in acetone (200 ml.) and water (30 ml.) saturated with silver bromide. The immediate precipitate of mauve microcrystals was filtered and washed with methyl alcohol followed by ether. Dried under vacuum. Yield 1·5 g.

Found: Cu, 8·75; Ag, 29·8; Br, 44·2%.
$[Cu(C_2H_4(NH_2)_2)_2][AgBr_2]_2$ requires Cu, 8·84; Ag, 30·0; Br, 44·4%.

The compound is insoluble in cold water but decomposed readily on heating to a purple solution of bis(ethylenediamine)copper (II) bromide and a precipitate of silver bromide.

(ii) *N-methyl-pyridinium Diiodo-argentate (I).*

To a warm solution of silver iodide (1·0 g. 0·0043 g. mole) and sodium iodide (10 g.) in acetone (100 ml.) was added a warm solution of N-methyl-pyridinium iodide (1·5 g. 0·0068 g. mole) dissolved in a mixture of acetone (10 ml.) and water (1·0 ml.). On standing cream microcrystals were deposited, which were filtered and washed with a small amount of cold acetone and dried under vacuum. Yield 1·4 g.

Found: Ag, 23·5; I, 55·5%.

$[C_5H_5NCH_3][AgI_2]$ requires Ag, 23·7; I, 55·7%.

Water decomposes the compound into its constituents.

iii) *The Reaction of N-methyl-pyridinium Iodide with an Acetone Solution of Ammonium and Silver Thiocyanates.*

A hot solution of silver thiocyanante (1·7 g. 0·010 g. mole) and ammonium thiocyanante (10 g.) in acetone (100 ml.) was treated with a solution of N-methyl-pyridinium iodide (2·5 g. 0·011 g. mole) dissolved in a mixture of acetone (10 ml.) and water (2·0 ml.). The immediate precipitate of white prisms was filtered from the cooled solution, washed with acetone and dried under vacuum. Yield 2·2 g. (82%).

Found: Ag, 31·2; I, 54·5%.

$[C_5H_5NCH_3][Ag_2I_3]$ requires Ag, 31·3; I, 55·1%.

The compound is decomposed by water, particularly on heating.

The Reaction of Bis(ethylenediamine)copper (II) Halides with an Acetone Solution of Ammonium and Silver Thiocyanates.

(*a*) *With Bis(ethylenediamine)copper (II) Bromide.*

A boiling solution of silver thiocyanate (3·3 g. 0·020 g. mole) and ammonium thiocyanate (4·0 g.) in acetone (60 ml.) was mixed all at once with a boiling solution of bis(ethylenediamine)-copper (II) bromide monohydrate (1·8 g. 0·0050 g. mole) in a mixture of acetone (50 ml.) and water (10 ml.). The precipitate of mauve microcrystals was washed with acetone and dried under vacuum. Yield 1·4 g. (80%) of compound I.

Found: Ag, 29·7; Br, 44·1%.

(*b*) *With Bis(ethylenediamine)copper (II) Iodide.*

To a boiling solution of bis(ethylenediamine)copper (II) iodide monohydrate (2·3 g. 0·0050 g. mole) and ammonium thiocyanate (2·0 g.) in acetone (150 ml.) and water (20 ml.) was added all at once a boiling solution of silver thiocyanate (1·7 g. 0·010 g. mole) and ammonium thiocyanate (10 g.) in acetone (100 ml.). The immediate precipitate of mauve microcrystals was washed with acetone and dried under vacuum. Yield 1·8 g. (78%) of bis(ethylenediamine)copper (II) diiodo-argentate (I).

Found: Cu, 7·08; Ag, 23·8; I, 55·3%.

Calculated: Cu, 7·01; Ag, 23·8; I, 56·0%.

This compound was also obtained by reacting a sodium iodide-silver iodide solution in acetone with bis(ethylenediamine)copper (II) iodide.

Found: Cu, 6·95; Ag, 23·6; I, 55·7%.

(iv) *N-methyl-pyridinium Triiodo-plumbate (II).*

Lead iodide (2·0 g. 0·00043 g. mole) and sodium iodide (5·0 g.) dissolved in boiling acetone (40 ml.) was treated with N-methyl-pyridinium iodide (2·0 g. 0·0091 g. mole) dissolved in a boiling mixture of acetone (10 ml.) and water (2·0 ml.). The immediate precipitate of pale yellow prisms was filtered from the cooled solution and washed with acetone followed by ether. Dried under vacuum. Yield 2·4 g. (80%).

Found: Pb, 30·4; I, 55·5%.

$[C_5H_5NCH_3][PbI_3]$ requires Pb, 30·4; I, 55·9%.

The compound is immediately decomposed by water depositing yellow lead iodide.

(v) *Bis(ethylenediamine)copper (II) Tetrabromo-plumbate (II).*

To a boiling solution of bis(ethylenediamine)copper (II) bromide monohydrate (2·0 g. 0·0055 g. mole) and ammonium bromide (40 g.) in acetone (200 ml.) and water (35 ml.) was added a boiling solution of lead bromide (2·0 g. 0·0054 g. mole) and ammonium bromide (40 g.) in acetone (410 ml.) and water (80 ml.). The immediate flocculent precipitate of mauve microcrystals was filtered from the hot solution and washed with acetone followed by ether. Dried under vacuum. Yield 2·9 g. (75%).

Found: Cu, 9·1; Pb, 29·0, 29·1; Br, 45·1%.

$[Cu(C_2H_4(NH_2)_2)_2][PbBr_4]$ requires Cu, 9·0; Pb, 29·2; Br, 45·0%.

The compound is decomposed by water, readily on heating, depositing a precipitate of lead (II) bromide and forming a purple solution of bis(ethylenediamine)copper (II) bromide.

(vi) *Bis(ethylenediamine)copper (II) Tetraiodo-plumbate (II).*

Lead iodide (2·0 g. 0·0043 g. mole) and sodium iodide (10 g.) in boiling acetone (150 ml.) was added to a boiling solution of bis(ethylenediamine)copper (II) iodide monohydrate (0·90 g. 0·0020 g. mole) and sodium iodide (2·0 g.) in a boiling mixture of acetone (75 ml.) and water (10 ml.). The immediate precipitate of greenish-grey microcrystals was washed with acetone followed by ether and dried under vacuum. Yield 1·8 g. (95%).

Found: Cu, 7·06; Pb, 22·9; I, 56·3%.

$[Cu(C_2H_4(NH_2)_2)_2][PbI_4]$ requires Cu, 7·08; Pb, 23·1; I, 56·5%.

The compound is decomposed by water similarly to the previous compound.

(vii) *Bis(ethylenediamine)copper (II) Diiodo-bromo-plumbate (II).*

Lead iodide (2·0 g. 0·0043 g. mole) was dissolved in a boiling mixture of acetone (200 ml.) and water (20 ml.) that had previously been saturated with ammonium bromide. This solution was added to a boiling solution of bis(ethylenediamine)copper (II) bromide monohydrate (1·6 g. 0·0044 g. mole) in acetone (100 ml.) and water (15 ml.). The immediate precipitate of mauve microcrystals was filtered and washed with acetone followed by ether. Dried under vacuum. Yield 2·6 g. (95%).

Found: Cu, 5·1; Pb, 32·3%. 0·289 g. compound gave 0·303 g. AgBr+AgI.

$[Cu(C_2H_4(NH_2)_2)_2][PbI_2Br]_2$ requires Cu, 5·0; Pb, 32·7%. 0·289 g. compound to give 0·300 g. AgBr+AgI.

SUMMARY.

The halogeno-argentates (I), $[Cu(C_2H_4(NH_2)_2)_2][AgBr_2]_2$, $[C_5H_5NCH_3][AgI_2]$, and $[C_5H_5NCH_3][Ag_2I_3]$, have been prepared from aqueous acetone solution. Halogenoplumbates (II), $[C_5H_5NCH_3][PbI_3]$, $[Cu(C_2H_4(NH_2)_2)_2][PbBr_4]$, $[Cu(C_2H_4(NH_2)_2)_2][PbI_4]$, and $[Cu(C_2H_4(NH_2)_2)_2][PbI_2Br]_2$, were also obtained using this solvent.

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PALLADIUM COMPLEXES.

PART IV. REACTIONS OF PALLADIUM COMPOUNDS WITH 1 : 10 PHENANTHROLINE.

By S. E. LIVINGSTONE.

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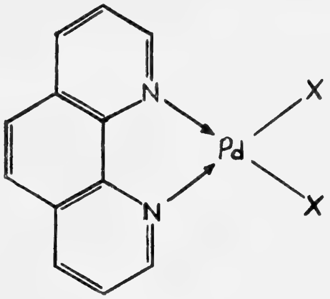
Coordination compounds of 1 : 10 phenanthroline with several of the metals, *e.g.* iron, nickel, osmium, etc., are known but it appears that only two complexes of palladium with this ligand have been reported (Ryan, 1949). 2 : 2′-Dipyridyl is very similar to 1 : 10 phenanthroline in the type of coordination compounds it forms with the metals; dichloro-2 : 2′-dipyridyl palladium was prepared by Morgan and Burstall (1933).

A series of compounds was prepared of the type Pd phen X_2 where phen=1 : 10 phenanthroline and X=Cl, Br, I, CNS, NO_2 and $2X=C_2O_4$.

These compounds are all insoluble in water and organic solvents and probably have the structure



since divalent palladium almost invariably exhibits the four covalent square planar configuration, involving dsp^2 orbitals.

These compounds are prepared by treating a solution of K_2PdX_4 (where X=Cl, Br, I, CNS, NO_2; $2X=C_2O_4$) in hot water with a hot aqueous solution of 1 : 10 phenanthroline monohydrate (I). The compound [Pd phen X_2] is immediately precipitated. It is interesting to note that no precipitate or change in colour occurs in the case of $K_2Pd(CN)_4$. Also these compounds dissolve in aqueous KCN to give colourless solutions, precipitating 1 : 10 phenanthroline. This tends to confirm the fact that the bond between Pd and CN is very strong, stronger even than that between Pd and I.

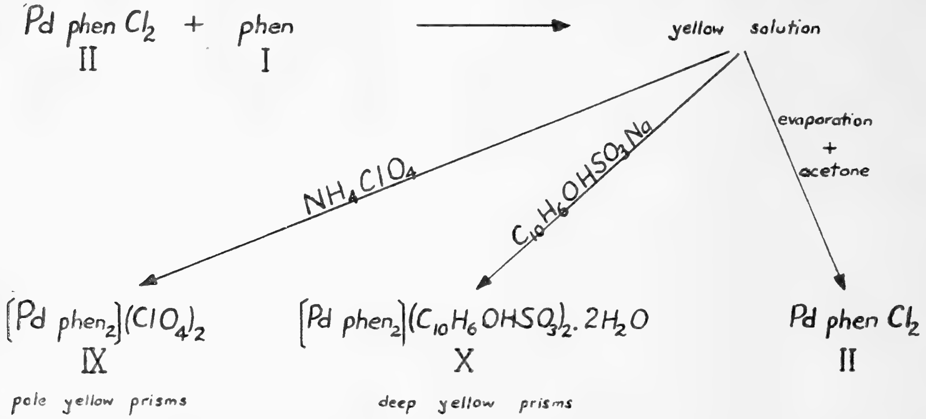
When chlorine is passed through a suspension of [Pd phen Cl_2] (II) in chloroform bright red prisms of *tetrachloro-1 : 10 phenanthroline palladium* (IV) are formed.

$$\underset{\text{II}}{[\text{Pd phen Cl}_2]}+\text{Cl}_2 \underset{\text{heat 150° C.}}{\overset{\text{CHCl}_3}{\rightleftarrows}} \underset{\text{VIII}}{[\text{Pd phen Cl}_4]}$$

This compound VIII rapidly loses chlorine in moist air, and on heating to 150° C. is converted back to the dichlorodiammine II. The tetrachlorodiammine VIII is analogous to Pd py_2Cl_4 and Pd en Cl_4 (where py=pyridine and en=ethylenediamine) (Rosenheim and Maass, 1898) and $Pd(NH_3)_2Cl_4$ (Drew *et alia*, 1932).

The reactions of II with various amines were investigated.

(*a*) *1 : 10 Phenanthroline.* Compound II dissolves on warming in excess aqueous 1 : 10 phenanthroline to give a clear yellow solution. Concentration and precipitation with acetone yields the original compound II. However,

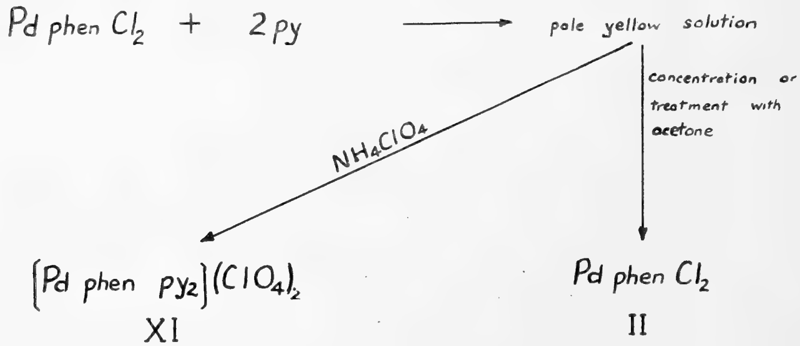


addition of a solution of ammonium perchlorate to the clear solution yields *bis(1 : 10 phenanthroline) palladium (II) perchlorate,* which can be recrystallized from water. Similarly, addition of a solution of sodium 2-naphthol-6-sulphonate to the yellow solution yields *bis(1 : 10 phenanthroline) palladium (II) 2-naphthol-6-sulphonate dihydrate.*

If a large excess of sodium chloride is added to the yellow solution, pale cream needles of II are precipitated. It seems certain that the yellow solution contains the tetrammine chloride [Pd $phen_2]Cl_2$ in solution and that there exists an equilibrium

$$[\text{Pd phen Cl}_2]+\text{phen} \rightleftharpoons [\text{Pd phen}_2]^{++}+2\text{Cl}^-$$

The tetrammine ion $[\text{Pd phen}_2]^{++}$ is apparently only stabilized by the presence of a large anion such as perchlorate or naphthol sulphonate.



(*b*) *Pyridine.* When II is warmed with water containing a little pyridine, it dissolves to a pale yellow solution which, on treatment with NH_4ClO_4, yields *dipyridine-1 : 10 phenanthroline palladium (II) perchlorate* which can be recrystallized from water.

If, however, the pale yellow solution is concentrated, or if acetone is added, the original dichlorodiammine II is precipitated, in analogy with the solution of [Pd phen$_2$]Cl$_2$ mentioned above. It is interesting to note that Morgan and Burstall (1934) found that [Pt dipy Cl$_2$] dissolves in excess aqueous dipyridyl and also in aqueous pyridine to give yellow solutions, but evaporation led only to viscid gums which decomposed into the original [Pt dipy Cl$_2$].

(*c*) *Ammonia.* II dissolves to a very pale yellow solution when treated with dilute aqueous ammonia at 40° C. Addition of NH_4ClO_4 precipitates *diammino-1 : 10 phenanthroline palladium* (*II*) *perchlorate.* This compound XII is obtained as colourless crystals by recrystallization from water.

(*d*) *Ethylenediamine.* A solution of the tetrammine ion [Pd phen en]$^{++}$ is obtained when II is warmed with a slight excess of aqueous ethylenediamine. Precipitation with NH_4ClO_4 and subsequent recrystallization yields colourless needles of *ethylenediamine-1 : 10 phenanthroline palladium* (*II*) *perchlorate*-XIII.

(*e*) *Quinoline.* II dissolves to a yellow solution when boiled with water and a considerable excess of quinoline. Addition of NH_4ClO_4 results in precipitation of a brownish resin from which no definite compounds were obtained.

EXPERIMENTAL.

(II) *Dichloro-1 : 10 Phenanthroline Palladium* (*II*).

To a hot aqueous solution (70 ml.) of K_2PdCl_4 (2 g.) was added a solution of 1 : 10 phenanthroline-I (Halcrow and Kermac, 1946) (1·2 g.) in boiling water (50 ml.). A precipitate of pale cream needles formed immediately, which was filtered, washed with hot water, then acetone. Yield 2·14 g.

Found: Pd, 30·0%; Cl, 19·8%.
$PdC_{12}H_8N_2Cl_2$ requires: Pd, 29·82%; Cl, 19·83%.

(III) *Dibromo-1 : 10 Phenanthroline Palladium* (*II*).

To a solution of K_2PdBr_4 (1·25 g.) in water (50 ml.) was added an aqueous solution (25 ml.) of I (0·45 g.). Yellowish orange prisms of III were precipitated, filtered, washed with hot water, then acetone. Yield 0·9 g.

Found: Pd, 23·9%; Br, 36·0%.
$PdC_{12}H_8N_2Br_2$ requires: Pd, 23·88%; Br, 35·78%.

(IV) *Diiodo-1 : 10 Phenanthroline Palladium* (*II*).

I (0·28 g.) dissolved in hot water (15 ml.) was added to a hot aqueous solution (50 ml.) of K_2PdI_4 (1·0 g.). Fine pinkish brown crystals of IV were thrown down; these were filtered, washed with hot water, then acetone in which they are slightly soluble. Yield 0·75 g.

Found: Pd, 19·5%; I, 46·9%.
$PdC_{12}H_8N_2I_2$ requires: Pd, 19·73%; I, 46·94%.

(V) *Dithiocyanato-1 : 10 Phenanthroline Palladium* (*II*).

K_2PdCl_4 (0·3 g.) and KCNS (1·5 g.) were dissolved in water (30 ml.); to this solution at the boiling point was added a solution of I (0·18 g.) in hot water (20 ml.). Bright yellow crystals were precipitated which were washed with hot water, then acetone. Yield 0·36 g.

Found: Pd, 25·8%; C, 42·0%; H, 1·9%.
$PdC_{12}H_8N_2(CNS)_2$ requires: Pd, 26·48%; C, 41·73%; H, 2·02%.

(VI) *Dinitrito-1 : 10 Phenanthroline Palladium* (*II*).

K_2PdCl_4 (0·4 g.) and KNO_2 (3 g.) dissolved in hot water (40 ml.) were treated with a hot aqueous solution (25 ml.) of I (0·25 g.). The precipitate (0·45 g.) of pale yellow needles was washed with hot water and acetone.

Found: Pd, 28·2%; N, 15·0%.
$PdC_{12}H_8N_2(NO_2)_2$ requires: Pd, 28·16%; N, 14·78%.

(VII) *Oxalato-1 : 10 Phenanthroline Palladium (II) Monohydrate.*

Potassium oxalatopalladate (II) tetrahydrate (Landersen, 1926) was prepared from K_2PdCl_4 and potassium oxalate monohydrate and recrystallized from water ; yield 84%.

$K_2[Pd(C_2O_4)_2].4H_2O$ (0·5 g.) in hot water (35 ml.) was treated with a hot aqueous solution (20 ml.) of I (0·24 g.). Bright yellow needles of VII were precipitated ; after washing with hot water and acetone the product was dried *in vacuo* over P_2O_5. Yield 0·42 g.

On heating in a closed tube water was evolved at a temperature just below decomposition.

Found : Pd, 27·4% ; C, 42·9% ; H, 2·8%.

$PdC_{12}H_8N_2C_2O_4.H_2O$ requires : Pd, 27·15% ; C, 42·79% ; H, 2·57%.

Reactions with Potassium Cyanide. An aqueous solution of I was added to a solution of $K_2Pd(CN)_4.3H_2O$. No precipitate or change in colour was observed, even on boiling. Compounds II, III, IV, V, VI and VII were found to dissolve in aqueous KCN in the cold to give colourless solutions, leaving a residue of I.

(VIII) *Tetrachloro-1 : 10 Phenanthroline Palladium (IV).*

Compound II (0·6 g.) was suspended in chloroform and chlorine passed through the suspension for one hour. The resulting bright red prisms were filtered, washed with chloroform, then ether and dried *in vacuo* over P_2O_5. The product rapidly loses chlorine in moist air, or on heating, to yield II, the crystals still retaining the original form but changing colour to cream.

Found : Pd, 24·9% ; loss on heating to 150° C., 16·4%.

$PdC_{12}H_8N_2Cl_4$ requires : Pd, 24·95% ; loss of two Cl, 16·58%.

Reactions of II with Amines.

(*a*) *1 : 10 Phenanthroline.* (i) II (2·15 g.) and I (1·4 g.) were boiled with 100 ml. water ; after 1 hour's heating the small amount of undissolved II was filtered off and the clear yellow solution concentrated to 15 ml. and acetone added. Cream needles of II were deposited. Yield 1·70 g.

(ii) II (0·2 g.) and I (0·25 g.) were heated with water to give a yellow solution ; to this was added NaCl (5 g.) dissolved in water (20 ml.). Immediate precipitation of cream needles of II occurred.

(IX) *Bis(1 : 10 Phenanthroline) Palladium (II) Perchlorate.*

II (0·4 g.) and I (0·5 g.) were heated in water until solution was complete ; an aqueous solution (20 ml.) of NH_4ClO_4 (0·3 g.) was added. Pale yellow prisms of IX were deposited, sparingly soluble in boiling water, from which they were recrystallized.

Found : Pd, 15·9%.

$Pd(C_{12}H_8N_2)_2(ClO_4)_2$ requires : Pd, 16·02%.

(X) *Bis(1 : 10 Phenanthroline) Palladium (II) 2-naphthol-6-sulphonate Dihydrate.*

To the clear solution obtained by heating II (0·35 g.) and I (0·5 g.) in water (30 ml.) was added an aqueous solution (20 ml.) of sodium 2-naphthol-6-sulphonate (0·6 g.). Deep yellow crystals of X were precipitated. When the compound, after having been dried *in vacuo* over P_2O_5, was heated in a closed tube, water was evolved at a temperature just below decomposition.

Found : Pd, 11·2% ; C, 55·4% ; H, 3·7%.

$Pd(C_{12}H_8N_2)_2(C_{10}H_6OHSO_3)_2.2H_2O$ requires : Pd, 11·23% ; C, 55·66% ; H, 3·61%.

(*b*) *Pyridine.* II (0·6 g.) was placed in water (30 ml.) and drops of pyridine added and the mixture warmed. After digestion for half an hour a pale yellow solution resulted. This was divided into two parts. The first part was concentrated to small bulk and yielded pale yellow crystals of II. The second part was treated with acetone and cream needles of II were deposited.

(XI) *Dipyridine-1 : 10 Phenanthroline Palladium (II) Perchlorate.*

II (0·5 g.) was warmed with water (30 ml.) and drops of pyridine until solution was effected. On treatment with aqueous NH_4ClO_4 a white precipitate (0·66 g.) was thrown down. On recrystallization from water (40 ml.) 0·45 g. of colourless crystals of XI were obtained.

Found: Pd, 16·5%.

$PdC_{12}H_8N_2(C_5H_5N)_2(ClO_4)_2$ requires Pd, 16·58%.

(*c*) *Ammonia.*

(XII) *Diammine-1 : 10 Phenanthroline Palladium (II) Perchlorate.*

II (0·36 g.), water (30 ml.) and 1N.NH_4OH (5 ml.) were warmed to 40° C. for three-quarters of an hour to give a very pale yellow solution. An excess of NH_4ClO_4 solution was added and the resulting white precipitate recrystallized from 40 ml. of water. 0·23 g. of colourless crystals of XII were obtained.

Found: Pd, 20·7%.

$PdC_{12}H_8N_2(NH_3)_2(ClO_4)_2$ requires: Pd, 20·52%.

(*d*) *Ethylenediamine*

(XIII) *Ethylenediamine-1 : 10 Phenanthroline Palladium (II).*

II (0·4 g.), water (20 ml.) and 3% aqueous ethylenediamine (4 ml.) were warmed to 40° C. for three-quarters of an hour when solution was complete. Excess of NH_4ClO_4 was added to the almost colourless solution and the subsequent white precipitate was recrystallized twice from water. 0·12 g. of colourless needles were obtained from the second recrystallization.

Found: Pd, 19·4%.

$PdC_{12}H_8N_2C_2H_4N_2H_4(ClO_4)_2$ requires: Pd, 19·55%.

(*e*) *Quinoline.* II (0·4 g.) was suspended in boiling water (25 ml.); addition of a considerable excess of quinoline produced a clear yellow solution; when this was treated with NH_4ClO_4 a brownish resin was thrown down. Attempts to free this resin from quinoline were unsuccessful and no definite compound was isolated.

SUMMARY.

Some reactions of palladium compounds with 1 : 10 phenanthroline (compound I) have been investigated. I reacts with K_2PdX_4 to form a series of compounds of the type [Pd phen X_2] (where phen=1 : 10 phenanthroline and X=Cl, Br, I, CNS, NO_2 and 2X=C_2O_4): the oxalato compound was obtained as the monohydrate. [Pd phen Cl_2]—compound II—is oxidized to [Pd phen Cl_4]— (compound VIII) by passing chlorine through a suspension of II in chloroform.

II dissolves in excess of aqueous solution of I to form a solution of the tetrammine chloride [Pd $phen_2$]Cl_2, which could not be isolated from solution; but treatment of this solution with ammonium perchlorate and sodium 2-naphthol-6-sulphonate yields compounds IX—[Pd $phen_2$]$(ClO_4)_2$ and X—[Pd $phen_2$]$(C_{10}H_8OHSO_3)_2.2H_2O$ respectively.

II also dissolves in aqueous pyridine (py), ammonia and ethylenediamine (en) to yield solutions of mixed tetrammines from which the following compounds were obtained on treatment with NH_4ClO_4: XI [Pd phen py_2]$(ClO_4)_2$; XII [Pd phen $(NH_3)_2$]$(ClO_4)_2$; XIII [Pd phen en]$(ClO_4)_2$.

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